

Comparisons of amplitude of pseudoaccommodation with aspheric yellow, spheric yellow, and spheric clear monofocal intraocular lenses

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Purpose: To determine the amplitude of pseudoaccommodation and higher-order aberrations with three types of implanted monofocal intraocular lenses (IOLs): aspheric yellow (IQ); spheric yellow (NT); and spheric clear (AT).

Setting: Department of Ophthalmology, Nara Medical University, Nara, Japan.

Methods: We studied 60 patients who underwent small incision phacoemulsification with the implantation of a monofocal IQ, NT, or AT IOL. The pseudoaccommodation was measured by the lens-loading method, and the postoperative ocular higher-order aberrations were measured with a Hartmann–Shack wavefront analyzer through natural and 4 mm pupils.

Results: Sixty eyes of 60 patients were studied. The average amplitude of the pseudoaccommodation was 0.45 ± 0.24 D with the IQ IOL, which was significantly lower than that with the AT IOL at 0.81 ± 0.37 D (Tukey's test; $P < 0.01$). The differences in the amplitude of the pseudoaccommodation between the IQ and the NT IOLs, and between the NT and the AT IOLs were not significant (Tukey's test; $P > 0.05$). The degree of spherical aberration was significantly different for the IQ, NT, and AT lenses (analysis of variance, $P = 0.016$). The spherical aberration through the IQ IOL was significantly lower than that through the NT and the AT IOLs (Tukey's test; $P < 0.01$). The fourth-order RMS (root mean square) aberration of the IQ lens was also significantly lower than that of the NT and AT IOLs (Tukey's test; $P < 0.01$).

Conclusion: Our results suggest that the spherical aberration and selective spectral transmission of IOLs may work together to increase the amplitude of the pseudoaccommodation.

Keywords: pseudoaccommodation, aspheric intraocular lens, spheric intraocular lens, higher-order aberrations

Introduction

The ability of an eye implanted with a monofocal intraocular lens (IOL) to see objects clearly at different distances (a clear zone of vision) has been called pseudoaccommodation, apparent accommodation, or pseudophakic accommodation.^{1–5} Several mechanisms for pseudoaccommodation have been advanced, such as a clear zone of vision between the first and second principal meridians due to astigmatism,⁶ depth of focus caused by the reduction of the blur circles by the pupil,² corneal multifocality,⁷ optical aberrations of the ocular optics,^{5,8} myopic changes induced by the forward movement of the IOL,^{9,10} and corneal steepening during attempted accommodation.^{11–13}

Chromatic aberrations, especially longitudinal chromatic aberrations (LCAs), are believed to be related to various physiological functions of the eye such as

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accommodation, visual resolution, and depth of focus. Fincham¹⁴ was the first to report that a chromatic signal due to LCA could stimulate accommodation and result in defocus. It has been widely assumed that chromatic defocusing degrades the retinal image at short wavelengths, but this assumption has not been tested at different wavelengths. However, McLellan et al¹⁵ found little variability in the quality of vision across the visible spectrum, as quantified by the modulation transfer function (MTF) technique.

Wavefront aberrations reduce the resolution of the eye for a single wavelength, but improve the average spatial sensitivity across the spectrum.¹⁵ The imperfect optics of human eyes may act as a counterforce against chromatic blur.

Eyes implanted with the SN60WF IOL (IQ [aspheric yellow]; Alcon Laboratories, Inc, Fort Worth, TX, USA) have significantly higher contrast sensitivity than eyes implanted with the SN60AT IOL (NT [spheric yellow]; Alcon Laboratories, Inc) or the SA60AT IOL (AT [spheric clear]; Alcon, Laboratories, Inc).¹⁶ The IQ lens has two advantages over the NT and AT IOLs: it has an aspherical anterior surface, and eyes implanted with aspheric IOLs generally have better contrast sensitivity than IOLs with spherical surfaces;¹⁶ and second, the IQ IOL has a yellow tint, which acts as a blue light-filtering chromophore. This is important because blue light exposure increases the risk of age-related macular degeneration,¹⁷ and the natural crystalline lens is known to absorb the short wavelengths of light when they are present. The retina can be harmed by high-energy visible blue light radiation that penetrates the retinal pigment of the macula. When the lens is removed, a higher level of blue light will pass to the retina; thus, implanting a yellow-tinted IOL can filter out the short wavelengths of light, resulting in a beneficial effect.¹⁵

Spherical aberration of the optical system of the human eye can stimulate accommodation,¹⁸ and the vertical coma of the cornea⁸ can increase the zone of clear vision in pseudophakic eyes. Chromatic aberration can also stimulate accommodation. The IQ IOL should have less spherical aberration than conventional spherical IOLs because of its aspheric optical surface. In addition, it should have reduced pseudoaccommodation because of its yellow tint. Thus, it would be expected that pseudoaccommodation will be reduced in eyes that are implanted with aspheric or spheric yellow IOLs compared to eyes implanted with spheric clear IOLs.¹⁶

Therefore, the purpose of this study was to determine the relationships between the amplitude of pseudoaccommodation, light transmission, and higher-order aberrations among the three monofocal IOLs.

Materials and methods

This was a cross-sectional, comparative, noninterventional study conducted at the Nara Medical University in Nara, Japan from April 2010 to October 2010. Patients diagnosed with only age-related cataracts at the Nara University of Medical Science Hospital were studied. This study was performed with informed consent. Before the cataract surgery, the axial length was measured with the A-scan UD-6000 (Tomey Corporation, Nagoya, Japan). The appropriate power of the IOL was calculated using the SRK/T formula in which the A-constant was 118.8 for the IQ IOL and 118.4 for the NT and AT IOLs. The eyes underwent small incision phacoemulsification and IOL implantation by the same surgeon. The inclusion criterion was having a corrected vision of $\leq 20/20$. The exclusion criterion was the existence of any other eye disorders, except cataracts.

Sixty eyes from 60 patients were divided into three groups: group 1 included 20 eyes of 20 patients who had an IQ IOL implanted; group 2 included 20 eyes of 20 patients who had an NT IOL implanted; and group 3 included 20 eyes of 20 patients who had an AT IOL implanted. If the patients had bilateral implantation, only the right eye was selected for the statistical analyses. All IOLs had the same Abbe number of 37.

Three months after the operation, the astigmatism was measured with the KR-8100 Auto Kerato-Refractometer (Topcon Corporation, Tokyo, Japan). Pupil diameter was measured with the Haab's pupillometer with the patient in an examination room looking at a point 33 cm away from the eye and under a constant illumination of 350 lux.

The amplitude of the pseudoaccommodation was measured by the lens-loading method in an examination room under the same illumination of 350 lux.⁵ A near vision test chart 1.0 optotypes in size (Kamiya's near distance test chart; Nippon Tenganyaku Kenkyusho Co, Ltd, Nagoya, Japan) was used. While wearing the best-corrected lenses for distant vision, the subjects were instructed to view the near vision 1.0 optotype placed 33 cm from the eye. When the recognition of the optotype was not possible without lenses, plus lenses were added in 0.25 D steps. The range of accommodation was calculated by subtracting the lens value at which the recognition became possible from 3 D. For example, with the target at 33 cm, we added the plus lenses in 0.25 D steps, and when the subject could no longer read the optotype, this would be the endpoint of accommodation. If the endpoint occurred with a +1.00 D lens, then the amplitude of the pseudoaccommodation would be 2.00 D. When recognition became possible after the addition of more than 3 D, the range of accommodation was taken to be 0 D.

If subjects were able to see this optotype, minus lenses were then added in -0.25 D steps until the subject could not read the optotypes correctly. The amplitude of the pseudoaccommodation was calculated as the value of the added minus lenses plus 3.0 D for the viewing distance. For example, if the near optotype could be read with a -0.75 lens, but not with a -1.0 D lens, the amplitude of the pseudoaccommodation would be $+3.75$ D.

During the testing phase, the examiner constantly instructed the subjects to make maximal efforts to recognize the near vision optotypes to try to stimulate pseudoaccommodation.

The ocular higher-order aberrations were measured with the KR-9000PW, a Hartmann–Shack type of wavefront analyzer (Topcon Corporation). The measurements were done through a 4 mm pupil diameter, and the measurements were repeated at least three times to acquire well-focused and properly aligned images.

Age, astigmatism, axial length, pupil diameter, IOL power, amplitude of the pseudoaccommodation, vertical coma (Z_7), horizontal coma (Z_8), spherical aberration (Z_{12}), the root mean square (RMS) of the third-order aberrations (S3), the RMS of the fourth-order aberrations (S4), and the RMS of the S3+S4 aberrations were compared among the three groups. Coma and spherical aberrations and RMS analysis was performed for a 4 mm pupil diameter. For the KR-9000PW, the analysis enabled the use of either 4 mm or 6 mm pupil diameter, so we selected a 4 mm pupil diameter.

Comparisons of quantitative variables were done with one-way analysis of variance (ANOVA), and the differences were calculated using the Tukey's test of multiple comparisons. A P -value ≤ 0.05 was taken to be statistically significant.

Results

The differences in patients' age, axial length, IOL power, and pupil diameter among the three groups were not significant (Table 1).

Table 1 Patient demographics

	SN60WF	SN60AT	SA60AT
Age (years)	70.71 \pm 5.31	70.53 \pm 5.29	78.38 \pm 2.91
Pupil diameter (mm)	2.98 \pm 0.34	2.88 \pm 0.39	2.93 \pm 0.29
The range of accommodation (D)	0.45 \pm 0.24	0.59 \pm 0.28	0.81 \pm 0.37
Axial length (mm)	24.05 \pm 1.05	23.58 \pm 1.21	23.12 \pm 1.02
IOL power (D)	20.63 \pm 3.04	21.39 \pm 2.41	21.57 \pm 2.30

Abbreviation: IOL, intraocular lens.

The average \pm standard deviation of the amplitude of pseudoaccommodation was 0.45 ± 0.24 D with the IQ IOL, 0.57 ± 0.29 D with the NT IOL, and 0.81 ± 0.37 D with the AT IOL. The differences in the amplitude of pseudoaccommodation among the three groups were significant (ANOVA; $P=0.01$; Figure 1). The amplitude of pseudoaccommodation was significantly lower with the IQ IOL than with the AT IOL (Tukey's test; $P<0.01$), but the differences between the IQ and the NT IOLs, and the differences between the NT and the AT IOLs were not significant (Tukey's test; $P>0.05$).

The vertical coma was 0.02 ± 0.102 μ m with the IQ IOL, -0.040 ± 0.080 μ m with the NT IOL, and -0.015 ± 0.172 μ m with the AT IOL. The differences between these values were not significant ($P>0.05$; Figure 2A).

The spherical aberration was 0.023 ± 0.030 μ m with the IQ IOL, 0.048 ± 0.041 μ m with the NT IOL, and 0.106 ± 0.051 μ m with the AT IOL. These values were significantly different (ANOVA; $P=0.016$; Figure 2B). The differences in the spherical aberrations between the IQ and the AT IOLs, and between the IQ and the NT IOLs were also significant (Tukey's test; $P<0.01$). However, the difference between the NT and the AT IOLs was not significant.

The S3 of the RMS aberrations was 0.173 ± 0.080 μ m with the IQ IOL, 0.156 ± 0.053 μ m with the NT IOL, and 0.207 ± 0.083 μ m with the AT IOL. The differences between the three pairs of IOLs was not significant (ANOVA; $P>0.05$; Figure 3A). The S4 was 0.068 ± 0.031 μ m with the IQ IOL, 0.098 ± 0.058 μ m with the NT IOL, and 0.121 ± 0.045 μ m with the AT IOL. The difference between three pairs of IOLs was significant (ANOVA; $P=0.004$; Figure 3B). There was a significant difference in S4 RMS aberrations between the IQ and the AT IOLs (Tukey's test; $P<0.01$), but the difference was not significant between the IQ and NT IOLs and between the NT and AT IOLs. The S3+S4 RMS aber-

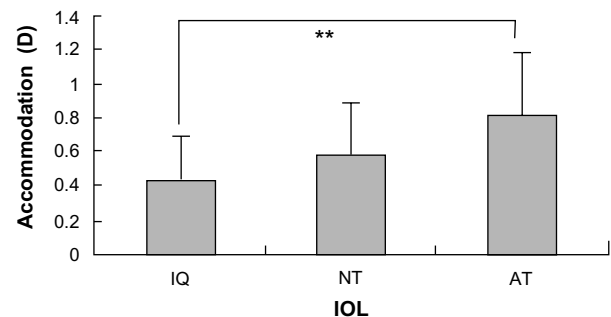


Figure 1 Amplitude of pseudoaccommodation in eyes implanted with IQ, NT, or AT IOLs.

Notes: There was a significant difference in the amplitude of pseudoaccommodation among the three groups (ANOVA; $P=0.004$). $**P<0.01$.

Abbreviations: D, diopters; IQ, aspheric yellow; NT, spheric yellow; AT, spheric clear; IOL, intraocular lens; ANOVA, analysis of variance.

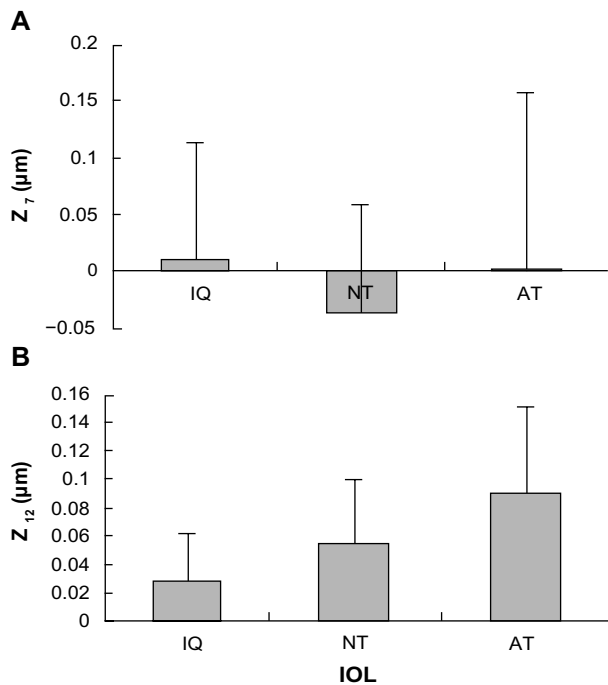


Figure 2 Optical aberrations of eyes implanted with IQ, NT and AT IOLs. The vertical comas of the three groups (A). The spherical aberrations of the three groups (B).

Notes: The differences between the values were not found to be significant in (A), (ANOVA, $P>0.05$). The differences between the values were found to be significantly different in (B), (ANOVA, $P=0.016$).

Abbreviations: IQ, aspheric yellow; NT, spheric yellow; AT, spheric clear; IOL, intraocular lens; Z, Zernicke; ANOVA, analysis of variance.

ration was $0.192\pm 0.090\ \mu\text{m}$ with the IQ IOL, $0.189\pm 0.067\ \mu\text{m}$ with the NT IOL, and $0.245\pm 0.077\ \mu\text{m}$ with the AT IOL. The differences in the S3+S4 RMS aberrations were not significant (ANOVA; $P>0.05$; Figure 3C).

Discussion

Our results showed that the amplitude of pseudoaccommodation with the IQ IOL was significantly lower than that with the AT IOL. On the other hand, the differences in the amplitude of the pseudoaccommodation observed between the IQ and the NT IOLs and between the NT and the AT IOLs were not significant. The IQ IOL also had less spherical aberration because of its aspherical optical surface, and its yellow tint reduced the LCA because the transmission of blue wavelengths was reduced from 71% at 400 nm to 22% at 475 nm.¹⁹ The NT IOL also reduced the transmission of blue wavelengths, but it had higher spherical aberration than that of the IQ IOL because of its spherical optical surface. These results suggest that both spherical aberration and the selective transmission of different wavelengths by the IOLs can affect the amplitude of pseudoaccommodation in pseudophakic eyes.

The simulation of retinal images during the MTF analyses showed that defocuses of $\pm 1.0\ \text{D}$ were significantly better with spheric than with aspheric IOLs.²⁰ We found that the

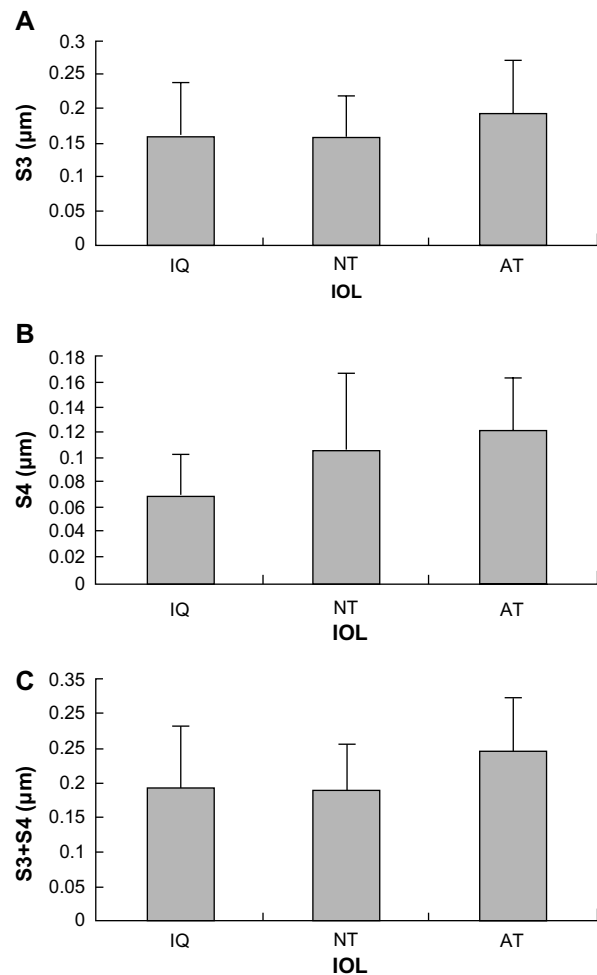


Figure 3 The S3 and S4 RMS aberrations of eyes implanted with IQ, NT and AT IOLs. The S3 of the three groups (A). The S4 of the three groups (B). The S3 and S4 of the three groups (C).

Notes: The differences between the values were not significant (A), (ANOVA, $P>0.05$). The differences between these values were significant (B), (ANOVA, $P=0.004$). The differences between the S3 and S4 RMS aberrations were not significant (C), (ANOVA, $P>0.05$).

Abbreviations: S3, third-order; IQ, aspheric yellow; NT, spheric yellow; AT, spheric clear; IOL, intraocular lens; S4, fourth-order aberration; Z, Zernicke; ANOVA, analysis of variance; RMS, root mean square; ANOVA, analysis of variance.

difference in pseudoaccommodation between the IQ and the NT IOLs was 0.14 D. Simulation of the MTF for a defocus of $\pm 0.14\ \text{D}$ was similar to that found with spheric and aspheric IOLs, suggesting that there should not be significant differences in the amplitude of pseudoaccommodation between spheric and aspheric IOLs.

The vertical coma of the cornea,⁸ as well as of the entire optical system of the eye, have been reported to improve accommodation in pseudophakic eyes.⁵ Computer simulation of the point-spread function and MTF showed that a focus shift of 0.5 D caused a greater deterioration in the retinal image in eyes without higher-order aberrations than in those with moderate coma-like aberrations.⁸

We did not find any significant differences in the vertical coma or the S3 RMS aberrations among the three IOLs studied. Coma aberrations can be induced in pseudophakic eyes by tilting the IOL.²¹ The three types of IOLs studied used the same materials and designs, which could account for the similarities found with respect to the degree of coma.

Nanavaty et al¹⁸ reported that the depth of focus for a 4.0 mm pupil scan size with the IQ IOL was 0.46 D, which was less than that with the NT IOL at 6 months after surgery. The authors studied two types of IOLs, and they measured the pseudoaccommodation using the software embedded in the aberrometer. The difference between the maximum and minimum refractions was used to calculate the depth of focus. We compared three types of IOLs and measured the amplitude of pseudoaccommodation by the lens-loading method in a subjective way, which may explain the differences found in the results.

Earlier, the calculated LCA of pseudophakic eyes was 0.98 D with an AcrySof® IOL (Alcon Laboratories, Inc) and 0.74 D in a Gullstrand schematic eye at wavelengths between 500 nm and 640 nm.²² In another study, it was found that an achromatic IOL undercorrected the LCA by 0.15 D.²³ Several factors may affect the LCA of human eyes, such as the Abbe number of the IOL. In our study, all of the IOLs studied had the same Abbe number; thus, the effect of the Abbe number on chromatic aberration should have been similar. However, the amplitude of accommodation was still different among the IQ, NT, and AT IOLs. These results indicate that both the aberrations and blue filtering influenced the pseudoaccommodation.

An earlier study that took into account the effects of monochromatic wavelength aberrations found that targets illuminated with blue light were less blurred.^{16,18} Thus, the aberrations of the optics of the human eye may act to counteract the chromatic blur. Our results demonstrated that the spherical clear AT IOL had better pseudoaccommodation than that of the IQ IOL, which is in agreement with the results of earlier reports.^{16,18,20,24}

Conclusion

Our results showed that eyes implanted with aspheric yellow IOLs had a lower pseudoaccommodation amplitude than eyes implanted with spherical clear IOLs. Spherical aberration and selective spectral transmission may work together to improve pseudoaccommodation through the implanted IOLs.

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Disclosure

The authors report no conflicts of interest in this work. This study was not prevented previously, and the authors did not receive financial support.

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