Apparent Accommodation and Corneal Wavefront Aberration in Pseudophakic Eyes

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PURPOSE. To assess the relationship between apparent accommodation in pseudophakic eyes, multifocal corneal effects, and wavefront aberrations of the cornea.

METHODS. In 102 eyes of 86 patients who had undergone phacoemulsification and posterior chamber intraocular lens implantation, the amount of apparent accommodation was measured with an accommodometer. The degree of corneal multifocality was determined on the corneal topography by measuring the maximum and minimum corneal refractive powers within the pupillary area. Wavefront aberrations of the cornea were calculated by expanding the height data of the corneal topography into Zernike polynomials for individual pupil size. The influence of higher-order aberration on the retinal image quality was simulated by computing the point-spread function (PSF) and modulation-transfer function (MTF) from the aberration function.

RESULTS. There was a significant positive correlation between the amount of apparent accommodation and corneal multifocality (Pearson correlation coefficient, \( r = 0.451, P < 0.001 \)). The coma-like aberration showed a significant positive correlation with the amount of apparent accommodation \( (r = 0.440, P < 0.001) \), but the spherical-like aberration did not \( (r = 0.001, P = 0.993) \). Among the coma-like aberrations, the component representing vertically asymmetrical distribution of corneal refractive power with greater refraction located in the lower part of the eye was most relevant to apparent accommodation. Computer simulation of PSF and MTF indicated that a focus shift of 0.5 D deteriorated the retinal image significantly more in eyes without higher-order aberrations than in eyes with a moderate amount of coma-like aberrations.

CONCLUSIONS. Coma-like aberration of the cornea, along with corneal multifocality, contributes to apparent accommodation in pseudophakic eyes. (Invest Ophthal Vis Sci. 2002;43: 2882–2886)

It has been known that refractive corneal surgery, such as radial keratotomy and photorefractive keratectomy, may create regional variation in corneal curvature. These multifocal corneal effects have been reported to help explain good uncorrected distance and near visual acuity in the eyes of patients who were in the age range in which presbyopia would be anticipated. Similarly, corneal multifocality has been demonstrated to play an important role in apparent accommodation (pseudoaccommodation) after cataract surgery. A study in which corneal topography was used exhibited that corneal multifocality (refractive power gradient within the pupillary area) has significant positive correlation with the amount of apparent accommodation in pseudophakic eyes. Thus, multifocality of the cornea may afford clinical advantages, but such multifocality may increase the noise, or static, in the eye’s optical system and potentially decrease some measures of visual performance. The influence of multifocality on corneal optical quality, however, has never been investigated. We conducted the present study to assess the relationship between apparent accommodation, corneal multifocality, and wavefront aberration of the cornea in eyes after cataract surgery.

METHODS

Subjects

One hundred and two eyes of 86 patients were examined. They were selected from consecutive routine clinical visits between 3 and 6 months (+4 ± 2.1 months, mean ± SD) after phacoemulsification with posterior chamber intraocular lens (IOL) implantation performed at Fukuyama Eye Clinic. Entry criteria included best corrected distance acuity of 20/20 or better, a well-positioned IOL within an intact continuous curvilinear capsulorrhexis, no intra- or postoperative complications, and an otherwise normal eye, as determined by slit lamp biomicroscopy and funduscopy through a dilated pupil. The male-to-female ratio was 31/55, and ages ranged from 51 to 86 years (mean, 70.5 ± 1.4). The type of IOL was polymethylmethacrylate (EZE-55, Storz, St. Louis, MO) in 29 eyes and acrylic foldable (AcrySof MA60, Alcon Laboratories, Fort Worth, TX) in 73 eyes. All patients signed an informed consent before the study, and the tenets of the Declaration of Helsinki were observed.

Apparent Accommodation

A near point of accommodation was determined in each eye with an accommodometer (NP Accommodometer AS-13; Kowa, Tokyo, Japan), with a cover over the fellow eye. A spherical lens of +2 or +3 D was added to the full distance correction, and the patient was required to read a Landolt target that corresponded in size to visual acuity of 20/30 at distance. The chart was slowly brought closer, until the patient reported blurring of the image. The target was then moved back until it became clear. Measurements were repeated 10 times, and the average distance in diopters at which blurring and refocusing occurred was recorded as the near point of accommodation. The amplitude of
accommodation (apparent accommodation) was calculated from the far and near points.

**Corneal Wavefront Aberration**

Corneal topography was obtained with the scanning slit videokeratoscope (Orbscan; Bausch & Lomb, Irvine, CA) under constant illumination. The measurements were repeated at least three times to obtain a well-focused, properly aligned image of the eye. For each eye, the horizontal and vertical pupillary diameter was measured on the display and averaged. Within the pupillary area of an individual eye, the difference between the maximum and minimum corneal optical power was calculated and recorded as the refractive gradient of the cornea, and averaged. Within the pupillary area of an individual eye, the central circular area of the cornea corresponding to the apparent pupil diameter of individual eyes, measured as described.

The calculation of wavefront aberrations was performed by expanding the anterior corneal height data into the set of orthogonal Zernike polynomials. The first six Zernike polynomials \(Z_0^0, Z_2^{-1}, Z_1^1, Z_2^{-2}, Z_0^2, Z_4^0\) represent fundamental corneal shapes, such as its base curvature, astigmatism, and any planar tilt. These polynomials were subtracted from the original height data to form a residual height map, and Zernike coefficients \(1\) through \(28\) \((Z_4^0, Z_6^0)\) were computed. Coefficients \(Z_4^0, Z_6^0\) correspond to spherical-like aberrations, \(Z_0^0, Z_4^0\) correspond to coma-like aberrations, \(Z_2^{-3}, Z_2^2\) express the fifth-order Zernike coefficients, and \(Z_5^5\) through \(Z_6^6\) are the sixth-order Zernike coefficients. These Zernike coefficients were used to calculate the global descriptors of monochromatic corneal aberrations, which are represented by the terms \(S_1, S_5, S_6, S_8\). Because spherical and coma aberrations refer to symmetrical systems and the eye is not rotationally symmetrical, the terms spherical-like and coma-like aberrations are used in this article. The \(S_5\) (third-order component of the wavefront aberration) represents the root mean squared wavefront variance from that of a perfect spherocylinder, due to coma-like aberration. Similarly, \(S_1\) (fourth-order component of the wavefront aberration) represents the root mean squared wavefront variance from that of a perfect spherocylinder, due to spherical-like aberration. The \(S_5\) and \(S_8\) are the fifth- and sixth-order components of the wavefront aberration, respectively. Because the variances of each term are independent, the odd-order aberrations were summed (root mean square of \(S_1, S_3, S_5\)) to examine the magnitude of coma-like aberrations, and the even-order aberrations were summed (root mean square of \(S_2, S_4, S_6\)) to evaluate the changes in spherical-like aberrations. These calculations were performed for the central circular area of the cornea corresponding to the apparent pupil diameter of individual eyes, measured as described.

![Figure 1](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933223/)

**Figure 1.** Significant positive correlation between the amount of apparent accommodation and corneal multifocality (Pearson correlation coefficient, \(r = 0.451, P < 0.001\)).

The influence of coma-like aberration on retinal image quality was simulated by computing the point-spread function (PSF) and modulation-transfer function (MTF) from an aberration function using standard Fourier optics methods. The pupil diameter was 4 mm and the focus shift \((Z_2^2)\) was at 0.5 D.

**RESULTS**

The polymethylmethacrylate and acrylic foldable IOL groups showed no intergroup differences in the amount of apparent accommodation \((2.08 \pm 1.01\text{ D vs. } 2.01 \pm 0.91\text{ D}, P = 0.721, \text{ Student’s } t\text{-test})\), pupillary diameter \((3.51 \pm 0.57\text{ mm vs. } 3.53 \pm 0.59\text{ mm}, P = 0.885)\), corneal multifocality \((5.62 \pm 2.00\text{ D vs. } 5.19 \pm 1.65\text{ D}, P = 0.267)\), coma-like aberration \((0.275 \pm 0.197\text{ μm vs. } 0.228 \pm 0.150\text{ μm}, P = 0.194)\), and spherical-like aberration \((0.747 \pm 0.666\text{ μm vs. } 0.635 \pm 0.568\text{ μm}, P = 0.351)\). Thus, the following analyses were performed in all 102 eyes.

On average, the amplitude of apparent accommodation was 2.03 ± 0.93 D and corneal multifocality was 5.31 ± 1.76 D. There was significant positive correlation between the amount of apparent accommodation and corneal multifocality (Fig. 1, **Figure 2**). Significant positive correlation between the amount of apparent accommodation and coma-like aberration of the cornea (Pearson correlation coefficient, \(r = 0.440, P < 0.001\)).

**Figure 2.** Significant positive correlation between the amount of apparent accommodation and coma-like aberration of the cornea (Pearson correlation coefficient, \(r = 0.440, P < 0.001\)).

**Figure 3.** Relation between the amount of apparent accommodation and spherical-like aberration of the cornea (Pearson correlation coefficient, \(r = 0.001, P = 0.995\)).
Pearson correlation coefficient $r = 0.451, P < 0.001$.

Wavefront aberrations of the cornea within the pupillary area were $0.241 \pm 0.165$ and $0.667 \pm 0.596 \mu m$ for coma-like ($S_3 + S_5$) and spherical-like ($S_4 + S_6$) aberrations, respectively. The coma-like aberration showed significant positive correlation with the amount of apparent accommodation (Fig. 2, $r = 0.440, P < 0.001$), but spherical-like aberration did not (Fig. 3, $r = 0.001, P = 0.993$). Among the third-order coma-like aberrations, the absolute value of each coefficient ($Z_3^{-5}$ through $Z_3^5$) was analyzed in terms of the relevance to apparent accommodation. The triangular astigmatism with base on the $x$-axis ($Z_3$) displayed the highest correlation with the amount of apparent accommodation (Fig. 4, $r = 0.394, P < 0.001$), followed by third-order coma along the $y$-axis ($Z_3^1$) ($r = 0.238, P = 0.017$), and third-order coma along the $x$-axis ($Z_3^{-1}$) ($r = 0.215, P = 0.051$).

**DISCUSSION**

It has been reported that some patients with pseudophakic eyes have good near and distance vision when they use their distance correction only. This phenomenon has been observed, and it was concluded that the Strehl ratio improved to 0.043, and the simulated retinal image of the Landolt ring became more distinguishable. By comparison, the eye with coma-like aberration showed less deteriorated PSF (Fig. 5) and MTF (Figs. 6 and 7).
corneal multifocality (refractive power gradient within the triangular astigmatism with base on the x-axis) has been attributed to several different optical properties of the eye and IOL system, including movement of the IOL along the anteroposterior axis and enhanced depth of focus associated with myopic astigmatism. The previous and current studies demonstrated that corneal multifocality (refractive power gradient within the pupillary area) has a significant positive relationship with the amount of apparent accommodation in pseudophakic eyes. Those eyes having wider range of corneal refractive power exhibited a greater amount of apparent accommodation.

As shown in the current results, coma-like aberration of the cornea significantly correlated with apparent accommodation. Among the third-order coma-like aberrations of the cornea, triangular astigmatism with base on the x-axis ($Z_{33}$) displayed the highest correlation with apparent accommodation. Positive values of the triangular astigmatism with base on the x-axis represent vertically asymmetrical distribution of corneal refractive power with greater refraction located in the lower part of the eye. This notion rather plausibly explains the mechanism of apparent accommodation. On the other hand, there was no association between spherical-like aberration of the cornea and apparent accommodation, indicating that the central-to-peripheral balance of the corneal curvature is not relevant to the ability of pseudoaccommodation. It has been reported that coma-like aberration of the cornea increases with age, but spherical-like aberration does not vary significantly with aging. It may be that age-related increases in coma-like aberration exert counteractive effects against the loss of accommodation along with aging.

As indicated in the current and previous studies, cornal multifocal effects can contribute to enhanced visual function, at least as measured by the high-contrast visual acuity chart. The clinician may consider the possibility of introducing coma-like aberration at the time of or after cataract surgery by manipulating corneal refractive status, to augment apparent accommodation. Another possibility includes induction of coma-like aberration in the cornea of a presbyopic eye with wavefront-guided excimer laser technology to restore accommodation. However, it should be deliberately evaluated whether such intentional induction of corneal higher-order aberrations would influence the optical quality of the eye. Applegate et al. reported that radial keratotomy causes an increase in the optical aberrations of the cornea that correlates with a decrease in contrast sensitivity. Seiler et al. showed that the reduction of low-contrast visual acuity after refractive surgery was significantly correlated with the total ocular aberration measured with an aberroscope. Verdon et al. suggested that abnormal findings in corneal topography after photorefractive keratectomy, such as decentration, were significantly related to low-contrast visual acuity. Applegate et al. investigated eyes with a variety of pathologic corneal conditions and reported that, regardless of the cause, corneas with an increased wavefront variance in the absence of spherical and/or cylindrical defocus errors show a quantifiable decrease in visual performance, as measured by contrast sensitivity and high- and low-contrast acuity. In eyes after photorefractive keratectomy, Tomidokoro et al. demonstrated that contrast sensitivity is adversely affected by the corneal irregular astigmatism that was computed using Fourier series harmonic analysis of the videokeratoscopy data.

Although influences on low-contrast visual acuity and contrast sensitivity were not addressed in the present study, it may be that such measures would be adversely affected in the setting of a multifocal cornea. Other possible adverse optical effects of a multifocal cornea include monocular diplopia, subjective glare, and halo effects. Thus, multifocality of the cornea would have both advantageous and disadvantageous effects on patients’ quality of vision. Moreover, there are many questions that are as yet unanswered about the optical performance of multifocal IOLs and multifocal contact lenses.

Further studies are needed to clarify the optimum corneal optical configurations after cataract surgery.

References


