Inferior Decentration of Multifocal Intraocular Lenses in Myopic Eyes

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• PURPOSE: To investigate the tilt and decentration of multifocal intraocular lenses (MfIOLs) implanted in myopic eyes.
• DESIGN: A prospective cohort study.
• METHODS: Twenty-eight myopic eyes and 56 emmetropic eyes were evaluated. Phacoemulsification with Tecnis ZMB00 MfIOL (Abbott Medical Optics, Santa Ana, California, USA) implantation was performed. At 1 year post-surgery, routine postoperative examinations were performed, and tilt and decentration of the MfIOLs, high-order aberrations, and modulation transfer function (MTF) were evaluated using the OPD-Scan III aberrometer (Nidek Co, Ltd, Gamagori, Japan). Subjective symptoms were assessed with a Quality of Vision questionnaire.
• RESULTS: Postoperative uncorrected distance visual acuity (VA), best-corrected distance VA, and uncorrected near VA did not differ between the 2 groups. The mean IOL tilt and horizontal decentration were not different between the control and myopic groups. However, the myopic group presented significantly inferior decentration in the capsular bag compared with the control group (\(-0.03 \pm 0.22 \text{ mm} vs -0.21 \pm 0.29 \text{ mm}, P = .002\)). The overall decentration values were 0.32 ± 0.14 mm in the controls and 0.40 ± 0.18 mm in the myopic group (\(P = .023\)). Axial length was negatively correlated with vertical decentration (\(r = -0.268, P = 0.014\)) and positively correlated with overall decentration (\(r = 0.334, P = .002\)). Worse aberration data, poorer MTF, and more subjective symptoms were also found in the myopic group than in the controls.
• CONCLUSION: Greater inferior decentration of MfIOLs and a consequent decrease in visual quality were found in myopic eyes, indicating that the increasing incompatibility between IOL and capsular bag size with axial length elongation should not be underestimated. (Am J Ophthalmol 2018;188:1–8. © 2018 Elsevier Inc. All rights reserved.)

METHODS

THIS PROSPECTIVE COHORT STUDY WAS APPROVED BY THE Institutional Review Board of the Eye and Ear, Nose, and Throat Hospital of Fudan University, Shanghai, China. All procedures adhered to the tenets of the Declaration of Helsinki. All patients provided written informed consent for their medical records to be used for research purposes. The study was registered at www.clinicaltrials.gov (accession number NCT03062085).

• SUBJECTS: A total of 28 eyes from 28 consecutive patients with myopia (AXL > 24.5 mm) and 56 eyes from 56 control subjects (22 mm < AXL < 24.5 mm) were recruited from the Eye and Ear, Nose, and Throat Hospital of Fudan University between January 10, 2015 and May 10, 2016. Eyes with corneal disease, irregular corneal...
FIGURE 1. Retrobulbar illumination analysis mode of a next-generation OPD-scan III aberrometer (Nidek Co, Ltd, Gamagori, Japan). The point of intersection between the blue and red lines in each image represents the center of the visual axis. The blue cross represents the center of the multifocal intraocular lenses. The green line crossing the center of the visual axis and blue cross were used for measurement of decentration. (Top) The short pink line crossing the green line indicates the vertical decentration; the direction and length are shown in the lower right box. (Bottom) The short pink line crossing the green line indicates the overall decentration; the direction and length are shown in the lower right box.
astigmatism, corneal astigmatism > 1 diopter (D), abnormal pupil and angle kappa, fundus pathologies, strabismus, previous trauma, glaucoma, zonular weakness, or diabetes were excluded from the study.

- **PREOPERATIVE EXAMINATIONS:** Careful preoperative ophthalmic examinations, including assessment of visual acuity, tonometry, funduscopy, corneal topography, B-scan ultrasonography, and AXL measurements (IOLMaster; Carl Zeiss AG, Oberkochen, Germany), were conducted.

- **SURGICAL TECHNIQUE:** Uneventful cataract surgeries were conducted by a single experienced doctor (Y.L.) according to a standard procedure. A 2.6-mm temporal clear corneal incision was created, followed by injection of viscoelastic into the anterior chamber. Phacoemulsification was performed after completion of a 5.5-mm continuous curvilinear capsulorhexis and hydrodissection. A Tecnis ZMB00 MfIOL (Abbott Medical Optics, Santa Ana, California, USA) was implanted into the capsular bag. After the viscoelastic was removed, the IOL was adjusted in the center, and the incision was hydrated. No stitches were used in any of the eyes.

- **POSTOPERATIVE FOLLOW-UP:** One year after surgery, all patients received postoperative follow-up examinations. Uncorrected distance, best-corrected distance, and uncorrected near visual acuities were assessed. Patients also completed the Quality of Vision questionnaire.

Intraocular lens tilts and decentrations were evaluated using an OPD-Scan III aberrometer. In the retrobulbar illumination analysis mode, the instrument identifies the visual axis and MfIOL diffraction-ring center. Horizontal and vertical IOL decentration values were then determined. Overall decentration, defined as the distance between the centers of the diffraction ring and visual axis, was also measured (Figure 1). The OPD-Scan III aberrometer provides information on total and intraocular higher-order aberrations (HOAs) under photopic, mesopic, and scotopic lighting conditions, as well as modulation transfer function (MTF) and kappa angle, in the form of distances between the centers of the pupil and visual axis.

- **STATISTICAL ANALYSIS:** All data are expressed as means ± standard deviations (SD). Between-group differences were assessed with Student t tests (continuous data) and χ² tests (categorical data). The relationships between continuous variables were assessed using Pearson correlation coefficients. P values < .05 were considered statistically significant. All analyses were performed using SPSS version 11.0 (SPSS, Chicago, Illinois, USA).

### RESULTS

TABLE 1 provides the patients’ demographic data. No statistically significant between-group differences were identified for age, sex, operated eye, or preoperative visual acuity (Student t tests for age and preoperative visual acuity, χ² tests for sex and operated eye, all P > .05). Postoperative uncorrected distance, best-corrected distance, and uncorrected near visual acuities did not differ significantly between the 2 groups (Student t tests, all P > .05). AXL was significantly longer in the myopic vs control group (Student t test, P < .001). No significant between-group differences were identified for kappa angles under the photopic, mesopic, or scotopic conditions (Student t tests, all P > .05).

The mean ± SD IOL-tilt values were 0.43 ± 0.35 and 0.58 ± 0.94 µm in the control and myopic groups, respectively, with no significant between-group difference (Student t test, P = .311). Moreover, no significant between-group differences were found for horizontal decentration values (−0.07 ± 0.26 mm and 0.01 ± 0.25 mm in the control and myopic groups, respectively; Student t test, P = .184). However, the myopic group showed significantly inferior decentration in the capsular bag compared to the control group (−0.03 ± 0.22 mm and −0.21 ± 0.29 mm in the control and myopic groups, respectively; Student t test, P = .002). The overall decentration values were 0.32 ± 0.14 mm and 0.40 ± 0.18 mm in
the control and myopic groups, respectively (Student t test, \( P = .023 \)). Table 2 presents the effects of IOL placement on vertical decentration. No statistically significant differences were identified in horizontal, vertical, or oblique placement ratios between the 2 groups (\( \chi^2 \) test, \( P = .685 \)). In general, MfIOLs in the myopic group showed

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**FIGURE 2.** Correlations between decentration and axial length. (Left) Vertical decentration correlated negatively with axial length (Pearson correlation coefficient, \( r = -0.268, P = .014 \)). (Right) Overall decentration correlated positively with axial length (Pearson correlation coefficient, \( r = 0.334, P = .002 \)).

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**FIGURE 3.** Between-group (control and myopic groups) differences in ocular (Left) and intraocular (Right) aberrations under different lighting conditions. *A significant difference was found between the 2 groups (Student t test, \( P < .05 \)). HOAs = higher-order aberrations; RMS = root mean square. Error bars represent standard error of the mean.

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**FIGURE 4.** Between-group (control and myopic groups) differences in modulation transfer functions (MTFs) at different spatial frequencies under different lighting conditions. (Left) Ocular MTF and (Right) intraocular MTF. The myopic group showed lower mean ocular and intraocular MTFs at each spatial frequency, without statistical significance (Student t test, all \( P > .05 \)). Error bars represent standard errors of the mean.
FIGURE 5. Schematic diagram showing a slight “sink” of the intraocular lens in the large capsular bag of a myopic eye.

more apparent “sinking” than those in the control group, regardless of horizontal, vertical, or oblique placement, and the amount of “sink” in the capsular bag was lowest for vertically placed IOLs in the control and myopic groups.

AXL correlated negatively with vertical decentration and positively with overall decentration (Pearson correlation coefficient, $r = -0.268, P = .014$ for vertical decentration, and $r = 0.334, P = .002$ for overall decentration; Figure 2). No obvious correlations were identified between IOL tilt and AXL (Pearson correlation coefficient, $r = 0.053, P = .639$) or between horizontal decentration and AXL (Pearson correlation coefficient, $r = 0.185, P = .093$).

Figure 3 provides a between-group comparison of ocular and intraocular aberrations under different lighting conditions. In terms of ocular aberrations, total HOAs and spherical aberrations under mesopic and scotopic lighting conditions, and coma under scotopic lighting conditions, were significantly higher in the myopic group (Student $t$ test, all $P < .05$). Intraocular total HOAs under mesopic and scotopic lighting conditions, and coma and spherical aberrations under scotopic lighting conditions, were significantly greater in the myopic group (Student $t$ test, all $P < .05$). Under photopic lighting conditions, ocular and intraocular aberrations showed no between-group differences.

Total ocular MTF (area under the curve) was significantly lower in the myopic vs control group under mesopic and scotopic lighting conditions (photopic: $35.77\% \pm 10.94\%$ vs $40.21\% \pm 15.72\%$, respectively; mesopic: $33.46\% \pm 12.67\%$ vs $39.80\% \pm 13.19\%$, respectively; scotopic: $31.82\% \pm 10.86\%$ vs $38.31\% \pm 12.88\%$, respectively; Student $t$ test, $P = .199, P = .444$, and $P = .03$ for photopic, mesopic, and scotopic lighting conditions, respectively). A between-group comparison of ocular and intraocular MTFs at different spatial frequencies under different lighting conditions is provided in Figure 4. MTF was lower in the myopic group at all evaluated spatial frequencies, albeit without statistical significance (Student $t$ test, all $P > .05$).

The myopic group had higher Rasch-adjusted Quality of Vision scores for frequency and severity of dysphotopsia symptoms than the control group (Student $t$ test, $P = .011$ and $P = .019$, respectively; Supplemental Table; Supplemental Material available at AJO.com). In addition, more subjective symptoms, especially halo, were reported in the myopic group than in the control group ($\chi^2$ test, $P < .001$ for halo, Supplemental Figure; Supplemental Material available at AJO.com).

DISCUSSION

DESPITE THE WIDE APPLICATION OF MFIOLS, THERE IS STILL uncertainty regarding their use in myopic eyes.12,16 Many surgeons are concerned that complicated fundal conditions in myopic eyes impair MfIOL optical function.17,18 However, few have considered IOL instability induced by incompatibility between fixed and increased sizes of IOLs and capsular bags in myopic eyes, respectively. In the current study, we used an OPD-Scan III aberrometer to evaluate the tilt and decentration of MfIOLs implanted in myopic eyes. We found that inferior decentration of MfIOLs significantly increased with AXL, affecting IOL optical function (as indicated by the aberration data, MTF measurements, and subjective symptoms).

Myopia is relatively prevalent in Asia.9,19,20 In the Blue Mountains Eye Study, among a cohort of 3654 white adults aged 49 years or more, the prevalence of myopia exceeding $-5.00$ D was $2.49\%$.21 The Beijing Eye Study found a higher prevalence of myopia exceeding $-5.00$ D ($3.29\%$) among 4439 adults over 40 years of age.20 Patients with myopia normally strongly desire independence from glasses. Younger patients turn to refractive surgeries, such as laser in situ keratomileusis or small-incision lenticule extraction surgery.22–26 Those too old for refractive surgery may opt for cataract surgery combined with MfIOL implantation. However, owing to the complexity of fundus in myopic eyes, cataract surgery is often contraindicated, or certainly recommended with substantial caution.17,18,27 Related maculopathy leads to decreased contrast sensitivity, and MfIOL implantation results in a compounded reduction in contrast sensitivity, potentially decreasing visual outcomes.27,28

Currently, there is insufficient evidence as to the compatibility between capsular bags and MfIOL sizes. Despite a power range from $+5$ to $+34$ D, commercially available MfIOLs are primarily designed according to Western eyeball structures. The AXLs of Westerners are typically within the emmetropia range, and the prevalence of myopia is much lower than in Asian populations.20,21,29 Thus, fixed-size IOLs cannot compensate for the slight increases in capsular bag sizes with eyeball elongation,
leading to size incompatibility between capsular bags and IOLs. In the current study, inferior decentration of MfIOLs was observed in myopic eyes, whereas horizontal decentrations did not differ significantly between myopic and control subjects. A possible explanation is the slight "sink" of MfIOLs, over time, in the larger capsular bags of myopic eyes (Figure 5).

The more optically sophisticated the IOL design, the greater the sensitivity to decentration. The visual performance of aberration-correcting IOLs is affected by decentration, more than that of aberration-free IOLs, while spherical IOLs are entirely unaffected by decentration. Soda and Yaguchi argued that if no complications occur during cataract surgery and IOLs are inserted in the bags, decentration may decrease to approximately 0.3 mm. They observed almost no changes in far or near MTFs for all MfIOLs evaluated (ReSTOR SA60D3, Alcon; Tecnis Multifocal ZM900, AMO; ReZoom, AMO; SFX-MV1, Hoya) at decentrations of 0.25 mm. However, their study was conducted in eye models and not actual eyes. By measuring optical quality, Holladay and associates provided evidence that decentrations > 0.4 mm and tilts > 7 degrees in aspheric IOLs decrease their optical performance to below that of conventional spherical IOLs. The optical design of MfIOLs is far more complicated than that of aberration-correcting IOLs, which are more sensitive to IOL decentration. In our study, we found overall decentrations of 0.4 mm in the myopic group, and the aberration data were generally worse under mesopic and scotopic lighting conditions in myopic patients, with inferior MfIOL decentrations, compared to controls. Moreover, visual quality, in terms of total ocular MTFs, was poorer in these patients compared to emmetropic controls. Inferior decentrations of MfIOLs in myopic patients may relate to higher frequencies of subjective symptoms, such as halo, which is often induced by increased coma and spherical aberrations.

Thus, it can be inferred that, in addition to MfIOLs, use of many other sophisticated designed IOLs with a fixed size in myopic eyes should also be monitored. Individualized correction of capsular bag sizes, with respect to AXLs, and the development of more adaptive IOLs for myopic eyes may enhance the use of IOLs in myopic eyes and improve surgical outcomes.

Several details need to be addressed with regard to this study. An OPD-Scan III aberrometer was used to determine IOL tilt from intraocular tilted data, and the center of the visual axis was identified automatically by the aberrometer in the retrobulbar illumination analysis mode. In MfIOLs, it is easy to identify the center of the IOL because of the diffractive ring design. Thus, measurement of the exact distance between the visual axis and IOL center (ie, real decentration) is possible using an OPD-Scan III aberrometer. Previously used methods, such as Scheimpflug imaging, necessitate the use of image processing software, and decentration is defined as the distance between the IOL vortex and pupillary axis. Consequently, fewer human factors are involved in OPD-Scan III measurements of IOL decentration and tilt, compared with earlier methods. Thus, the method used in this study may be more convenient and accurate. A limitation of this machine is that it tends to be less effective in eyes implanted with multifocal IOLs; however, the centers are not easily identified without sufficient pupil dilation or in eyes with poor fixation. It is also important to note the effect of MfIOL placement. In this study, the amount of "sink" in the bag was generally less in vertically placed IOLs in the control and myopic groups, possibly owing to the different mechanical effects of haptics, depending on placement type (ie, the inferior haptics may provide more support to the IOL optic during vertical as opposed to horizontal placement). Another factor for consideration is the effect of kappa angle, which is reported to be associated with photic phenomena, such as halo and glare. This may add to the complexity of the optical effects of MfIOLs with decentration. Although in the current study no between-group differences were found in kappa angles, it is possible that the kappa angle effect was magnified by inferior decentration in the myopic group, as indicated by the significantly higher frequency of subjective symptoms (such as halo) in this group. Future studies are required to further elucidate the above perspectives.

To conclude, data obtained using an OPD-scan III aberrometer revealed greater inferior decentration of MfIOLs, and consequent decreased visual quality in myopic eyes. Thus, incompatibility between IOL and capsular bag sizes should not be underestimated in eyes with elongated AXLs.

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REFERENCES


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