Comparison of Visual Performance between Refractive and Diffractive Multifocal Intraocular Lenses

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Abstract

AIM To compare the visual performance of asymmetric refractive multifocal intraocular lenses (MIOLs) with all optic zone diffractive MIOLs.

METHODS A prospective study. Patients underwent phacoemulsification were divided into two groups according to the type of MIOLs: 25 patients were implanted with asymmetric refractive MIOLs and 25 patients with all optic zone diffractive MIOLs. Visual acuity, refraction, defocus curves, objective optical quality and the questionnaire of life quality were measured 3 months after surgery.

RESULTS There was no significant difference between two groups in uncorrected distance visual acuity□uncorrected near visual acuity□best corrected distance visual acuity or distance corrected near visual acuity. However, the uncorrected intermediate visual acuity was 0.24±0.10 in refractive group and 0.31±0.13 in diffractive group ($P<0.05$); the distance corrected intermediate visual acuity was 0.22±0.09 in refractive group and 0.31±0.14 in diffractive group ($P<0.05$). Defocus curves showed two crests in both groups. However, the curve between two crests of refractive group was smoother than diffractive group. The Modulated transfer function cut-off frequency was (22.74±12.29)c/d in refractive group and(30.50±10.04)c/d in diffractive group ($P<0.05$); the OQAS values 100% (OV100%) were 0.75±0.41 in refractive group and 1.02±0.34 in diffractive group($P<0.05$),OV20% were 0.52±0.34 in refractive group and 0.71±0.25 in diffractive group ($P<0.05$).There was no significant difference between two groups at overall satisfaction, independence spectacles ratio or visual interference phenomenon.

CONCLUSIONS Both MIOLs achieve good visual acuity at distance and near. The asymmetric refractive MIOLs show better intermediate visual acuity, and the all optic zone diffractive MIOLs appear to have better objective visual quality.

Background

Multifocal intraocular lenses (MIOLs) have become a widely accepted option in cataract surgery. All MIOLs developed until now with reported clinical outcomes are based on the principles of diffraction and refraction. With these technologies, incoming light rays are distributed onto two principal focal points (near and distance foci) or onto several foci, to provide post-surgery patients clear view at all distance [1–5]. {Alio, 2012 #93}Meanwhile, these designs produce several consequences such as loss of light reducing contrast sensitivity, permanent overlapping images generating halos and glare and loss of image quality [6–8].

In clinic, refractive and diffractive MIOLs have proved their own advantages and side effects. However, few studies have been done to compare these two types of MIOLs [2, 4]. Some researchers believe that after eliminating the diffraction ring, the energy loss of light will be less, which is more beneficial to the improvement of visual quality [9–11]. And according to the newest design theory of refractive MIOLs, excellent objective and subjective visual acuity are able to be gained [2, 3, 12–14]. Is this true? Will this new design give patients a better visual acuity and visual quality as it states?

The aim of this study is to compare the refractive rotationally asymmetrical MIOLs with the full optic zone diffractive MIOLs using both objective and subjective methods, and to provide a comprehensive reference for personal MIOLs choice in clinic.

Methods

This non-randomised, case-control observational study was performed at the Eye Hospital of Wenzhou Medical University (Zhejiang, China), approved by the institutional review board and ethics committee of Wenzhou Medical University. Practices and research were conducted in accordance with the Declaration of Helsinki. All patients signed informed consent before participation.

Patients' records between October 2016 to August 2017 were evaluated and fifty patients (50 eyes) with uneventful phacoemulsification and IOL implantation surgery were included. Twenty-five patients were implanted with refractive rotationally asymmetrical MIOLs (Oculentis MF30) and twenty-five patients were implanted with all optic zone diffractive MIOL (TecnisZMB00). Inclusion criteria were otherwise healthy eyes (except for age-related cataract), axial length between 22 and 25 mm and IOL implantation in the capsular bag. Exclusion criteria excluded patients less than 50 years of age; with corneal astigmatism of more than 1.0 D; with cornea or optic nerve lesions, macular diseases, ocular inflammation or eyes with any ocular surgical history. All patients provided informed consent.

First operated eye was selected when the patient had binocular cataract surgeries. The IOL type implanted was self-selected by the patient. Visual functional data were collected by clinical research staff who did not know the lens type the patient received.

Patient assessment

All patients had a full pre- and post-operative ophthalmologic assessment. The preoperative examination included refraction, uncorrected distance visual acuity (UCDVA), best-corrected distance visual acuity (BCDVA), slit-lamp examination (SL115;Carl Zeiss, Oberkochen, Germany), fundus examination under dilation, corneal topography (Pentacam, Oculus, Inc.), endothelial cell count (SP 2000P specular microscope, Topcon Europe BV), biometry (IOLMaster, Carl Zeiss Meditec AG), retinal optical coherence tomography (Cirrus 4000 OCT, Carl Zeiss MeditecAG), Postoperatively. Patients were evaluated at 1 day, 1 week, and 1 and 3 months. At each follow-up visit, the UCDVA and BCDVA, Uncorrected near visual acuity (UCNVA) and distance corrected near visual acuity (DCNVA), Uncorrected intermediate visual acuity (UCIVA) and distance corrected intermediate visual acuity (DCIVA), refraction, Optical Quality Analysis System (OQAS) II were measured At the 3-month evaluation, defocusing curve was measured and patients were requested to complete a purpose-developed satisfaction questionnaire.

Intraocular lens

The Lentis Mplus LS–313 MF30 (Oculentis GmbH) (figure 1a) is an asymmetric refractive MIOL that has been used extensively and has evolved to a plate haptic. This asymmetric refractive MIOL is unusual in not refracting light symmetrically around the optical axis. It is designed with a 6.0 mm optic and a sector-shaped 3.0 diopter (D) near segment. The ZMB00 (Advanced Medical Optics, Santa Ana, California,USA) (figure 1b) is a diffractive MIOL with 4.0 diopter (D) near segment. The posterior surface has a full diffractive optic, blue light allowing lens, which has a special margin design that is round in the front portion and square in the back. Therefore, toric piggyback IOL implantation is recommended as an alternative way for congenital cataract patient with short axis length and big corneal astigmatism.

Surgical procedures

A single surgeon did all the surgeries. The surgical procedure was the same for both lenses. Phacoemulsification was performed under topical anaesthesia through a 2.2 mm transparent corneal incision and used continuous curvilinear capsulorrhex of about 5–5.5 mm. Endocapsular phacoemulsification of the nucleus was performed using Infinity vision system unit (Alcon). Polishing of the posterior capsule was also performed. The IOL was implanted in the capsular bag.

Outcome measurements

UCDVA and BCDVA of each selected eye was measured at 5m using standard logarithmic visual acuity chart with illumination of 80 cd/m2. UCNVA and DCNVA were measured, at the reading distance patients prefer, using near logarithmic visual acuity chart. UCIVA and DCIVA were measured at distance of 80 cm using logarithmic visual acuity chart. Both intermediate and near visual acuity were measured under photopic conditions with illumination of 80 cd/m2. Visual acuity results were recorded in logMAR.

Optical Quality Analysis System (OQAS) II is the only available system to provide objective analysis of visual quality at present.[15]. This system is based on a double-pass technique, analyzing the visual quality in human eyes from aberration, scatter and diffraction. In this study, OQAS II was used to obtain the ocular objective optical quality parameters at 4.0 mm pupil, including modulation transfer function (MTF) cut-off frequency, objective scatter index (OSI), Strehl ratio (SR), and OQAS values (OVs 100%, 20% and 9%) 3 months after IOL implantation.

Defocus curves in the same patients were evaluated at 5m using standard logarithmic visual acuity chart. Defocus was performed from the best distance correction in 0.5 diopter (D) steps from 1.0 D to –4.0 D. Visual acuity results were recorded in logMAR[16, 17].

The subjective visual quality of post-surgery patients was investigated by using a Chinese version of the National Eye Institute Visual Function Questionnaire (CHI-VFQ–25)[18] , including subjective visual evaluation, independence spectacles ratio, and visual disturbance symptoms. Patients' subjective visual quality was evaluated with 0 ~ 10 points, with 10 points being full marks. Whether it is necessary to wear frame glasses or corneal contact lenses at distance, medium and near after surgery to calculate the rate of independence from spectacles. Symptoms of visual interference include glare and halo.

Data analysis

All statistical analyses were performed using the SPSS V.19.0 statistical software. Categorical data used $\chi 2$ test and Spearman rank correlation; measurement data in accordance with normal distribution used the t test and Pearson correlation; Mann–Whitney U test and Spearman correlation were used when a normal distribution was not expected. The categorical results were expressed as mean±SD for data in accordance with normal distribution, and expressed as median (range) for data not conforming to normal distribution. Differences with $p<0.05$ were considered to be statistically significant.

Results

General data

All patients completed examinations at 3 months after surgery. No intraoperative complications occurred. No cornea decompensation, glaucoma, posterior capsular opacification or cystoid macular edema was observed during follow-up examination. The preoperative conditions of eyes in the two groups were analyzed, and no statistically significant differences were found for any preoperative parameter. No significant differences between two groups were found in age, sex, pre-surgical VA as shown in table 1.

Table 1 Clinical and demographic data of patients implanted with refractive and diffractive MIOL (visual acuity results were recorded in logMAR)

Visual and refractive outcomes

The postoperative visual and refractive outcomes were summarized in table 2. No statistically significant differences were found between the two groups in UCDVA、UCNVA、BCDVA or DCNVA. However, significantly better UCIVA and DCIVA were found in the refractive group at 3 months postoperatively (table 2).

Table 2 Postoperative visual and refractive outcomes in the refractive and diffractive groups at 3 months postoperatively (results were recorded in logMAR)

Objective optical quality outcomes

No significant differences were found in the OSI, SR, or the OV 9% between the two groups. However, MTF cut-off frequency, OV100% and OV20% were significantly better in diffractive group (table 3).

Table 3 Objective measures by OQAS II in the refractive and diffractive groups at 3 months postoperatively (the pupil is 4mm)

Defocusing curve

Defocus curves showed two crests in both groups. However, the curve between two crests of refractive group was smoother than diffractive group (Figure 2).

VF questionnaire

No significant differences were found in the glare/halo, independence spectacles ratio or overall satisfaction between the two groups (table 4).

Table 4 Questionnaire results in the refractive and diffractive groups at 3 months postoperatively

Discussion

Refractive and diffractive MIOLs are two main types MIOLs popularly used in cataract surgery. In this study, we found the improvement of UCDVA and BCDVA in both groups to be similar and consistent with previous findings reported by other studies using MIOLs. Both types of MIOLs seem to have a similar capacity to successfully restore the distance visual function after cataract surgery. Also, results showed both groups gained good UCNVA and DCNVA, which means both IOLs are able to provide enough near visual function at reading distance for post-surgery patients. And there results are also consistent with previous reports.[2, 4–6, 14, 19]. However, better results were found in UCIVA and DCIVA for the refractive group. Also, defocus curves showed a smoother curve in the refractive group than the diffractive group, which was consistent with the visual outcomes. These outcomes were expected, as this refractive model should provide better intermediate vision performance because of the design theory. This refractive model is based on the concept of refractive rotational asymmetry. The design of this lens includes an inferior surface-embedded segment with the optical power required for near vision and seamless transitions between the near and far vision zones. This type of design theoretically makes this MIOL independent of pupil size and ensures optimum adjustment of near and distance vision acuity. Besides, the plate-haptic design may contribute to the good visual outcomes. Previous research has compared plate-haptic models and C-loop haptic model of this refractive MIOLs and found better refractive predictability and intraocular optical quality with the plate-haptic design than with the C-loop haptic model due to a better IOL stability[20]. Our findings accord with this theory.

In the study, we found MTF cut-off frequency, OV100% and OV20% were significantly better in the diffractive group under 4mm pupil than the refractive group, which was unexpected. MTF is the ratio of contrast between the retinal image and the original scene. The MTF cut off provided by OQASII is the cut off frequency (cpd) at 1% of maximum MTF. In other words, it indicates the spatial frequency corresponding to the contrast of the retinal image at 1% of the original scene [21]. The OV100%, OV20%, and OV9% represent the OQAS value calculated by the system at three contrasts commonly used in ophthalmic practice. The OV100% is the MTF cut off frequency divided by 30 cpd. The OV20% and OV9% are linked to 0.05 and 0.01 MTF values. Therefore, the three OVs are closely related to the MTF curve. SR describes the ratio of central maximum of the illuminance of the point spread function in the aberrated eye to the central maximum of the aberration-free system—the closer it is to 1, the smaller the aberration of the eye. OSI is an index of intraocular scattered light, equal to the amount of light outside the double pass retinal intensity point spread function image in relation to the amount of light on the center.[22, 23]. The higher the value of the MTF cut off, SR and OVs, and the lower the OSI, the better the optical quality. The measurements were taken with an artificial pupil diameter of 4.0 mm, set by the instrument, which is the standard size used in clinical double-pass studies[24]. The artificial pupil with a diameter of 4mm reduces the impact of pupil diameter on the MTF, decreasing the variability of the SR. In our study, all outcomes derived from OQASII of the diffractive group were better than the outcomes of the refractive group as seen in table 3. Although the differences of OSI, SR and OV9% between two groups were not significant, which we considered may because of the limited case numbers. Therefore, it seems that the all optic zone diffractive MIOLs appear to have better objective visual quality than the asymmetric refractive MIOLs. Besides, the OQAS results of the diffractive MIOL in this study is very close to the results we gained in a previous report[5], which indicates that the data is reliable.

Meanwhile, no significant differences were found in subjective visual quality between the two groups. We found no difference in glare, halo, and independence from spectacles or patient satisfaction between the two groups. Besides, previous studies have report that ZMB00 has similar subjective visual quality with same material monofocal IOL [1, 5]. These findings indicate that this diffractive MIOL can provide both good objective and subjective visual quality.

We consider that for the refractive MIOL MF30, although giving up using diffractive rings in optical zone may be beneficial to the use of light rays, however, the division of the pupil area could result in loss of light source, which may cause the impairment of objective and subjective visual quality. For the diffractive MIOL ZMB00, the material properties and the design of MIOL may play important roles in improvement of visual quality. Recent studies have shown that achromatisation by diffractive MIOLs provided significant improvement in polychromatic retinal image quality [5, 19, 25]. A high Abbe number of 55.5 was used in ZMB00 lens. Contrast sensitivity increased by 12% due to the lower chromatic dispersion when compared with other materials. This minimizes the impact of chromatic aberration. In addition, instead of anterior surface, the posterior diffractive surface concentrating light while travelling inside MIOLs also helps in better focus promoting visual performance. ZMB00 MIOLs also have margin design which is round in the anterior portion and square in the posterior. Compared with the traditional reticular margin design, this design reduces diffraction and refraction along the edge. All of these factors help reducing impact of glare and contrast sensitivity which improves optical quality.

Conclusions

These results suggest that apart from paying attention to the improvement of the principle of focal separation, we should also pay attention to aberrations, color differences, IOL edge design and the placement of the front and back of the focal plane. We also need to consider the needs of different groups, such as the height of the patients, preoperative refractive state, the nature of the work and so on. Choosing a MIOL that works best for the patient will truly meet personalized vision requirements.

Abbreviations

MIOLs, multifocal intraocular lenses; UCDVA, uncorrected distance visual acuity; BCDVA, best-corrected distance visual acuity; DCNVA, distance corrected near visual acuity; UCIVA, uncorrected intermediate visual acuity; DCIVA, distance corrected intermediate visual acuity; OQAS, optical Quality Analysis System.

Declarations

- Ethics approval and consent to participate: our study was submitted to and approved by the institutional ethics committee of Eye Hospital of Wenzhou Medical University. This study was obtained written informed consent from all participants.
- Consent for publication: Not applicable. Our manuscript contains none of individual person's data.
- Availability of data and materials: Data and materials of this analysis were extracted from the original researches which were referenced in this article.
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- Authors' contributions: The authors on this paper all participated in study design. All authors read, critiqued and approved the manuscript revisions as well as the final version of the manuscript. Also, all authors participated in a session to discuss the results and consider strategies for analysis and interpretation of the data before the final data analysis was performed and the manuscript written. All authors have the appropriate permissions and rights to the reported data.
- Acknowledgements: JL had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: JL and LY. Acquisition, analysis or interpretation of data: all authors. Drafting of the manuscript: LY and TC. Critical revision of the manuscript for important intellectual content: all authors. Statistical analysis: LY and TC. Technical support: ZH and QS. Study supervision: JL. Endorsing of the data and conclusions: all authors.5. Acknowledgements

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9. Competing interests

The authors declare no interest.

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Tables

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Figures

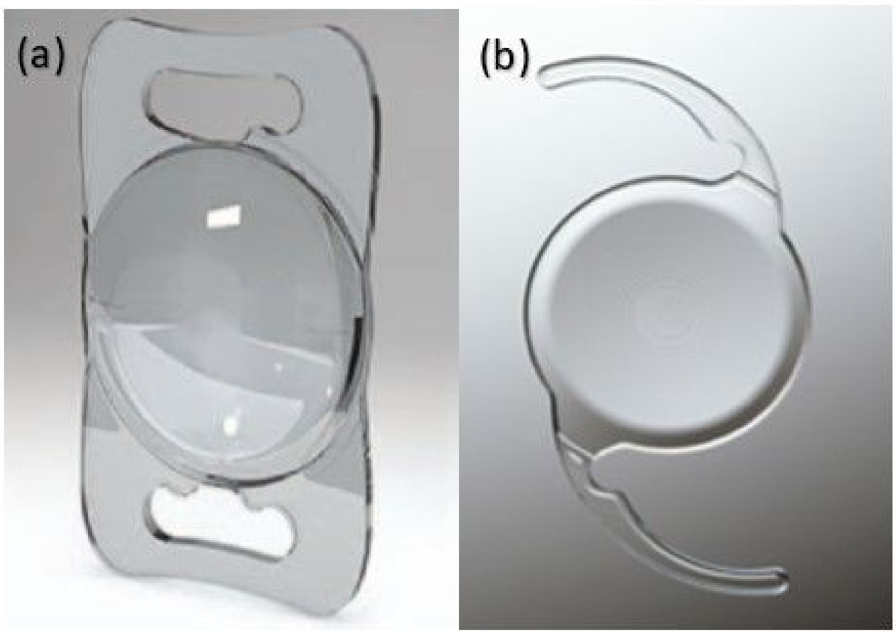

Figure 1 (a) Lentis Mplus LS-313 MF30 multifocal IOL (b) ZMB00 multifocal IOL

Figure 1

(a) Lentis Mplus LS-313 MF30 multifocal IOL (b) ZMB00 multifocal IOL

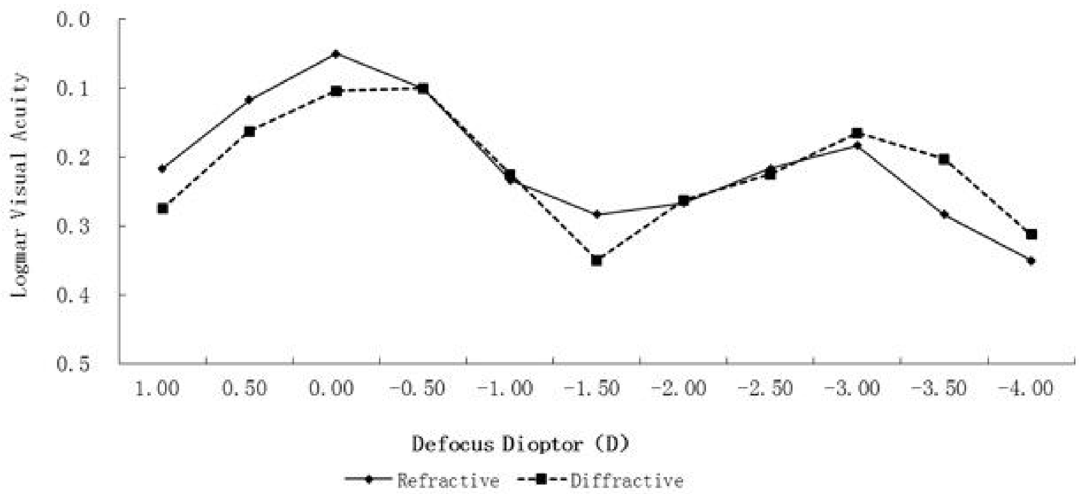

Figure 2 Defocusing curves of refractive and diffractive groups

Figure 2

Defocusing curves of refractive and diffractive groups

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