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Study of wavefront aberration after multi-focal intraocular lens implantation

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Abstract: *To study the wavefront aberration of patients with multi-focal IOL implantation and evaluate the imaging quality of IOL, fifty-nine eyes of 56 patients undergoing cataract surgery are collected, including 24 eyes in the multi-focus intraocular lens group and 35 eyes in the single-focus intraocular lens group. The two groups of patients are implanted with Diffractiva-aA multi-focus intraocular lens or Aspira-Aay single-focus intraocular lens, respectively. The wavefront aberration of the operative eye was measured by VISX WaveScan wavefront aberration meter one month after surgery. The results of the two groups of measurement data were compared. The results showed that the total aberration of the multi-focus intraocular lens group and the single-focus intraocular lens group were 1.13±0.19μm and 0.92±0.26μm (F= 0.975, P=0.001) respectively, and the difference was statistically significant. The total high-order aberrations in the multi-focus IOL group were higher than those in the single-focus IOL group, 0.61±0.13μm and 0.38±0.10μm, (F= 0.963, P=0.000), respectively, and the difference was statistically significant. The spherical difference in the multi-focus IOL group was higher than that in the single-focus IOL group, 0.26±0.12μm and 0.16±0.094 μm (F=1.239, P=0.001), respectively, and the difference was statistically significant. Therefore, we conclude that multi-focus intraocular lens can provide patients with better far and near vision after surgery, but higher order aberrations are increased compared with single-focus intraocular lens, which has a negative impact on imaging quality.*

Keywords: *Intraocular lens; Multi-focus; Cataracts; Wavefront aberration; Spherical aberration*

1. Introduction

Multi-focal intraocular lens (IOL) provides better distant and near vision for cataract patients after surgery. The comparison of postoperative visual quality between single-focus intraocular lens and multi-focus intraocular lens has important guiding significance for clinical work. Studies have shown that compared with single-focus IOL, patients, multi-focus IOL implantation also have better contrast sensitivity between light and dark[1-2], but some patients still have adverse visual experience such as reduced contrast sensitivity, glare, and difficulty seeing at night after implantation of multi-focus IOL. On the one hand, the reduction of contrast sensitivity is due to less than 50% of the light energy allocated to each focal point in the eye, and on the other hand, it may be due to image interference in the retina [3-5]. However, the interference of low-order aberrations and high-order aberrations on retinal images of multi-focal IOL may result in the decrease of contrast sensitivity. The diffractive ring structure on the front or back surface of multi-focal group intraocular lens may interfere with each other by refracted light, which increases the high-order aberrations [6]. Low-order and high-order aberrations of intraocular lenses can be analyzed by wavefront aberrations and their influence on individual optical quality can be evaluated [7]. However, it is still unclear whether the influence of low-order aberration and high-order aberration on imaging quality and whether the simultaneous existence of two focal points in the eye of multi-focus IOL will affect the measurement results of wavefront aberration. This study intends to study the wavefront aberration of patients with multi-focus IOL implantation after surgery, so as to evaluate the imaging quality of multi-focus IOL.

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2. Materials and methods

2.1 Cases included by criteria

1) The patients diagnosed with cataract and requiring surgical treatment in the ophthalmology department of the Second Hospital of Hebei Medical University are selected to implant the Diffractiva-aA multi-focus intraocular lens (HumanOptics, Germany) or Aspira-Aay single-focus intraocular lens (HumanOptics, Germany) respectively.

2) History of eye surgery (including laser therapy) and ocular trauma were excluded.

3) No history of corneal opacity, retinopathy, glaucoma, uveitis or other eye diseases

4) Corneal astigmatism ≤ 1.0 D; Myopia patients diopter ≤3.0 D.

5) There was no intraocular lens eccentricity or posterior capsular opacity.

A total of 59 eyes of 56 patients diagnosed with cataract and requiring surgical treatment were observed in the ophthalmology Department of the Second Hospital of Hebei Medical University. In the multi-focus intraocular lens group, a total of 24 eyes were observed, including 16 males, 8 females, 9 left eyes, and 15 right eyes, aged 44-68 years, with an average age of 55.8±7.25 years. There were 35 eyes in the unifocal IOL group, including 22 males, 13 females, 19 left eyes and 16 right eyes, aged 58-76 years, with an average age of 68.4±6.48 years.

2.2 Methods

2.2.1 Preoperative examination

Vision examination; Routine slit lamp examination; Mydriatic fundus examination; MyLab Seven Eye ultrasound examination; The intraocular pressure was measured by CT-60 non-contact tonometer. Intraocular lens-Marster uses the SRK-T formula to calculate the size of the intraocular lens, with a target diopter of 0 or -0.5D.

2.2.2 Surgical method

All operations were performed by the same surgeon. Local surface anesthesia with promecaine hydrochloride was performed before surgery. A 3mm clear corneal incision was made at 11:00 direction, an auxiliary lateral incision was made at 2:00 direction, a viscous elastic agent was injected into the anterior chamber, and continuous circular capsulorhexis was performed with capsulorhexis forceps. The diameter of the capsulorph is about 5.5mm. Infiniti phacoemulsification machine (from Alcon) emulsifies the lens nucleus, injectes the cortex, and implants the intraocular lens in the capsule. The two groups of patients are implanted with Diffractiva-aA multi-focus intraocular lens or Aspira-Aay single-focus intraocular lens, respectively. The incision is watertight and self-sealing. After operation, tobramycin dexamethasone and praloprofen eye drops were applied 4/ day and gradually decreased for 4 weeks.

2.2.3 Observation index

Uncorrected distance visual acuity (UDVA) and uncorrected near visual acuity (UNVA) were measured whihin 1 day, 1 week and 1 month after surgery. For all patients, the international standard E visual acuity chart was used to check the far visual acuity, and the 30cm near visual acuity chart was used to check the near visual acuity, and was converted into logMAR units and arranged in order. Wavefront aberration was measured one month after the operation [8]. The VISX WaveScan wavefront aberration instrument (Abbott, USA) measured the wavefront aberration of the operative eye. The sampling range of the VISX WaveScan wavefront aberration instrument was 4mm. In the dark room, the patient was dilated with compound topicamide, and the pupil diameter was at least 6mm[7]. The patient placed the jaw and forehead on the detector, asked the patient to focus on the bull's eye, and the examiner aimed at the center of the cornea, focusing when the iris texture was clearest. After focusing, the patient blinked twice and opened the eyes to fully expose the cornea, scanned and obtained images. The measurements were checked by the same inspector at least three times in succession, and the results with good consistency were selected for analysis.

2.3 Statistical method

The SPSS21.0 software package was used for statistical analysis of all the measured data. The

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measurement data consistent with normal distribution were represented by independent sample t test as (mean ± standard deviation), while those not consistent with normal distribution were represented by rank sum test as median (interquartile). P < 0.05 was considered statistically significant.

3. Results

3.1 Postoperative vision

On the first day after surgery, UDVA in the multi-focus IOL group and the single-focus IOL group was 0.12±0.06logMAR and 0.13±0.08logMAR (z= -0.287, P=0.432), respectively. The difference was not statistically significant. The UNVA values were 0.28±0.16logMAR and 0.65±0.06logMAR (z= -6.317, P=0.00), respectively, indicating statistically significant differences. One week after surgery, UDVA in the multi-focus IOL group and the single-focus IOL group were 0.11±0.08 logMAR and 0.09±0.08 logMAR (z=-6.826, P=0.000), respectively, and the difference was statistically significant. The UNVA of the two groups was 0.24±0.15logMAR and 0.64±0.06logMAR (z= -0.676, P=0.499), respectively, and the difference was not statistically significant. One month after surgery, UDVA in the multi-focus IOL group and the single-focus IOL group was 0.08±0.07logMAR and 0.06±0.07logMAR (z=-1.049, P=0.294), respectively, and the difference was not statistically significant. The UNVA of the two groups was 0.19±0.03 logMAR and 0.63±0.06 logMAR (z= -6.259, P=0.000), respectively, and the difference was statistically significant. UDVA and UNVA in both the multi-focus IOL group and the single-focus IOL group increased with the prolongation of recovery time 1 day, 1 week and 1 month after surgery (See Table 1 and Table 2).

Table 1: Postoperative UDVA (logMAR) of multi-focus intraocular lens group and single-focus intraocular lens group

Group category	The number of eyes	1 day after surgery (M±SD)	1 week after surgery (M±SD)	1 month after surgery (M±SD)
Multi-focal intraocular lens group	24	0.12±0.06	0.11±0.08	0.08±0.07
Single focus intraocular lens group	35	0.13±0.08	0.09±0.08	0.06±0.07
P value		0.432	0.000*	0.294

*P<0.05

Table 2: UNVA (logMAR) after operation of multi-focus IOL group and single-focus IOL group

Group category	The number of eyes	1 day after surgery (M±SD)	1 week after surgery (M±SD)	1 month after surgery (M±SD)
Multi-focal intraocular lens group	24	0.28±0.16	0.24±0.15	0.19±0.03
Single focus intraocular lens group	35	0.65±0.06	0.64±0.06	0.63±0.06
P value		0.000*	0.499	0.000*

*P<0.05

3.2 Wavefront aberration 1 month after surgery

The wavefront aberration data were recorded one month after surgery because some patients with mild corneal edema 1 day and 1 week after surgery or mild corneal distortion due to transparent corneal incision edema could not obtain the wavefront aberration images well. So the wavefront aberration data were recorded one month after the operation. The total aberrations of multi-focus IOL group and single-focus IOL group were 1.13±0.19μm and 0.92±0.26μm (F= 0.975, P=0.001), respectively, and the difference was statistically significant. The total high-order aberrations were 0.61±0.13μm and 0.38±0.10 μm (F= 0.963, P=0.000), respectively, and the difference was statistically significant. The spherical aberrations in the multi-focus IOL group and the single-focus IOL group were 0.26±0.12μm and 0.16±0.09μm (F=-1.239, P=0.001), respectively, and the difference was statistically significant. There was no statistical significance in defocus, astigmatism and clover difference (See Table 3).

Table 3: Statistical results of wavefront aberration 1 month after operation for each group (unit: μm)

Wavefront aberration 1 month after surgery	Multi-focal intraocular lens group μm	Single focus intraocular lens group μm	F Value	*P* Value
Total aberration	1.13±0.19	0.92±0.26	0.975	0.001*
Total higher order aberration	0.61±0.13	0.38±0.10	0.963	0.000*
Out of focus	0.32±0.64	0.12±0.66	0.175	0.242
Astigmatism	0.67±0.23	0.64±0.26	0.840	0.656
Coma	0.32±0.13	0.22±0.09	0.643	0.001*
Spherical aberration	0.26±0.12	0.16±0.09	1.239	0.001*
Trifolium aberration	0.36±0.15	0.29±0.15	0.285	0.091

*P<0.05

4. Discussion

Phacoemulsification (PHacoemulsification) plus intraocular lens (IOL) implantation has become a major surgical method for cataract treatment in recent years for its rapid development. The requirements of modern cataract patients are no longer simply able to see things, but also tend to "look comfortable and bring convenience to life", which requires cataract surgery from the beginning of the function of blindness prevention, gradually to the development of refractive surgery, which is the reason for the emergence of multi-focus intraocular lens. The implantation of multi-focus intraocular lens (IOL) after cataract surgery can help patients get rid of glasses and help them obtain good distant and near vision [9, 10], which has gradually become the choice of many cataract patients. However, after multi-focal IOL implantation, some patients have problems such as glare, dark vision difficulty and reduced contrast sensitivity. The imaging quality of multi-focal intraocular lens still needs further study.

The study uses Diffractiva-aA aspherical diffractive multi-focus intraocular lens, and Aspira-Aay aspherical single-focus intraocular lens. The two Iols use the same IOL platform with an optical diameter of 6mm, the same 0 spherical nonspherical front surface, and a 360-degree epithelial cell barrier design. The Diffractiva-aA intraocular lens constructs nine step diffraction rings in the 3.5mm central region of the non-spherical front surface (0 spherical aberration). The height of the three steps in the center is equal, and the height of the six steps in the outward direction is gradually lowered, so that when the pupil is dilated, it can smoothly transit to the vision dominated by farsightedness. The additional diopter of the intraocular lens plane is +3.5D, which is equivalent to the glass plane +2.8D. The outer area with a diameter of 3.5mm is a refracting optical surface, which is used for seeing far away. The diffraction ladder and diffraction zone are constructed on the optical surface to send light to the far and near foci respectively by using the light wave dynamic diffraction principle, so as to provide patients with near and far vision independent of pupil size. Diffractive multi-focus intraocular lens contains many gradually narrowed annular diffraction bands, and diffraction steps and diffraction bands play an optical role together.

Multi-focus intraocular lenses provide full vision, but due to the presence of multiple focal points, multiple images are formed on the retina, which may reduce contrast sensitivity and aggravate visual maladjustment symptoms. With the passage of time and the selective adaptation process of the brain, patients will gradually adapt to multiple focal images on the retina, and the contrast sensitivity will be partially improved [11-12]. In this study, the total aberration of multi-focus intraocular lens was larger than that of single-focus intraocular lens, and total aberration was the total root mean square of low-order aberration and high-order aberration. There was no statistical difference between defocus and astigmatism in the two low-order aberrations, and the increase of total aberration was caused by the total aberration of multi-focus intraocular lens being larger than that of single-focus intraocular lens. Studies have suggested that the spherical aberration of cornea is 0.27μm[13-14], but there are large individual differences in corneal spherical aberration [15-16]. The intraocular lens with 0 spherical aberration was used in this study, which would not bring new spherical aberration after implantation into the eye. However, the measurement results showed that the spherical aberration of multi-focus intraocular lens and single-focus intraocular lens were 0.26±0.12μm and 0.16±0.09μm, respectively. Zhang Hongxiang et al. [17] observed spherical errors of 0.336±0.1μm and 0.327±0.081μm for spherical multi-focus intraocular lens and spherical single-focus intraocular lens, respectively. The postoperative spherical errors of the 0-spherical multi-focus intraocular lens used in this study were 0.26±0.12μm, which was lower than that of spherical intraocular lens. However, it is higher than the single-focus aspherical intraocular lens (0.16±0.09μm). For patients implanted with aspherical AcrySof IQ ReSTOR SN6AD1 multi-focal intraocular lens, Hun Lee et al.[18] used a dual-path optical measurement system to set the diameter of 2mm incident pupil and 4mm exit pupil, and the measurement spherical difference was 0.07±0.1μm. The negative spherical aberration of the intraocular lens cancels out most of the corneal spherical aberration. The difference in pupil diameter in the measurement process may be part of the influence leading to the difference in spherical aberration. In addition, the front surface of the intraocular lens used in this study is an asspherical design of 0 spherical aberration, diffractive-AA multi-focus intraocular lens and Aspira-Aay single-focus intraocular lens. However, the aspherical design of 0 spherical aberration is designed to optimize the curvature of the base arc of Iols with different diopters, and the diffraction ring with a diameter of 3.5mm in the center of multi-focal Iols increases the additional degree of +3.50D, which covers most of the measurement area. Therefore, the increase in the degree of additional spherical lenses may be part of the reason for the increase in the spherical aberration of multi-focal Iols. In addition, it is not known whether the superposition of aberrations in another focal image has an effect on the mathematical decomposition of spherical aberrations.

Compared with single-focus intraocular lens (IOL), multi-focus IOL can provide better far and near vision for postoperative patients, but higher order aberrations are increased compared with single-focus IOL, which has an impact on imaging quality. In addition, for multi-focal IOL, whether the current calculation method can accurately make mathematical decomposition of the superposition of two focal samples in the measurement process is still uncertain, and the wavefront aberration analysis of multi-focal Iol still needs further research.

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