· Clinical Research ·

Early outcomes of vision and objective visual quality analysis after cataract surgery with trifocal intraocular lens implantation

Mei-Fang Chu[1], *Na Hui*[1], *Cong-Yi Wang*[1], *Lei Yu*[1], *Bo Ma*[1], *Yan Li*[1], *Cheng Pei*[2]

[1]Ophthalmology Department, Xi'an Fourth Hospital, Shaanxi Ophthalmological Hospital, Xi'an 710004, Shaanxi Province, China

[2]Ophthalmology Department, First Affiliated Hospital of Xi'an Jiaotong University, Xi'an 710061, Shaanxi Province, China

Correspondence to: Cheng Pei. Ophthalmology Department of First Affiliated Hospital of Xi'an Jiaotong University, No.277, West Yanta Street, Xi'an 710061, Shaanxi Province, China. peich71@163.com.

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Abstract

● AIM: To investigate the early outcomes of vision, objective visual quality and their correlation after cataract surgery with trifocal intraocular lens implantation.

● METHODS: The visual examination and objective visual quality analysis using Optical Quality Analysis System (OQAS) at 1mo and 3mo, and defocus curve examination at 3mo were performed in 20 patients (27 eyes) after phacoemulsification combined with trifocal intraocular lens implantation surgery.

● RESULTS: The uncorrected distant (UD), intermediate and near visual acuity (VA) were significantly improved after surgery (*P*<0.001). UDVA at 1mo after the surgery was slightly better than that after 3mo (*P*=0.026). The defocus curve after 3mo indicated that the peak of distant vision was close to 0 logMAR, and UDVA was lower than 0.3 logMAR in the range of -1.5 D to -3.0 D. The modulation transfer function (MTF) cutoff frequency, strehl ratio (SR), Optical Quality Analysis System values (OVs), includes OV100, OV20 and OV9 after the surgery were significantly better than before surgery (*P*<0.001), but the objective scattering index (OSI) was significantly decreased (*P*<0.001). UDVA at 3mo after the surgery had correlations with MTF cutoff, OSI, OV100 and OV20 (*r*=-0.400, 0.431, -0.437, -0.411, *P*=0.039, 0.025, 0.023, 0.033). The uncorrected intermediate VA after 3mo of the surgery had correlations with OSI and OV100 (*r*=0.478, -0.411, *P*=0.012, 0.033).

● CONCLUSION: Trifocal intraocular lens implantation can provide good distant, intermediate and near VA, and the vision shows a well correlation with objective visual quality during early surgery.

● **KEYWORDS:** visual quality; trifocal intraocular lens; vision; correlation

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INTRODUCTION

Cataract is a globally widespread blinding eye disease. Phacoemulsification combined with intraocular lens implantation is regarded as a milestone in cataract surgery development. The acclimatization with traditional monofocal intraocular lens is limited, and the patients require the help of glasses to correct good near vision. The internet and the availability of smartphones have greatly influenced the reading habit of old people. The requirements for near or intermediate-distance reading and the demands of reading without presbyopic glasses are higher among old people. How to accomplish clear distant and near vision in cataract patients without glasses after the surgery is a challenge for the doctors. Previously, implantation of multifocal intraocular lens or accommodative intraocular lens were practiced. Implantation of multifocal intraocular lens which can distribute parallel light into two or more focuses, has caused substantial associated problems, such as decreased contrast sensitivity and night glare. Meanwhile, as the light is mainly distributed to the distant and near foci, the intermediate visual acuity was not satisfactorily achieved. Based on the operating principle, the accommodative intraocular lens was designed to create the accommodation effect through the shift of optics, but the amplitude of accommodation was very limited. Moreover, the capsular fibrosis may limit the movement of optics over time after the surgery, which could further reduce the accommodation effect. Hopefully, with these existing circumstances, a new-type intraocular lens could provide good distant, intermediate, and near visual acuity and overcome these problems such as decreased contrast sensitivity, night glare, and small amplitude of accommodation. Thus, trifocal intraocular lens has attracted more attention because it could successfully resolve the above problems to a certain degree. Besides, it was reported with high spectacle independent rate and patient satisfaction[1-2].

Vision examination and contrast sensitivity evaluation are subjective, which could not comprehensively and objectively indicate the visual quality after intraocular lens surgery. Wavefront aberrometer is a commonly used clinical device to objectively evaluate the optical quality of human eye. The aberrometer indirectly deduces spread function by directly measuring wavefront aberration of a finite number of point light source, and analyzes the optical quality parameters. However, it neglects the influence of intraocular scattering on imaging with fewer indices. Optical quality analysis system (OQAS) is based on the dual channel technique, and directly obtains point spread function measuring all the refractive media in the path of light. Moreover, OQAS significantly indicate the retinal imaging quality under the co-effects of aberration and intraocular scattering with comprehensive detection indices. Therefore, it can accurately reflect the optical quality of human eyes[3], which has been applied in evaluating the visual quality after implantation of monofocal non-spherical intraocular lens, Toric intraocular lens, and multifocal intraocular lens. Currently, there has been no report on the objective visual quality analysis after trifocal intraocular lens implantation.

In this study, we observed the early outcomes of distant, intermediate and near visual acuity after trifocal intraocular lens implantation, and used OQAS to evaluate the indices of objective visual quality. Furthermore, we first analyzed the correlations among them, which could provide convincing theoretical basis for its successful clinical application.

SUBJECTS AND METHODS

Ethical Approval The study followed the Declaration of Helsinki and was approved by the Ethics Committee. Each patient had signed the informed consent.

Patients Totally 20 patients (27 eyes) receiving phacoemulsification combined with intraocular lens implantation between Jul. 2016 and Dec. 2017 were enrolled. Inclusion criteria: 1) cataract patients, including age-related cataract and complicated cataract without fundus disease; 2) corneal astigmatism ≤1.25 D (estimated postoperative corneal cylinder of ≤0.75 D based on the estimation of the surgically induced astigmatism by the clear corneal incisions); 3) ocular axis <29 mm; 4) clear cognitive ability; 5) corneal higher-order aberration <0.3 μm. Exclusion criteria: 1) corneal diseases, such as corneal degeneration, keratitis, corneal leukoma; 2) optic nerve diseases, such as glaucoma, ischemic optic neuropathy; 3) retinal diseases, such as retinal vascular disease, retinal detachment, macular degeneration; 4) lens subluxation; 5) previous history of trauma of eyes, excimer laser surgery or other intraocular surgery; 6) severe systemic diseases that cannot receive surgery.

Surgical Technique All the surgeries were performed by the same experienced surgeon using the phacoemulsification machine (Bausch & Lomb Stellaris). The parameters were set as follows: ultrasound energy upper limit 30%, vaccum 450 mm Hg, height of infusion bottle 100 cm. Intraoperative conventional sterile draping was performed, and proparacaine eye drop was dropped to the eye receiving surgery. All incisions were made at the steep axis of the cornea with a length of 1.8 mm. Continuous curvilinear anterior capsulorhexis was performed, followed by water separation, ultrasound, cortex infusion suction, and implantation of AT LISA tri839MP intraocular lens using an injector. The viscoelastic agent was then removed.

Intraocular Lens There are 3 trifocal intraocular lens widely applied in clinic[4]: 1) FineVision (Physiol, Liège, Belgium) with +3.5 D and +1.75 D, 2) Acrysof IQ PanOptix (Alcon Laboratories, USA) with +3.25 D and +2.17 D; 3) AT LISA Tri 839MP (Carl Zeiss Meditec AG, Germany) with +3.33 D and +1.66 D. The first two are not yet available in China. AT Lisa tri 839MP is designed as one-piece diffractive-refractive multi-focus, composed of hydrophilic acrylate with a water content of 25%, and covered with a hydrophobic surface. The length of intraocular lens is 11 mm, and the diameter of dual convex section is 6.0 mm. The central area within 4.34 mm is trifocal optical zone, and surrounded by 4.34-6.0 mm bifocal optical region[5-7]. The light distribution is 50% to far, 20% to intermediate and 30% to near, respectively[8]. The design of 360° square edge not only has 0° angle between optics and haptics, but also could prevent the occurrence of posterior capsule opacification. Spherical aberration is -0.18 μm, and the corneal spherical aberration could be appropriately corrected.

Examination Protocol All the patients received preoperative cataract examination before the surgery, including uncorrected distance visual acuity (UDVA) by standard logarithmic visual acuity chart; uncorrected intermediate visual acuity (UIVA) at 80 cm and uncorrected near visual acuity (UNVA) by standard near vision chart at 40 cm; eye B ultrasound, IOL-Master, corneal topography, OPD-Scan III refractive power/corneal analysis meter and OQAS. The degree of intraocular lens was calculated by Haigis equation, and the preoperative target diopter was set as 0±0.25 D. The UDVA, UIVA and UNVA were recorded at 1mo and 3mo after the surgery, and converted into logMAR. OQAS was examined to record modulation transfer function cutoff frequency (MTF cutoff), strehl ratio (SR), object scatter index (OSI), OVs (OQAS values) and so on. After 5min of darkroom adaptation, the patients gazed at the visual target in OQAS. When a clear pupil image was seen on the screen and the detection center coincides with the

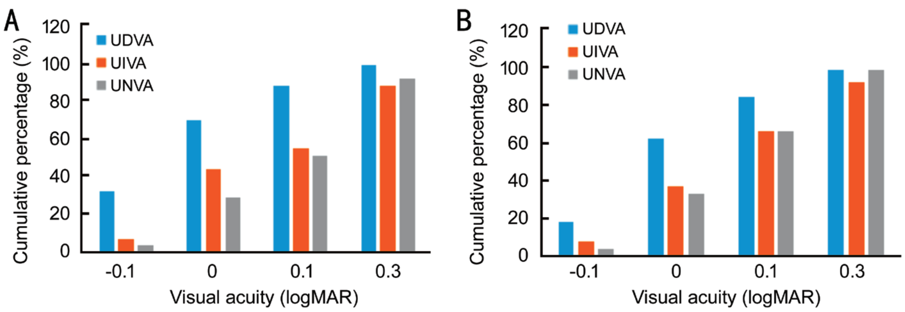

Figure 1 Cumulative percentage of UDVA, UIVA, UNVA at 1mo (A) and 3mo (B) after the surgery.

pupil center, "Objective refraction" button was clicked and the system automatically selects the best focus. Then "Optical Quality" button was clicked to measure MTF cut-off, SR, OVl00%, OV20%, OV9, and "Scatter Meter" to measure OSI. Defocus curve examination was performed at 3mo after the surgery: spherical lens with +1.0 D - -4.0 D was used in front of the surgical eye, and decreased by +0.5 D step to simulate the visual requirement of different distance. The vision was examined and transferred into logMAR. Spherical degree was used as X axis, and logMAR vision was used as Y axis to draw the curve.

Statistical Method SPSS 23.0 software (USA) was used to analyze the data. Measurement data were expressed as mean±SD. All the data were tested by normality test and homogeneity test of variance. The comparison of the data in each time point was analyzed by repeated ANOVA. Spearman correlation coefficient was used to analyze the correlations of distant, intermediate and near visual acuity with objective visual quality at 3mo after the surgery. $P<0.05$ was termed as statistically significant.

RESULTS

General Information A total of 20 patients (27 eyes) were enrolled: 13 males and 7 females. The age range was 30-66 years old, and the average age was 51.9±9.53y. Ocular axis was 21.85-28.34 mm with an average value of 24.40±2.09 mm, and the astigmatic degree was -1.25 to -0.17 D with an average of -0.58±0.30 D. The intraocular lens power ranged from 7.0 to 24.5 D with an average of 18.89±4.80 D, and the target refraction -0.33 D-0.13 D with an average of -0.09±0.11 D.

Vision Comparison Before and After Surgery UDVA, UIVA and UNVA of the 27 eyes at 1mo and 3mo after the surgery were significantly improved compared with those before the surgery ($P<0.05$). UDVA at 1mo after the surgery was slightly better than that at 3mo ($P<0.05$), as shown in Table 1.

Visual Percentage After Surgery The percentages of UDVA, UIVA and UNVA greater than or equal to logMAR 0.3 at 1mo after the surgery were 100%, 89% and 93%, respectively. The percentages of UDVA, UIVA and UNVA greater than or equal to logMAR 0.3 at 3mo after the surgery were 100%, 93% and 100%, respectively, as shown in Figure 1.

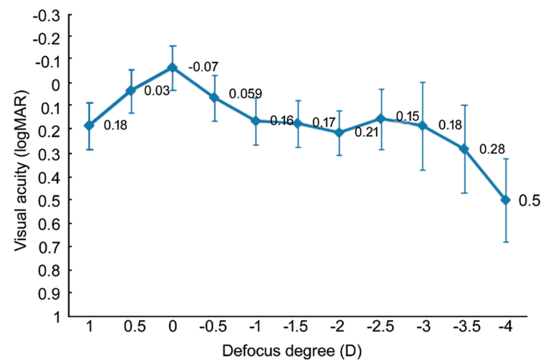

Figure 2 Defocus curve at 3mo after trifocal intraocular lens implantation.

Table 1 Comparison of vision at different time point before and after trifocal intraocular lens implantation *n*=27, logMAR

Parameters	UDVA	UIVA	UNVA
Preoperative	0.83±0.41	0.72±0.36	0.63±0.21
1mo	0.01±0.11	0.12±0.15	0.15±0.14
3mo	0.04±0.10[b]	0.11±0.13	0.11±0.11
F	115.45[a]	79.38[a]	97.50[a]
P_1	<0.001	<0.001	<0.001
P_2	<0.001	<0.001	<0.001

[a]Comparison within group was statistically significant ($P<0.05$); [b]UDVA has statistical significance between 3mo and 1mo after the surgery ($P<0.05$). F: Value of significant difference within visual acuity in different time; P_1: Comparison between 1mo after the surgery and before the surgery; P_2: Comparison between 3mo after the surgery and before the surgery; UDVA: Uncorrected distance visual acuity; UIVA: Uncorrected intermediate visual acuity; UNVA: Uncorrected near visual acuity.

Postoperative Defocus Curve Defocus curve had two vision peaks at 0 and -2.5 D at 3mo after the surgery, and the corresponding logMAR vision was -0.07±0.097 and 0.15±0.13, representing the best corrected distance visual acuity and near visual acuity, respectively. Between -1 to -2.5 D, the defocus curve is lower than logMAR0.3 and is smooth, as shown in Figure 2.

Postoperative Objective Visual Quality The MTF, SR, OV100, OV20 and OV9 at 1mo and 3mo after surgery were significantly increased compared with before surgery. OSR was significantly reduced compared with before surgery ($P<0.001$).

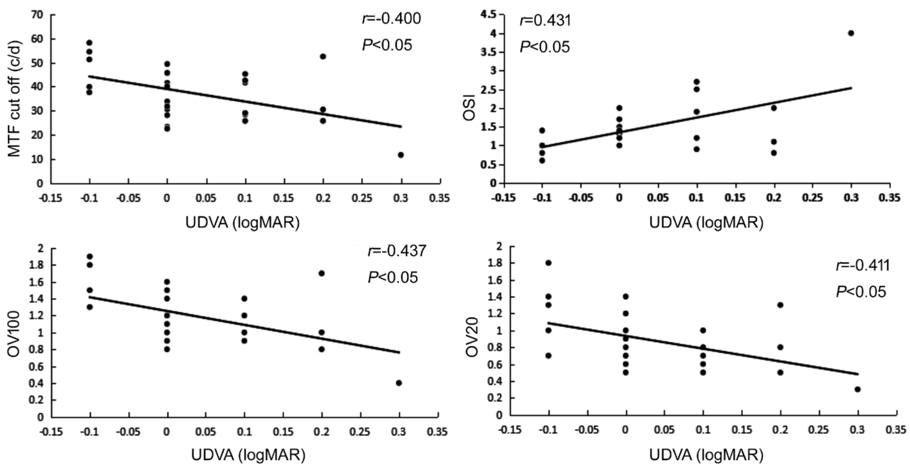

Figure 3 Scatter diagram of UDVA with MTF cutoff, OSI, OV100 and OV20 at 3mo after the surgery.

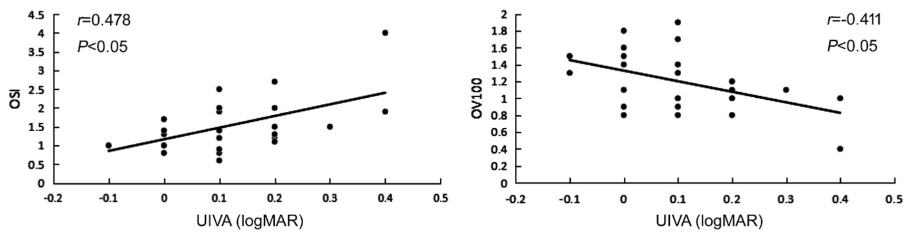

Figure 4 Scatter diagram of UIVA with OSI and OV100 at 3mo after the surgery.

Table 2 Comparison of objective visual quality at different time point before and after trifocal intraocular lens implantation *n*=27

Parameters	MTF cutoff	OSR	SR	OV100	OV20	OV9
Preoperative	5.10±3.55	8.9±3.33	0.051±0.019	0.18±0.11	0.12±0.088	0.081±0.062
1mo	34.77±13.20	1.62±0.90	0.20±0.095	1.14±0.43	0.84±0.41	0.58±0.32
3mo	37.05±11.26	1.50±0.72	0.23±0.21	1.19±0.34	0.88±0.35	0.57±0.31
F	133.32[a]	123.78[a]	15.067[a]	136.084[a]	80.947[a]	49.927[a]
P_1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P_2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[a]Comparison within group was statistically significant ($P<0.05$); F: Value of significant difference within OQAS in different time; P_1: Comparison between 1mo after and before surgery; P_2: Comparison between 3mo after and before surgery. MTF cutoff: Modulation transfer function cutoff frequency; OSI: Object scatter index; SR: Strehl ratio; OV100, OV20, OV9: OQAS values.

There was no statistical significance in objective visual quality analysis between 1mo and 3mo after the surgery ($P>0.05$) as shown in Table 2.

Correlation Analysis The UDVA after 3mo of surgery had correlations with MTF cutoff, OSI, OV100 and OV20 (r= -0.400, 0.431, -0.437, -0.411, P=0.039, 0.025, 0.023, 0.033). UIVA had correlations with OSI and OV100 (r=0.478, -0.411, P=0.012, 0.033). UNVA had no significant correlation with their corresponding index of objective visual quality ($P>0.05$), as shown in Figures 3 and 4.

DISCUSSION

In this study, we have reported that the trifocal intraocular lens provided good visual acuity at far, intermediate, and near distance. The UDVA, UIVA and UNVA at 3mo postoperatively were 0.04 logMAR±0.10, 0.11 logMAR±0.13 and 0.11 logMAR±0.11, respectively. Kohnen *et al*[6] and Kretz *et al*[7] observed binocular uncorrelated visual outcomes of 27 patients (54 eyes) and 38 patients (76 eyes) respectively at far, intermediate, and near distance after intraocular lens implantation, and all of them reached 0.1 logMAR or better. Bilbao-Calabuig *et al*[8] followed up 2141 patients receiving trifocal intraocular lens implantation (4282 eyes) for more than 3mo. UDVA, UIVA and UNVA was -0.01 logMAR±0.06, -0.05 logMAR±0.14 and 0.05 logMAR±0.08, respectively. Many studies have reported data focusing on the binocular vision after trifocal intraocular lens implantation. Due to the limitation of this condition in this study, we could only observe the monocular vision after the implantation. By comparison of 50 binocular and monocular vision of patients (100 eyes) implanted with trifocal intraocular lens, Kretz *et al*[9] found that the binocular uncorrelated visions at different distances was better than that of monocular vision in patients implanted with a diffractive trifocal intraocular lens. We also have found that uncorrelated distance visual acuity at 1mo after the surgery was slightly better than that at 3mo. Mojzis *et al*[10] found that binocular uncorrelated distance visual acuity at 1mo after trifocal intraocular lens implantation was better than that at 3mo, which was in line with our study. Kohnen *et al*[6] could not find any difference in UDVA between 1mo and 3mo after the surgery. Mendicute *et al*[11] followed up 104 patients (208 eyes) and reported that the percentages of monocular UDVA reaching 0.5 at 1mo and 3mo after the surgery were 93.7% and 94.7%, those of monocular UDVA were 86.3% and 87.4%, and those of monocular UNVA were 81.9% and 85.4% respectively. In our study, we found that the corresponding indices were 100%, 100%, 89%, 93%, 93% and 100% respectively.

Defocus curve is an important index indicating full range of vision. The defocus was achieved by using different lens in front of eyes to simulate visual requirements for different distance. Generally, the higher the defocus curve is, the better the vision will be. The peak vision will be achieved in the focal distance of ocular lens. In our study, the peak vision was between 0 and -2.5 D, which was in line with Kohnen *et al*'s[6] study. Between 0 to -2.5 D, the curve was smooth, and vision was lower than 0.3 logMAR, suggesting that trifocal intraocular lens could provide good vision under different focal lengths.

MTF is a widely used index for evaluating intraocular lens visual quality[12-13]. MTF is defined as the contrast ratio between output image and input image of optical system under different spatial frequencies. Papadatou *et al*[14] and Carson *et al*[4] evaluated the visual quality of trifocal intraocular lens by measuring MTF *in vitro*. Apparently, the visual quality after trifocal intraocular lens implantation is more attractive. OQAS directly collects optogram of point light source by dual channel technique to analyze and obtain the point spread function (PSF)[15], which in turn further helps to obtain other main measurement parameters. OQAS is used to analyze all the optical information in one surface. Not only the influence of aberration, but also the influences of scattering and diffraction should be considered to obtain corrected PSF images.

MTF cutoff refers to the corresponding spatial frequency when MTF=0.01, which represent the spatial frequency when the image on the retina is 1% contrast of original image. Theoretically, MTF cutoff is related with human vision, macular function and neural processing function. The higher MTF cutoff value indicates a higher human eye resolution and a better visual quality[16]. In 2005, OQAS was used to evaluate the objective visual quality by micro-incision implantation of mono-focal spherical intraocular lens[17]. Later, OQAS was used to evaluate the visual quality of mono-focal non-spherical intraocular lens[18-19], Toric intraocular lens[20-21], and multi-focal intraocular lens[22]. We found that the MTF cutoff of trifocal intraocular lens at 1mo after the surgery was 34.77±13.20 cpd, which was higher than that of micro-incision mono-focal intraocular lens (30.05±13.86 cpd)[19]. MTF cutoff of trifocal intraocular lens after 3mo was 37.05±11.26 cpd, which was higher than the MTF cutoff (26.49±12.17 cpd) detected by Lee *et al*[18] at 3mo after non-spherical mono-focal intraocular lens. Debois *et al*[20] and Xiao *et al*[21] found that the MTF cutoffs at 3mo in patients implanted with Toric intraocular lens were 27.28±8.45 and 22.86±5.58 cpd, respectively. While, MTF cutoffs at 1, 3, and 6mo after the multi-intraocular lens implantation obtained by Alió *et al*[22] were 24.91±7.19, 22.69±8.36, and 18.38±6.43 cpd, respectively. All the above studies indicated that the MTF cutoff of trifocal intraocular lens was better than monofocal, Toric, and multifocal intraocular lens. There was no statistical difference in the MTF cutoff between 1mo and 3mo, suggesting that the visual quality of trifocal intraocular lens within 3mo after the surgery was relatively stable and was not decreased over time. Jiménez *et al*[19] found that there was no statistical significance in the MTF cutoff at 1, 3, and 6mo of mono-focal intraocular lens, indicating the optical quality in the early stage was stable, which was in accordance with our study. Alió *et al*[16,22] evaluated the visual quality of micro-incision zero spherical aberration mono-focal non-spherical intraocular lens and multi-focal intraocular lens implantation. They found that MTF cutoff at 12mo of mono-focal intraocular lens was lower than that at 3mo after the surgery. Moreover, the value at 6mo after multi-focal intraocular lens implantation was lower than that at 1mo after the surgery. It indicated the possibility of decreased visual quality in intraocular lens over time. Whether trifocal intraocular lens could maintain stable MTF for a long time after the surgery still needs further investigation.

OSI is an objectively quantitative index related to intraocular scattering. The higher the OSI value is, the greater the intraocular scattering will be. OSI<2 suggests no cataract, 2-5 indicates early-stage cataract, and >5 suggests mature cataract. In this study, preoperative average OSI was 8.9±3.33, and those at 1mo and 3mo after the surgery were 1.62±0.90 and 1.50±0.72, respectively, which was consistent with the diagnostic criteria of OSI evaluating cataract. There was no statistical significance between them, suggesting that the early-stage OSI value was consistent after trifocal intraocular lens implantation. The OSIs detected by Jiménez *et al*[19] at 1mo and 3mo after micro-incision mono-focal intraocular lens implantation were 1.36±0.22 and 1.48±0.16, respectively. No statistical difference was found in the OSI at 1 and 3mo after the implantation, which was close to our results. The OSI in normal Chinese population aged 50-59y was 0.54±0.26, and 1.06±0.56 for those aged 60-69y[3]. In this study, although the OSI was significantly decreased after trifocal intraocular lens implantation, it was still slightly higher than those in normal people. These findings suggested that OSI was not only related to the intraocular scattering caused by cataract, but also with other influencing factors (such as higher order aberration of cornea, stability of tear film). Thus, further research may be required to explore the OSI in cataract.

OV (OQAS value) is the vision when the contrast is 100%, 20% and 9%, simulating the vision at day, dusk and night, respectively. It has been found that the uncorrelated distance visual acuity at 3mo after trifocal intraocular lens implantation is related with MTF cutoff, OSI, OV100 and OV20. The uncorrelated intermediate visual acuity was related with OSI and OV100. logMAR had negative correlations with MTF cutoff, OV100 and OV20, and positive correlation with OSI. As the values of MTF cutoff, OV100 and OV20 increase, the logMAR values decrease with a better vision. The uncorrelated distance visual acuity may be greatly influenced by eye resolution, intraocular scattering and contrast. Whereas, the uncorrelated intermediate visual acuity may be greatly influenced by intraocular scattering and contrast. Lee *et al*[18] had reported that corrected distant vision was negatively correlated with MTF cutoff at 3mo after non-spherical monofocal intraocular lens implantation (r=-0.453), and was positively correlated with OSI (r=0.516), which was consistent with our results. Besides, Lee also found that MTF cutoff was negatively correlated with total aberration, total higher-order aberration and spherical aberration. Moreover, the OSI was positively correlated with total aberration, total higher-order aberration and spherical aberration.

In summary, trifocal intraocular lens implantation could provide good visual acuity at far, intermediate and near distance and objective visual quality in the early stage. Vision at far and intermediate distance had a certain correlation with the index of OQAS. The limitation of this study is the small sample size, and short follow-up time. Therefore, the conclusions are still limited. In the future, a large sample size and longer follow-up period are needed to investigate the long-term clinical effect after trifocal intraocular lens implantation.

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Conflicts of Interest: Chu MF, None; **Hui N,** None; **Wang CY,** None; **Yu L,** None; **Ma B,** None; **Li Y,** None; **Pei C,** None.

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