· Clinical Research ·

# Effectivity and safety of trifocal intraocular lenses and capsular tension rings implantation for cataract patients with axial high myopia

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## Abstract
● **AIM:** To assess effectivity and safety of trifocal intraocular lenses (IOLs) and capsular tension rings in treating cataract patients with axial high myopia.
● **METHODS:** A prospective nonrandomized controlled clinical trial was conducted. Totally 98 eyes (74 patients) who underwent femtosecond laser-assisted cataract surgery (FLACS) with trifocal IOLs were enrolled in the study and followed up for 2y after surgery: 46 eyes (33 patients) with capsular tension ring implantation in the long axial lengths (AL) group (26<AL<29 mm) and 52 eyes (41 patients) in the normal AL group (22<AL<24.5 mm). Postoperative outcomes about effectivity and safety, including the subjective and objective visual quality, and postoperative complications were assessed.
● **RESULTS:** Uncorrected distance visual acuity at 5 m and uncorrected intermediate visual acuity at 60 and 80 cm in the long AL group were significantly worse than those in the normal AL group at 3mo postoperatively ($P<0.05$). The differences in reading speed, spectacle independence and potential visual complaints between the two groups were not statistically significant ($P>0.05$). The dysfunctional lens index and total modulation transfer function (MTF) average height were similar between the two groups. The postoperative internal coma aberrations in the axial high myopia eyes were significantly higher than that in the normal AL group ($P<0.05$). The total satisfaction score in the long AL group (91.32±2.76) was slightly higher than that in the normal AL group (90.36±3.47), but there was no difference ($P=0.136$). A statistically negative correlation was found between corrected distance visual acuity (CDVA) and dysfunctional lens index ($r=-0.382$, $P=0.009$), and between CDVA and the total MTF average height ($r=-0.374$, $P=0.01$). But there was no significant correlation between CDVA and total satisfaction score ($r=0.059$, $P=0.696$). Postoperative complications mainly presented as posterior capsular opacity (PCO), retinal detachment and cystoid macular edema. There was no difference in the incidence of fundus disease (6.5% *vs* 3.8%, $P=0.663$) or PCO (17.4% *vs* 7.7%, $P=0.217$) between the two groups at two years.
● **CONCLUSION:** The utilization of trifocal IOL and capsular tension ring implantation is beneficial for cataract patients with axial high myopia undergoing FLACS. This approach not only ensures excellent subjective feelings and objective visual quality, but also does not increase the incidence of postoperative complications.
● **KEYWORDS:** trifocal intraocular lenses; capsular tension ring; axial high myopia; cataract; visual quality
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## INTRODUCTION

As it is widely recognized, axial high myopia (AHM) is the main type of high myopia and is characterized by a progressive increase in axial length (AL>26 mm)[1]. AHM is closely associated with cataracts due to the growth of the posterior segment and alterations in blood flow, leading to abnormal protein oxidation and necrosis in the lens of extended AL[2-5]. With the significant increase in the number of individuals experiencing high myopia[6], cataract patients with AHM are becoming more prevalent and are now found among younger demographics[3,7]. The traditional treatment for cataract patients with AHM involves conventional phacoemulsification with the use of monofocal intraocular lenses (IOLs). However, the outcomes have been suboptimal. To address the visual needs of daily activities, there is an urgent demand for safer and more precise surgery. The femtosecond laser-assisted cataract surgery (FLACS) combined with the implantation of multifocal intraocular lenses (MfIOLs) has been used in patients with AHM. However, the implantation of MfIOLs in cataract patients with AHM remains controversial due to the complexity of their fundus, unsatisfactory refractive errors, a high incidence of postoperative complications, and adverse visual symptoms. While previous studies suggest that MfIOLs can attain satisfactory visual and refractive outcomes for cataract patients with high myopia[8-10], there are undesirable visual effect. Some studies reported a reduction in near vision for highly myopic eyes in low illumination environments because of poorer objective visual quality and visual outcomes in the highly myopic group slightly inferior to the normal AL group[11-12]. Another study found greater inferior decentration of MfIOLs in myopic eyes[13]. In addition, many prior studies have methodological issues, such as a lack of clear distinctions between refractive myopia and axial myopia, vague inclusion criteria for subjects, outdated IOL power calculations, variations in examination equipment and surgical methods, leading to biased conclusions.

As far as we know, although capsular tension rings (CTRs) are commonly used in conventional cataract surgery for extended AL or MfIOLs[14-15], there is limited literature on the use of trifocal IOL, CTR and FLACS in cataract patients with AHM, particularly in assessing postoperative visual quality using dysfunctional lens index (DLI). This prospective study aims to comprehensively evaluate the effectiveness and safety of trifocal IOLs in cataract patients with AHM. We will reduce confounding factors by specifying the selection criteria for subjects, reformulating surgical indications, standardizing surgical methods, using consistent examination equipment, refining IOL calculations, and employing comprehensive evaluation indicators including subjective results, objective visual quality and complications.

## SUBJECTS AND METHODS

**Ethical Approval** The research was conducted in accordance with the Declaration of Helsinki and approved as a prospective study by the Ethics Committee of Dongguan Aier Eye Hospital (2020-KYPJ002). All patients were aware of the surgical procedure and the risks involved and signed consent forms.

**Subjects** Seventy-four consecutive patients (22 females, 52 males) aged 40 to 60y who underwent FLACS with trifocal IOLs in Dongguan Aier Eye Hospital were enrolled from July 2020 to May 2023. Cataract patients with AL>26 mm and <29 mm were regarded as the study group, and cataract patients with AL>22 mm and <24.5 mm were designated the control group. The subjects were followed up for 2y after surgery.

All patients were enrolled using the following criteria: age between 40 and 60y; corrected distance visual acuity (CDVA) below 0.5 and DLI below 5 point[16-17]; scotopic pupil diameter between 3 mm and 5.5 mm and corneal astigmatism diopter below 0.75 D; corneal high-order aberration (HOA) less than 0.3 μm; kappa angle and alpha angle below 0.5 mm or less than half the diameter of the central refractive zone[18]. The exclusion criteria were previous ocular surgeries and ocular trauma, abnormal cornea and zonular abnormality, retina and optic nerve diseases, severe dysfunction of tear metabolism, unobtainable information from IOLMaster 700, systemic diseases related to blood vessels and poor coagulation function, psychological disorders and incomplete follow-up data.

**Preoperative Examination** All patients underwent preoperative routine examinations in detail, including uncorrected distant visual acuity (UDVA) and CDVA at 5 m, uncorrected intermediate visual acuity (UIVA) and distance corrected intermediate visual acuity (DCIVA) at 60 cm and 80 cm[19], uncorrected near visual acuity (UNVA) and distance corrected near visual acuity (DCNVA) at 40 cm (a standard distance for reading tests recommended by the International Council of Ophthalmology), intraocular pressure (IOP), slit lamp examination, refractive diopter, three-mirror contact lens fundoscopy, ultrawide field fundus imaging (Optos200TX, Dunfermline, Scotland), and swept source-optical coherence tomography (SS-OCT; Heidelberg Engineering, Germany). The decimal visual acuity using international standard logarithmic eye chart were converted to logarithm of the minimum angle of resolution (logMAR) notation for analysis. Biometric measurements involving AL and anterior chamber depth (ACD) were measured by IOLMaster 700 (Carl Zeiss, Germany), and then we measured keratometry by IOLMaster 700 and Pentacam HR (Oculus Optikgerate GmbH, Germany) to verify consistency. Objective visual outcome analysis covered HOA, DLI, and modulation transfer function (MTF), which were observed by iTrace (Tracey Technologies, USA). The total average height of the MTF curves were acquired from 5 to 30 cycles/degree of spatial frequency of each eye.

**IOLs, CTRs and Lens Refractive Power Calculation** All patients were implanted with trifocal IOLs (AT LISA tri839MP, Carl Zeiss, Germany) after FLACS. The lens is made of hydrophilic acrylic material with a hydrophobic surface, which incorporates diffractive and refractive operating principles. The lens is a single piece and a 4-haptic design with a refractive diopter from 0 to 32.0 D. Additional diopters of the lens, including +1.66 and +3.33 D, can provide intermediate

(80 cm) and near (40 cm) visual acuity. RingJect 13-mm (OPHTEC BV, the Netherlands) was implanted before the IOL injection. The IOL power was calculated by the Barrett Universal II formula after Wang-Koch formulas modified AL, and the target refraction approached 0 to -0.50 D.

**Surgical Technique** The same experienced surgeon (Hua S) performed all surgeries, with no intraoperative complications. Meanwhile, patients with long AL were implanted with CTRs after phacoemulsification. FLACS was performed by the femtosecond laser system (LenSx, Alcon Laboratories, USA) and phacoemulsification system (Stellaris PC, USA). In the femtosecond laser process, the laser was used to make a three-plane corneal primary incision (2.8 mm), perform a capsulotomy with a diameter of 5.2 mm and lens nucleus fragmentation with chop or frag pattern (5.1 mm); then the cataract was removed by phacoemulsification, and the trifocal IOL was implanted into the capsular bag by an injector. Topical levofloxacin (Santen Pharmaceutical Co., LTD, China) and tobradex (0.3% tobramycin and 1% dexamethasone, Alcon, USA) were administered for 2wk after surgery, and diclofenac sodium (Xingqi Pharmaceutical Co., LTD, China) and sodium hyaluronate (Santen Pharmaceutical Co., Ltd. China) were administered for 2-3wk.

**Postoperative Outcome Evaluation** Routine examinations, including UDVA, UIVA, UNVA, CDVA, DCIVA, DCNVA, residual spherical equivalent (SE), tonometry, slit lamp examination, and fundus examinations, were performed at 1d, 1wk, 1mo, and 3mo postoperatively. Subjective visual evaluations included reading speed, spectacle independence, potential visual complaints (double vision/blur, halo/glare, starburst), patient satisfaction surveys, objective visual function evaluated by DLI, MTF, and HOAs (coma aberration, trefoil aberration, spherical aberration) at 3mo postoperatively. Finally, we also observed postoperative complications with follow-up 2y in this study.

A Chinese textbook with content used for the third grade in primary school was printed with Song Typeface 9 pt size and 1.5 spacing. The number of words read per minute at 40 cm was recorded under natural light as the reading speed results. Reading speed=(words×60)÷seconds spent reading.

After the operation, the patients were also observed at different distances to assess whether they needed to wear glasses to assist their vision, with 1 indicating "yes" and 0 indicating "no". On the basis of the VF-14 QOL questionnaire, we added Chinese visual characteristics. The questionnaire covered the following aspects: 1) watching TV/watching movies/seeing a variety of street signs; 2) participating in sports activities (such as badminton, yoga, dancing, *etc*.); 3) cooking or joining in entertainment (such as mahjong, cards, *etc*.); 4) seeing the stairs or steps and walking normally; 5) reading books, using mobile phones or doing fine work; 6) whether there were visual complaints when driving or cycling during the day; 7) whether there were visual complaints when driving or cycling at night. The patients were instructed to respond with the appropriate answer according to the difficulty of performing the above activities because of their vision, as follows, A: None, B: A little, C: Moderate, D: A great deal, E: Unable to do so. The answers corresponded to scores of 4, 3, 2, 1 and 0. The final score was equal to sum of the factored amounts/total number of checked boxes in column ×25.

**Statistical Analysis** SPSS statistical software for Windows (version 26.0 IBM Corp, USA) was used to analyze all data. Continuous variables were presented as the means±standard deviations. The quantitative data that conformed to a normal distribution were evaluated by *t*-test, and those that did not follow a normal distribution were compared by nonparametric tests (Mann-Whitney *U* or Kruskal-Wallis). The frequency (percentage) was used for categorical variables, and Fisher's exact test was used to compare differences between groups. The Shapiro-Wilk method was used for the normality test for continuous variables, and the correlation between variables was assessed using Spearman correlation analysis when the variables did not obey normality. A *P* value less than 0.05 was considered statistically significant.

## RESULTS

**Demographic Characteristics** Totally 98 eyes of 74 patients were enrolled in research. Among these subjects, there were 9 female patients (27.3%) in the long AL group and 13 female patients (31.7%) in the normal AL group. Table 1 demonstrates the demographic and preoperative clinical characteristics. No significant differences were found in age, UDVA, IOP, scotopic pupil diameter, corneal astigmatism, predicted postoperative refractive diopter, DLI, HOA, kappa angle and alpha angle, or total MTF (average height) between the two groups ($P$>0.05). AL and ACD were significantly different between the two groups ($P$<0.05).

**Postoperative Visual Acuity** The uncorrected visual acuity of the two groups at different distances was better than 0.3 (logMAR) at 3mo after surgery. In addition, over 80% of the patients had a corrected visual acuity higher than 0.15 (logMAR). As shown in Table 2, there were no differences between the mean UNVA, CDVA, DCIVA, and DCNVA values of the two groups at 3mo postoperatively ($P$>0.05). However, UDVA, UIVA in the long AL group for 60 cm and 80 cm was slightly worse than that in the normal AL group ($P$<0.05). No difference was found in the residual SE value of the two groups ($t$=-0.202, $P$=0.840).

**Subjective Visual Quality**

**Postoperative reading speed and spectacle independence** The reading speeds of the long AL group and normal AL group were 200.41±6.56 and 199.13±9.30 words/min respectively ($t$=0.087, $P$=0.439). Figure 1 shows the situation of spectacle assistance for the three focal positions representing distant, intermediate and near vision in daily life. There was no significant difference in the spectacle independence between the two groups.

**Potential visual complaints and overall satisfaction** There was no significant difference in potential visual complaints, including double vision/blur, halo/glare and starburst at 3mo (Figure 2). Nevertheless, among the different types of positive dysphotopsia, starburst was higher (17.34%), but there was no significant difference between the two groups. Although the outcome of the VF-14 QOL questionnaire showed that the total satisfaction score in the long AL group (91.32±2.76) was slightly higher than that in the normal AL group (90.36±3.47), there was no statistically significant difference between the two groups ($t$=0.108, $P$=0.136).

**Objective Visual Quality** The DLI and MTF were similar between the two groups, with no significant differences (Table 3). There were no significant differences in total HOA and internal HOA between the two groups. Higher internal coma was observed in the long AL group, which was significantly different from the normal AL group ($P$=0.044). However, internal spherical and trefoil in the long AL group were similar to those in the normal AL group, with no significant differences.

**Correlation Between CDVA and Objective Visual Parameters** There was a negative correlation between CDVA and DLI ($r$=-0.382, $P$=0.009; Figure 3). In addition, a statistically negative correlation was found between CDVA and total MTF average height ($r$=-0.374, $P$=0.01; Figure 4).

**Correlation Between CDVA and Total Satisfaction Score** There was no significant correlation between CDVA and total satisfaction score ($r$=0.059, $P$=0.696; Figure 5).

**Postoperative Complications** Some patients had temporary corneal edema and high IOP in the long AL group at 1d, and recovered completely within 1wk. Following up for 2y, late postoperative complications mainly present as posterior capsular opacity (PCO) and retinal disease, including retinal detachment (RD), retinal degeneration, and cystoid macular edema. In the study group, PCO usually occurred in about 1.6y and the visual acuity was improved after neodymium (Nd): yttrium aluminum garnet (YAG) laser posterior capsulotomy. Two of the 46 eyes (4.3%) experienced RD in the study group. One of them had its visual acuity restored to 0.097 (logMAR) after RD surgery, and the visual acuity of the other was still poor after fundus surgery because of the trauma occurred at 3mo postoperatively. One patient experienced cystoid macular edema at 3mo, and the visual acuity recovered from 0.6 to 1.0

**Table 1 Demographic and preoperative characteristics**

mean±SD (range)

| Parameters | Long AL group | Normal AL group | P |
|---|---|---|---|
| No. of patients | 33 | 41 | - |
| No. of eyes | 46 | 52 | - |
| Age (y) | 52.48 ±6.41 | 54.32±5.90 | 0.141 |
| CDVA (logMAR) | 1.07±0.34 | 0.97±0.36 | 0.119 |
| IOP (mm Hg) | 14.40±2.79 | 13.65±2.73 | 0.184 |
| AL (mm) | 27.09±1.01 | 23.65±0.62 | <0.001 |
| ACD (mm) | 3.54±0.34 | 3.22±0.40 | <0.001 |
| Scotopic pupil diameter (mm) | 4.71±0.51 | 4.65±0.60 | 0.581 |
| Corneal astigmatism (D) | 0.49±0.17 | 0.46±0.18 | 0.253 |
| Predicted SE | -0.17±0.09 | -0.19±0.10 | 0.340 |
| DLI | 2.96±1.29 | 2.77±1.49 | 0.522 |
| Total HOA (μm) | 0.44±0.35 | 0.48±0.50 | 0.650 |
| Corneal HOA (μm) | 0.11±0.61 | 0.12±0.71 | 0.596 |
| Internal HOA (μm) | 0.44±0.37 | 0.43±0.71 | 0.956 |
| Kappa angle (mm) | 0.23±0.12 | 0.25±0.10 | 0.445 |
| Alpha angle (mm) | 0.21±0.09 | 0.20±0.09 | 0.856 |
| Total MTF (average height) | 0.21±0.90 | 0.19±0.09 | 0.249 |

AL: Axial length; CDVA: Corrected distance visual acuity; IOP: Intraocular pressure; ACD: Anterior chamber depth; SE: Spherical equivalent; DLI: Dysfunctional lens index; HOA: High-order aberration; MTF: Modulation transfer function; D: Diopters.

**Table 2 Three-month postoperative visual acuity** mean±SD

| Visual acuity | Long AL group | Normal AL group | P |
|---|---|---|---|
| UDVA (5 m) | 0.144±0.11 | 0.095±0.10 | 0.029 |
| UIVA (60 cm) | 0.161±0.10 | 0.111±0.11 | 0.025 |
| UIVA (80 cm) | 0.146±0.11 | 0.102±0.08 | 0.032 |
| UNVA (40 cm) | 0.162±0.11 | 0.132±0.12 | 0.180 |
| CDVA (5 m) | 0.072±0.09 | 0.043±0.08 | 0.102 |
| DCIVA (60 cm) | 0.052±0.08 | 0.066±0.07 | 0.356 |
| DCIVA (80 cm) | 0.062±0.08 | 0.051±0.06 | 0.455 |
| DCNVA (40 cm) | 0.039±0.09 | 0.038±0.08 | 0.944 |

AL: Axial length; UDVA: Uncorrected distant visual acuity; UIVA: Uncorrected intermediate visual acuity; UNVA: Uncorrected near visual acuity; CDVA: Corrected distance visual acuity; DCIVA: Distance corrected intermediate visual acuity; DCNVA: Distance corrected near visual acuity.

**Table 3 Three-month postoperative objective visual quality** mean±SD

| Parameters | Long AL group | Normal AL group | P |
|---|---|---|---|
| DLI | 9.696±0.62 | 9.789±0.51 | 0.421 |
| Total MTF (average height) | 0.408±0.08 | 0.410±0.08 | 0.890 |
| Total HOA (μm) | 0.114±0.06 | 0.109±0.67 | 0.747 |
| Internal HOA (μm) | 0.081±0.04 | 0.086±0.04 | 0.555 |
| Coma aberration (μm) | 0.053±0.04 | 0.037±0.03 | 0.044 |
| Spherical aberration (μm) | 0.001±0.03 | -0.003±0.01 | 0.428 |
| Trefoil aberration (μm) | 0.074±0.06 | 0.067±0.06 | 0.524 |

AL: Axial length; DLI: Dysfunctional lens index; MTF: Modulation transfer function; HOA: High-order aberration.

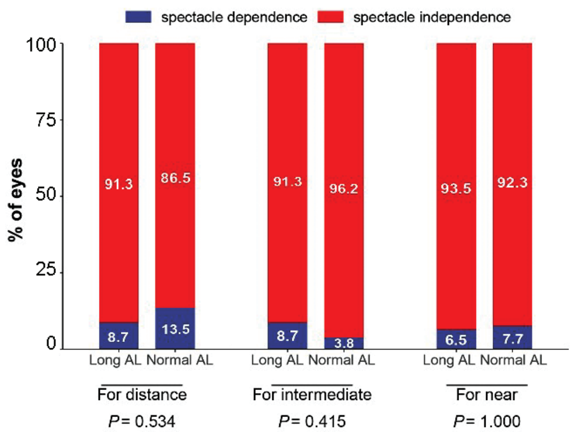


**Figure 1 Postoperative spectacle independence at 3mo** AL: Axial length.

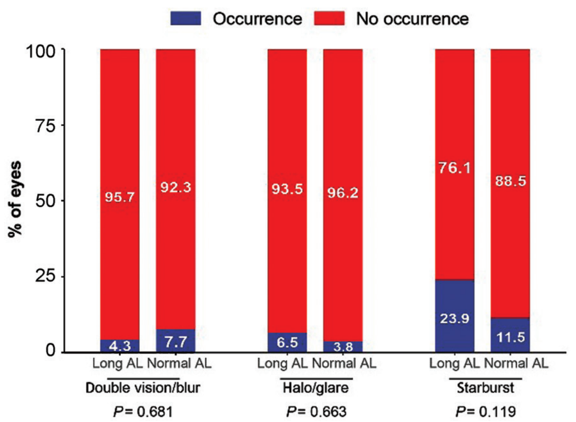


**Figure 2 Potential visual complaints at 3mo** AL: Axial length.

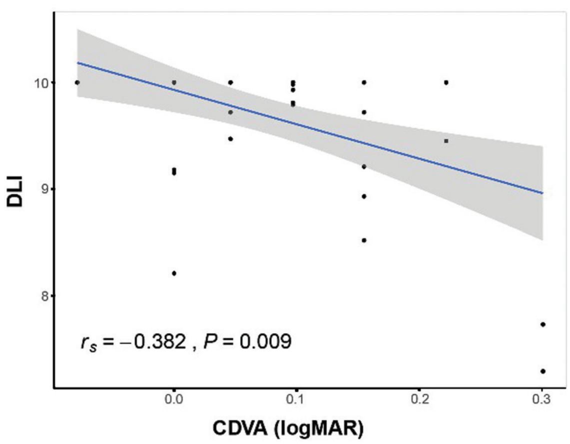


**Figure 3 The correlation between CDVA and DLI** CDVA: Corrected distance visual acuity; DLI: Dysfunctional lens index.

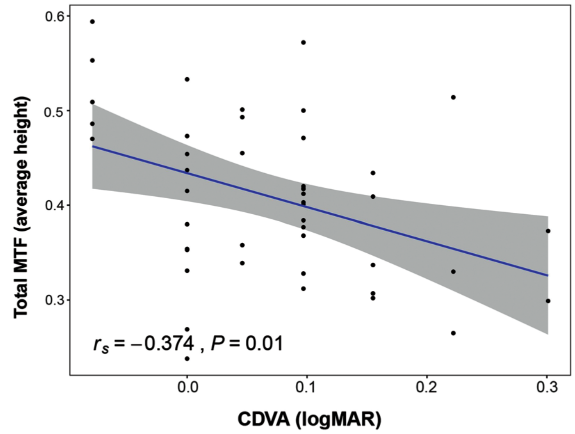


**Figure 4 The correlation between CDVA and total MTF average height** CDVA: Corrected distance visual acuity; MTF: Modulation transfer function.

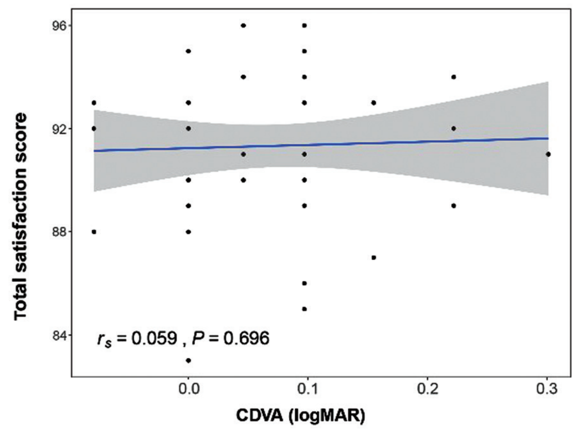


**Figure 5 The correlation between CDVA and total satisfaction score** CDVA: Corrected distance visual acuity.

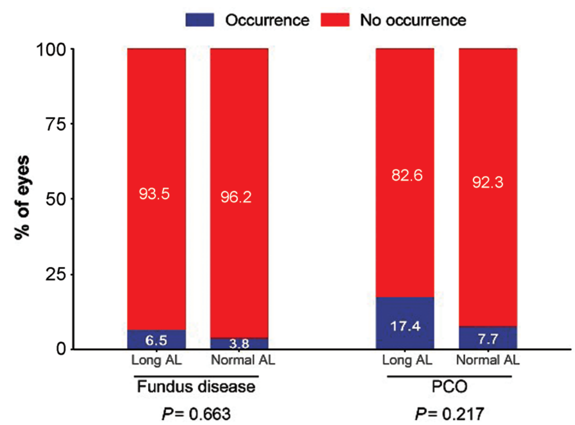


**Figure 6 Incidence of fundus disease and PCO at 2y** AL: Axial length; PCO: Posterior capsular opacity.

after conservative treatment. There was no difference between the two groups in the incidence of fundus disease or PCO at 2y (Figure 6).

## DISCUSSION

With the rapid development of surgical technology and MfIOLs, the current risks of cataract surgery have already undergone great changes compared with the conventional phacoemulsification or monofocal IOL implantation. Our results demonstrated trifocal IOLs can obtain nice subjective, objective visual quality following implantation of CTRs combined with FLACS in treating cataract patients with AHM and similar result of postoperative complication to normal AL patients. There was not significant difference between two group on most visual acuity, subjective feeling, partial optical quality and complication. However, UDVA at 5 m, UIVA at 60 cm and 80 cm in the long AL group was worse than that in the normal AL group, and higher internal coma was observed in the long AL group. Unexpectedly, there was no significant correlation between CDVA and total satisfaction score in cataract patients with AHM.

From pseudophakic monovision to bifocal IOLs, and then to rotational asymmetric IOLs, upgraded IOLs were constantly apply for cataract patients with high myopia to achieve vision with a range of distances[8,20-21], but the results were not satisfactory. In recent years, a few doctors started trying to implant trifocal IOLs into highly myopic eyes, even with AL of >30 mm or patients with nasal-inferior staphyloma[22-24]. The researches showed that trifocal IOLs can achieve better predicted vision for cataract patients with high myopia, however, there are still some problems in previous studies. For instance, the satisfaction of cataract patients and clear lens patients who underwent refractive lens exchange surgery was evaluated together postoperatively. IOL power was used as the inclusion and grouping criteria for cataract patients with high myopia, lack of objective visual results, *etc*[10,12]. To obtain the distinct results about effectivity and safety of cataract patients with AHM after the implantation of trifocal IOLs and CTRs, our study definitively referred to AHM, and excluded other interference factors that may have affected the results as possible as.

Given that the purpose of trifocal IOL implantation is to improve vision without the assistance of spectacles postoperatively, uncorrected visual acuity was used as one of the key evaluation indices in this study. UDVA and UIVA at 60 cm and 80 cm postoperatively in cataract patients with long AL were significantly worse than those in other patients ($P$<0.05), and CDVA, DCIVA, UNVA and DCNVA were not different between the two groups, which suggests that residual diopter has a great influence on distance and intermediate vision in the long AL group. Previous studies have focused on near and distance vision, with few people paying attention to intermediate visual acuity. Steinwender *et al*[12] implanted trifocal IOLs or toric trifocal IOLs by FLACS used for a study group with IOLs above +10.0 D and a control group with IOLs below +10.0 D. There was no significant difference between the two groups in UDVA (4 m) and UIVA (80 cm), and the UNVA (40 cm) in the group with IOLs below +10.0 D was worse than that in the other group. Part of the difference between the two studies may be due to differences of grouping criterion and the distance at which distant vision was assessed.

Accurate biometric measurements are the prerequisite for perfect vision for MfIOLs. However, most cataract patients with AHM are difficult to obtain the accuracy of outcomes by ordinary optical measuring instruments because of opaque dioptric medium and poor penetration ability. Therefore, we adopted IOLMaster700 with stronger penetrability and visualization of the macular fovea tomography. On that basis[25], the IOL power was calculated by the Barrett Universal II formula after Wang-Koch formulas modified AL. In addition to preoperative refractive error, postoperative refractive shift has also received much attention. In our study, all patients were implanted with plate-haptic trifocal IOLs after FLACS. Among these patients, CTRs were applied cataract patients in long AL group to set up a relatively fair evaluation criteria, reduce the hyperopic shift that is most likely to occur in patients with long AL and make the results more objective and reliable. The research shows no difference in the postoperative SE value of the two groups, which is basically consistent with the results of previous studies[8,14,26]. The desire of most cataract patients with AHM is to no longer depend on spectacles after surgery, which improves quality of life and enhances self-confidence. In the report of Ogawa *et al*[8], the use spectacle in different AL group was no significant difference, and a slightly larger proportion of patients used near vision spectacles in the AL>26 mm group. Our outcomes showed patients who use spectacles at distance was slightly more than them who need spectacles at medium and distance. The nuance may be due to the differences in the type of IOL, the predicted refractive power, iatrogenic problems, *etc*. However, some patients wore glasses only when they had difficulties driving and reading, and none of them used spectacles at all distances. In addition to the spectacle independence, reading ability is also an important ability possessed in modern life. Because it requires stronger contrast sensitivity and a better understanding of memory ability than near vision function. Judging from the results, the reading speed of cataract patients with AHM was slightly faster than that of common patients, with no significant difference. The reason for this outcome might be that the patients were younger in the study group, and most patients with AHM had a long-term habit of near vision; thus, the postoperative adaptation of near vision might have been faster. Unfortunately, reports on reading speed are rare.

Positive dysphotopsia is one of the most important complications after MfIOLs implantation, and it is also the most common cause of patients' dissatisfaction. Given that some patients could not describe the specific shape of adverse photic phenomena and that the incidence of dysphotopsia when doctors inquired about it was significantly higher than that when patients actively complained, we accepted the results of potential visual complaints automatically generated by iTrace, including double vision, halo/glare and starburst. In the present study, we found that the incidence of double vision/blur and halo/glare ranged from 4.3% to 7.7% and 3.8% to 6.5%, which is much lower than that in previous research reports[8-9]. The difference may be due to the type of IOLs and the effective position of IOL. The trifocal AT LISA tri839MP adopts smooth microphase technology to design smoother diffraction steps that decrease light scattering and increase light energy utilization, thereby reducing partial dysphotopsia. In our study, despite no significant difference, the incidence of starburst was higher than that of other dysphotopsia. The reported studies mostly focus on halo/glare, while there are few reports on starburst. To our knowledge, different types of positive dysphotopsia are derived from different HOAs. Spherical aberration will appear as a halo or glare; coma aberration can produce double vision and blurred vision; trefoil aberration may cause starburst. Among them, trefoil aberration which cannot be corrected, accounts for a large proportion of the overall HOA, which corresponds to the incidence of starburst, and this phenomenon existed in the two groups. An prospective cohort study, Sun *et al*[26] observed that there were no significant differences in the coma aberration, spherical aberration and trefoil aberration among eyes with different ALs, and the proportion of trefoil aberration was also larger than other aberrations from 0.23 μm to 0.25 μm. While Meng *et al*[27] found there was the greater intraocular HOAs and coma aberration in the extreme myopia group (AL>28 mm). As for whether CTRs can reduce internal HOAs is still controversial. Kwon *et al*[15] reported use of the CTRs lowered ocular coma after TFNT00 IOL implantation for cataract eyes with normal AL. Our study just found that the coma aberration in the study group was significantly higher than that in the control group postoperatively. Certainly, the detailed data in those studies cannot be compared with those in our study due to differences in sample size, surgical methods, and measuring instruments. But at least CTRs didn't manifest obvious superiority in decreasing internal coma aberration in our research. Coma aberration is a type of third-order aberration and is close to central axis of the Zernik polynomial, which has a greater impact on visual function trefoil aberration theoretically and might result in suboptimal UDVA and UIVA, but it is still poorly understood why the main type of positive dysphotopsia was not double vision/blurred vision but starburst in cataract patients with AHM. It might be that the sensitivity of coma aberrations is reduced due to poor fundus function in patients with AHM, but a longer follow-up time and larger sample size are required to confirm this hypothesis.

Visual acuity is a subjective method for visual quality, and patients with the same visual acuity may exhibit evident differences in visual effects. Therefore, we wanted to compare the real visual quality by quantification of the objective visual quality. Unlike the previous OPD Scan-III or OQAS II, the iTrace visual function analyzer uses unique Ray-Tracing technology to trace the position of 256 parallel laser beams falling on each point of the retina through the pupil, rapidly measure wavefront aberrations, and integrate data with a corneal topographic map. It includes DLI, MTF, and aberrations, and quickly separates HOA to obtain internal aberrations and different types of HOAs, which is more effective and practical to help clinicians distinguish the source and degree of unsatisfactory visual quality. To date, DLI has already been applied to assist cataract diagnosis and operative indication, especially when the lens opacity on slit lamp examination is inconsistent with the subjective symptoms. Faria-Correia *et al*[28] reported that compared with the Lens Opacities Classification System III (LOCS III) score, DLI showed a stronger correlation with the best corrected visual acuity in cataract patients at different stages. Some studies indicated that, in contrast with the objective scatter index and contrast sensitivity, the DLI was significantly negatively correlated with the LOCS III score in the different types of cataract[29]. DLI is the dysfunctional lens index according to the internal HOA, contrast sensitivity, and pupil diameter of the cataract eye; thus, DLI and LOCS III play equally important roles in the cataract grade, particularly regarding nuclear cataracts. Since DLI has already been shown to effectively assess cataract and visual quality before surgery, it can also be applied to quantitatively evaluate the performance of postoperative IOLs and the posterior capsule theoretically. However, few reports were found on this topic, not to mention cataracts eyes with AHM. The current study revealed that a strong relationship between DLI and CDVA existed in cataract patients with AHM, and DLI showed no differences between the two groups. Moreover, we recognized the image of the patient by DLI and then further analyze the difference between the image and the object at different spatial frequencies to infer the visual quality of the optical system more comprehensively and subtly. The total MTF of the two groups was significantly improved postoperatively, and this part of the improvement was mainly due to an increase in the intraocular MTF. In addition to the different IOLs, fundus changes usually decrease contrast sensitivity in cataract patients with AHM, so the changes theoretically lead to an inferior MTF. However, we didn't find the specificity in our study. The total MTF average height of 56% of patients in the study group exceeded 0.4, which is one of the reasons for the high satisfaction after surgery. DLI and MTF were significantly correlated with CDVA, suggesting that DLI and MTF are reliable visual quality evaluation indicators for cataract patients with trifocal IOL implantation, and hinting cataract patients with long AL can achieve better postoperative vision function with FLACS and CTRs. CTRs played a key role in reducing the diopter shift caused by the change in IOL position, decreasing the possibility of eccentricity and tilt of the IOLs, thereby reducing intraocular aberration[30-31].

For postoperative visual quality, the patient's self-perception is equally very important. Therefore, our questionnaire, which was more focused on the practicability of visual function in daily routine postoperatively, was used to reflect the patients' subjective feelings. From the results of the questionnaires, there was no significant difference between the two groups, which is similar to several reported studies[9-10]. Curiously, despite certain parts of the subjective and objective visual quality in cataract patients with AHM being inferior to those in cataract patients with normal AL, the satisfaction of the former (91.32±2.76) was still slightly superior to that of the latter (90.36±3.47). This explains why there is no correlation between CDVA and satisfaction and illustrates that good visual acuity does not represent high satisfaction. This situation might arise in part from the improvement of psychological factors and mental state due to the activated excitability of the cerebral visual center when long axial patients no longer depend on spectacles suddenly. In the future, research can be carried out jointly with psychological studies, which may be more helpful for clinical work.

In our study, 6.5% of the patients experienced fundus complications and 4.3% of the patients had RD. Martiano and Cochener[32] once conducted a 6-year follow-up study on cataract patients aged 40-69y with high myopia and after implantation of MfIOLs. They found that 3.8% (2 of 52 patients) occurred RD, most cases of which occurred at approximately 20mo. The results of the two studies were basically similar. In fact, with the improvement of surgical technology and the updating of surgical equipment, the operation time is greatly shortened, the disturbance to the intraocular structure is decreased, and the incidence of postoperative fundus diseases will decrease in the future. Srinivasan *et al*[33] believed that if comprehensive preoperative fundus examinations were carried out, regular follow-up until complete posterior vitreous detachment could further reduce the risk of postoperative RD and other fundus lesions. From our study, the incidence of retina complication in cataract patients with AHM was no difference with normal AL patients. It indicates that the change in surgical approach does not increase the probability of postoperative complication. Besides retinal diseases, long AL is also a high-risk factor for PCO[34-35]. Just because of the high sensitivity of refractive IOLs to PCO[36], the issue has always given rise to researchers' concern. A Meta-analysis confirmed CTRs might reduce capsule opacification in normal population[37]. In our study, it is disappointing CTRs did not show an additional advantage in reducing PCO in eyes with AHM. There may be dormant degeneration of the zonular and posterior capsules of the lens in AHM, coupled with vitreous degeneration and liquefaction, leading to poor adhesion of the posterior capsule and IOLs. Therefore, more attention should be given to lens abnormalities before surgery, and ultrasound biomicroscopy or anterior segment OCT examination should be performed when necessary. Regarding the post-YAG, the effect of CTR on maintaining the effective position of the lens requires long-term observation. Cho and Kim[38] found that the ACD and capsulotomy retained stability even 15mo after Nd:YAG laser capsulotomy in patients with normal AL, even in cases involving larger CTRs. However, such findings have not been documented in patients with long AL.

In summary, this study aimed to address every important aspect of the perioperative period. The findings suggest that employing a surgical approach involving trifocal IOLs and CTRs implantation results in excellent subjective feelings and objective visual quality for cataract patients with AHM after FLACS, without an increase in postoperative complications. Nevertheless, UDVA and UIVA in cases with long AL were not as favorable as the control group. In addition, the higher internal coma observed in cataract eyes with AHM may be linked to the extended AL. But anyway, this thesis has provided some hope for this specific population. Future studies need to aim to increase sample size and incorporated more extended follow-up periods to validate these outcomes. Additionally, increasing attention to HOA is crucial for mitigating postoperative dysphotopsia.

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**Authors' contributions:** Zhong JX had access to all of the data in the study. Study concept and design: Zhong JX and Hua S. Drafting of the manuscript: Hua S. Technical support and statistical analysis: Wang H and Xie QX. Study supervision: Zhong JX.

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