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| Citation | Acta medica Nagasakiensia, 62(3), pp.101-106; 2019 |
| Issue Date | 2019-03 |
| URL | http://hdl.handle.net/10069/38943 |
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*Acta Med. Nagasaki* 62: 101－106

# Predictive factors for postoperative visual acuity following multifocal diffractive intraocular lens implantation using corneal topography and tomography

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**Purpose:** To identify predictive factors for postoperative uncorrected visual acuity (UCVA) following diffractive multifocal intraocular lens implantation.

**Subject and Method:** Forty five eyes of 28 patients who underwent cataract surgery with diffractive multifocal intraocular lens TECNIS® ZMB00 (AMO) implantation from January 2015 to March 2018 were included. We formed two groups randomly with 18 eyes of 11 patients defined as the training set for preoperative factors and 27 eyes of 17 patients defined as the validation set for postoperative effects. All eyes had undergone superior corneal incisions of 2.4 mm. The predictive factors included age, mean corneal refractive power, corneal astigmatism, spherical equivalent, coma and spherical aberration of cornea, depth of angle recess, mesopic and photopic pupil diameters, PDist and MDist (distances from the alignment light to the photopic and the mesopic pupil centers, respectively). The good-UCVA group was defined as patients who had logMAR ≦ 0 one month after the surgery. Independent-related factors were identified by stepwise logistic regression analyses.

**Results:** Only PDist was adopted (P = 0.0108) in the training set. The area under the curve (AUC) of the receiver operating characteristic (ROC) curve was 0.91. In the validation set, it had a sensitivity of 66%, a specificity of 100% and a cut-off value of 0.23.

**Conclusions:** It is supposed that distances from the alignment light to the PDist influence the postoperative UCVA following multifocal diffractive intraocular lens implantation.

ACTA MEDICA NAGASAKIENSIA 62: 101−106, 2019

**Key words:** predictive factors, diffractive multifocal intraocular lens , anterior segment OCT, logistic regression analysis, kappa angle, cornea

Multifocal intraocular lenses (MIOLs) have been widely used since the 1980s to obtain optimal vision at various distances after cataract surgery. They have a rotationally symmetric design taking advantage of light refraction and diffraction. Three types are available, refractive type, diffractive type and hybrid model that includes both refractive and diffractive.[1-3] Multifocal diffractive intraocular lenses can provide patients uncorrected visual acuity (UCVA) of more than one focal point such as far and near. Patients' satisfaction depends on postoperative UCVA. To increase patients' satisfaction, it needs not only visual acuity (VA) but also visual quality. Multifocal intraocular lens has halo and glare of light phenomena as side effects. In addition, contrast sensitivity decreases because the amount of light entering is divided into the near and far focuses through the multifocal intraocular lens. Both the photic phenomena evaluated halo and glare have been associated with the kappa angle[4] which is defined as the angle between the pupil axis and the visual axis.

In the present study, we investigated the visual parameters, optical performance, and wavefront analysis results of the AMO Tecnis® ZMB00 (Abbott Medical Optics, Santa Ana,

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Received December 4, 2018; Accepted January 7, 2019

CA, USA) implantation. This new design of multifocal IOL is a 1-piece IOL combining diffractive and aspheric optics. Specifically, the aspheric surface of this IOL induces a controlled amount of negative spherical aberration that compensates for the positive spherical aberration usually present in the cornea. It has 32 concentric rings with a central 1-mm ring that adds 4 diopters (D), thus corresponding to 3.2 D in the lens plane, regardless of the pupil size.[5,6] Predictive factors for postoperative UCVA may help in choosing the operative procedure and making prognosis with postoperative visual performance. We used multiple logistic regression analysis to identify predictive factors for good postoperative UCVA.

## SUBJECTS AND METHODS

### Study population

Subjects: For this prospective case series, we examined 45 eyes of 28 patients who underwent diffractive multifocal intraocular lens TECNIS® ZMB00 implantations from January 2015 to March 2018. We formed two groups of eyes randomly, with 18 eyes of 11 patients defined as the training set for preoperative factors and 27 eyes of 17 patients defined as the validation set for postoperative effects (Table 1). We followed all patients for at least 6 months after the surgery. We conducted this study adhering to the tenets of the Declaration of Helsinki and obtained informed consents from all study individuals. The Department of Ophthalmology and Visual Sciences at Graduate School of Biomedical Sciences in Nagasaki University received approval from the local ethics committee.

**Table 1.** Demographic data of patients

| | Training set | Validation set |
|---|---|---|
| Patients (n) | 11 | 17 |
| Eyes (n) | 18 | 27 |
| Mean age (y) ± SD | 60.3 ± 10.7 | 54.8 ± 16.9 |
| Male/Female | 5/6 | 8/9 |

There is no significant difference in the age between two sets (P=0.78, t-test).
SD=standard deviation;

### Examination for visual acuity

More than six months after the surgery, we examined the patients to obtain the primary efficacy endpoints for uncorrected visual acuity (UCVA) at far (5 m) and near (30 cm) distances. We measured the decimal VA at both distances using a Landolt ring chart under photopic light conditions and calculated the base-10 logarithm of the decimal VA as the logarithm of the minimum angle of resolution (logMAR).

### Surgery

We performed all surgeries under topical and sub-Tenon's anesthesia using a standard phacoemulsification technique. Briefly, a 2.4-mm clear incision was made at the superior cornea with a knife. After removing the crystalline lens, we implanted IOL through the incision into the capsular bag. At the end of the procedure, we confirmed that IOL was placed in the capsular bag.

### Measurement

We used an aberrometer (OPD-Scan, NIDEK, Japan) to evaluate preoperative corneal curvature radii, corneal astigmatism, spherical equivalents, coma and spherical aberrations, mesopic and photopic pupil diameters, distances from the alignment light to the mesopic and photopic pupil centers (MDist and PDist, respectively), and distance from the photopic to the mesopic pupil center (pupil center shift) (Fig.1).

Additionally, we defined the depth of angle recess as the length between the corneal endothelium and a perpendicular bisector of both of angle recesses (Fig. 2) and measured the angle recess depths using an anterior segment optical coherent tomograph (SS-1000 CASIA, Tomey, Japan).

### Statistics

We performed all statistical analyses using the JMP version 13.0 software (SAS Institute, Cary, NC, United States). We identified good-VA group eyes as those in the training set with uncorrected far VA and uncorrected near VA value of $<0$ logMAR after surgery and classified all other eyes into a non-good-VA group. We used multiple logistic regression analysis to compare values obtained by the aberrometer and those by anterior segment optical coherent tomograph for the two eye groups (The good-VA and the non-good-VA groups). We considered all P values $<0.05$ as statistically significant. Predictive factors included age, mean corneal curvature radius (mm), corneal astigmatism (D), spherical equivalent (D), coma and spherical corneal aberrations ($\mu$m), the depth of angle recess (mm), mesopic and photopic pupil diameters (mm), and distance from the alignment light to the photopic pupil center and distance from the alignment light to the mesopic pupil centers [PDist and MDist (mm), respectively]. We applied the multiple regression equation determined by multiple logistic regression analysis to the validation set and calculated the sensitivity and specificity.

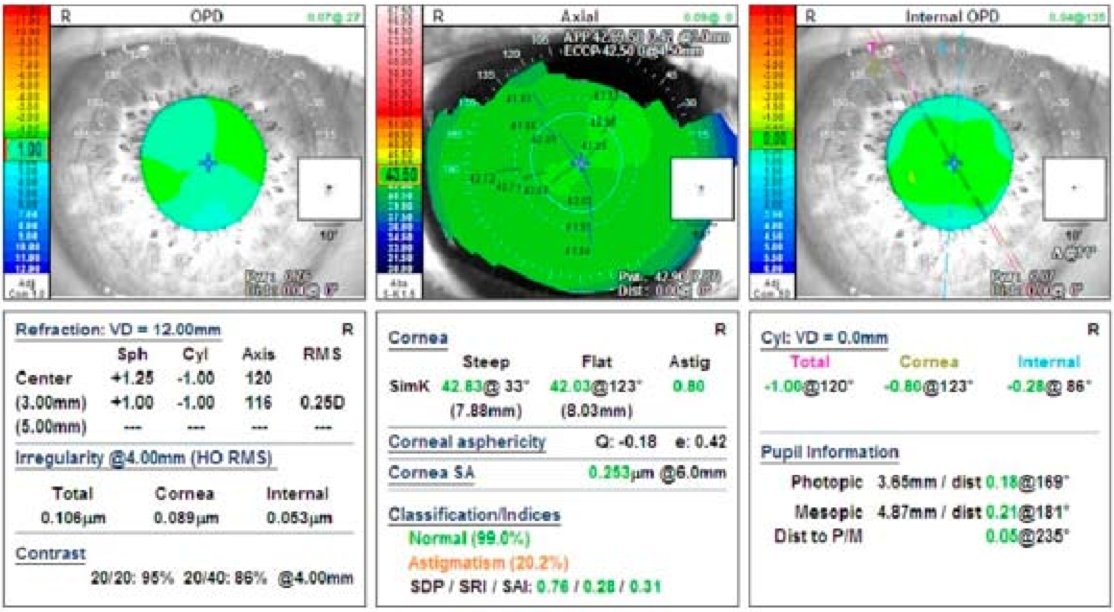


**Figure 1.** Representative display of aberrometer
The aberrometer can measure the higher order aberration (coma, spherical aberration and so on), and parameters of photic phenomena such as PDist and MDist by using topographic data. This eye has 0.089 $\mu$m of the corneal higher order aberration, 0.8D of the corneal astigmatism, 3.65mm of the photopic pupil diameter, 4.87mm of the mesopic pupil diameter, 0.18mm of PDist, 0.21mm of MDist, and 0.05 of PDist/MDist.


**Figure 2.** Representative display of anterior segment OCT
The anterior segment OCT can display the tomographic view. The depth of angle recess was defined as the length (blue line) between corneal endothelium and perpendicular bisector of both of angle recesses (white line).

## Results

Table 1 lists the demographic data of the individuals in the training and validation sets, and shows that the sets had no significant differences. Table 2 shows a comparison of the parameters measured with the aberrometer and anterior segment OCT between the two group sets. Our t-test confirmed the absence of significant differences in variables between the two groups. On the training set, our multiple logistic regression analysis determined the regression equation as the discriminant function and identified only PDist ($P$ = 0.0108). Fig. 3 shows the receiver operator characteristic (ROC) curve in the training set; the area under the curve

(AUC) had a value of 0.91. The point of tangency, where the tangent line y = x + b (b is an arbitrary constant) and ROC curve meet, was defined as the "optimal solution." Logistic regression analysis yielded the discriminant function at the optimal solution by defining the coefficient. In the present study, only one variable, PDist, was adopted; therefore, the discriminant function contained only one variable, and the cut-off value was 0.23. We ran the validation set with the discriminant function and calculated a sensitivity of 66% and specificity of 100%.

Fig. 4 shows the scatter plot between postoperative uncorrected far and near VAs in all eyes with a significant positive strong correlation [correlation coefficient R = 0.58 ($p < 0.001$)].

Fig. 5 shows the distribution of axial lengths according to age. The average axial lengths were 25.26 ± 1.93 mm, 24.45 ± 0.83 mm, 25.0 ± 1.27 mm, and 25.08 ± 0.94 mm,

**Table 2.** Output data of two sets

| | Training set | Validation set | P-value (t-test) |
|---|---|---|---|
| Curvature radius (mm) | 7.8 ± 0.16 | 7.5 ± 1.4 | 0.37 |
| Corneal astigmatism (D) | -0.88 ± 0.56 | -0.68 ± 0.53 | 0.24 |
| Corneal coma aberration RMS (μm) | 0.087 ± 0.053 | 0.12 ± 0.15 | 0.37 |
| Corneal spherical aberration RMS (μm) | 0.079 ± 0.10 | 0.053 ± 0.026 | 0.29 |
| Spherical equivalent (D) | -1.8 ± 3.3 | -3.1 ± 3.4 | 0.22 |
| Axial length (mm) | 24.9 ± 1.0 | 25.0 ± 1.5 | 0.85 |
| Depth of angle recess (mm) | 3.4 ± 0.35 | 3.5 ± 0.33 | 0.27 |
| Photopic pupil diameter (mm) | 3.9 ± 1.0 | 3.8 ± 0.84 | 0.83 |
| Mesopic pupil diameter (mm) | 5.5 ± 0.98 | 5.5 ± 1.1 | 0.91 |
| PDist (mm) | 0.24 ± 0.22 | 0.27 ± 0.18 | 0.60 |
| MDist(mm) | 0.33 ± 0.34 | 0.24 ± 0.085 | 0.37 |

PDist = Distance between alignment target and photopic pupil center.
MDist= Distance between alignment target and mesopic pupil center.

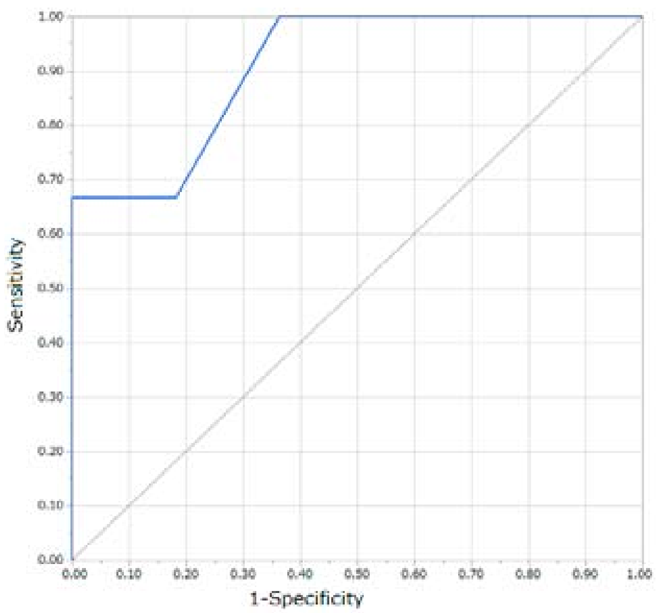


**Figure 3.** Receiver Operator Characteristic (ROC) Curve
Multiple logistic regression analysis determined regression equation as the discriminant function (P=0.0108). Only PDist was adopted. The area under the curve (AUC) was 0.91 with the cut-off value of 0.23.
Discriminant function: f(x)=1/ (1 + Exp( (-5.28) + 17.1*x))
x=PDist

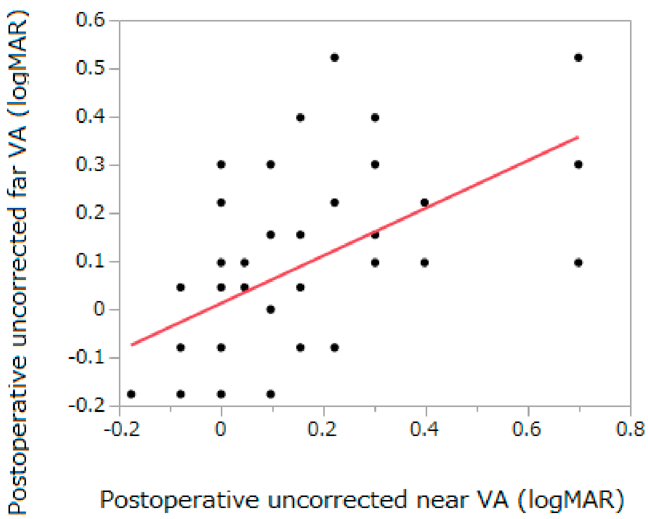


**Figure 4.** The scatter plot between postoperative uncorrected far and near visual acuity.
A scatter plot displays ordered pairs of X and Y variables in a coordinate plane.
Y= 0.49X + 0.012
X= Postoperative uncorrected near VA (logMAR)
Y= Postoperative uncorrected far VA (logMAR)
There was significant positive strong correlation (correlation coefficient R = 0.58 ($p<0.001$)).

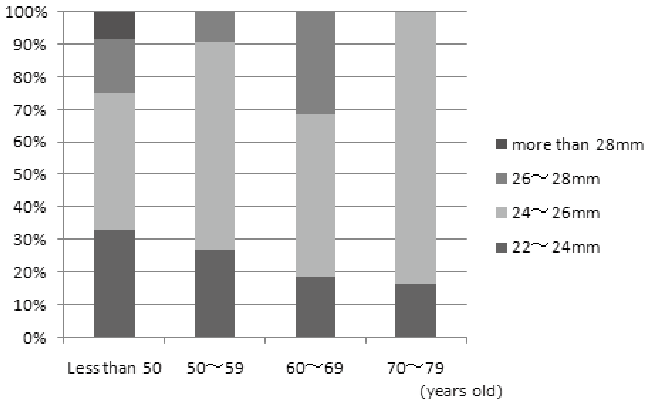


**Figure 5.** The axial length among ages.
This graph shows the percentage of the axial length for each age. The average axial lengths were 25.26 ± 1.93mm, 24.45 ± 0.83mm, 25.0 ± 1.27mm, 25.08 ± 0.94mm, in patients aged less than 50 years, 50-59 years, 60-69 years, 70-79 years respectively (no significant differences, p>0.05, Tukey-Kramer method).

in patients aged >50 years, those aged between 50 and 59 years, those aged between 60 and 69 years, and those between 70 and 79 years, respectively (no significant differences, p > 0.05, Tukey-Kramer method).

## DISCUSSION

The use of MIOLs provides patients good far and near VA. It is a growing surgical option to improve postoperative visual performance and spectacle independence for the patient.[7-9] However, some patients might be dissatisfied with worse results than they expected.[10-12] Predictive factors for postoperative VA can help decide the operative procedure and to predict visual performance more accurately. In this study, multiple logistic regression analysis selected the parameter of PDist as predictive factors for good uncorrected far VA (logMAR≦0) using diffractive MIOLs in the training set (Fig.3). Some bias in making training set for patients with positive outcome possibly existed. Another set is needed to eliminate potential selection bias. It is confirmed by validation set. It is supposed that there might be no bias of an estimator in two sets: the training set and the validation set because two sets had no significant difference in all parameters.

Tchah et al[13] reported it was effective for both of PDist and MDist as predictive factors. The reason might be that refractive MIOLs they used have structure more easily affected of pupil diameter than diffractive MIOLs we used. Refractive MIOLs have clearly two zones for far vision and near vision and have the problem that the boundary between far vision and near vision in the center of the lens must be located with the center of the pupil. If the boundary of the lens is not in the center of the lens, far vision and near vision are not focused on the retina and the patient might suffer visual losses. Mastropasqua et al[14] reported that the gap between the photopic and mesopic pupil centers may influence VA after MIOLs implantation, and this may be because they used the refractive MIOLs in which the gap of pupil center might have more influence.

Diffractive MIOLs are susceptible to the effects of age and older patients have lower VA in both of far and near vision.[15] It is supposed that the brain adaptation might play an important role for good far and near VA.[16] Some reports described that the retinal sensitivity could decrease with age.[17,18] Our study targeted mainly comparatively young people preoperatively. It might be the reason why the age was not selected in our study. It needs highly information processing of the brain central nerve system to proceed the information of some focuses on the retina through the MIOLs. Fig.4 resulted that there is a significant correlation between postoperative uncorrected far and near VA, that is, it has a tendency that the patients with worse postoperative uncorrected far VA had worse postoperative uncorrected near VA. It is suggested that the refraction could not be the reason for visual loss. The refraction is closely related with the axial length. It is supported that the refraction might not have influence on the ages as Fig.5 didn't show the significant difference in axial length among the ages.

Some studies reported that both tilt and misalignment of the center of MIOL may have an impact on the postoperative VA.[19,20] In our cases the aberration was lower than 0.3 $\mu$m with aberrometer and the asymmetry parameter and the higher order aberration were lower than 0.5 $\mu$m with anterior segment OCT. In particular, the coma aberration was lower than 0.5 $\mu$m, which is associate with lower tilt parameter. MIOLs should not be recommended for eyes with higher order aberrations.

It was reported that IOL power calculation using depth of angle recess detected with anterior segment OCT is the higher accuracy than anterior chamber depth[21], but our multiple logistic regression analysis didn't select the depth of angle recess. In this study, the refraction was not associated with postoperative VA in describing above. The refractive error of between IOL power calculation and post-operative refraction was small in our cases, which may suggest depth of angle recess had a low impact on analysis.

Photic phenomena such as halo and glare was associated with preoperative kappa angle.[22] PDist parameter is the value which can estimate Kappa angle. Although other diffractive MIOLs studies[13,23] have not included PDist clearly in the past, our study showed that the high PDist had an effect on worse VA and it might be included as the postoperative complication. The AUC of the ROC curve was 0.91, which is comparatively good result. However, the sensitivity of 66% is not good toward specificity of 100%. We should be careful for false-positives, and should develop the parameter of the higher sensitivity in the future. Patients who have the large gap of pupil center should not be recommended for MIOLs.[24)]

There are several limitations in this study. The number of subjects was small. There is the bias that the older people were excluded. We hope to participate in future studies overcoming these limitations to confirm and expand our present results. However, the results of this study are important because they show predictive factors for postoperative VA following multifocal diffractive IOL implantation using corneal topography and tomography.

In conclusion, it is supposed that PDist might have an impact on postoperative UCVA following multifocal diffractive IOL implantation. This should be taken into consideration for eyes with high PDist before MIOLs implantation.

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