• Review Article •

Personalized aspheric intraocular lens implantation based on corneal spherical aberration: a review

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Abstract

• With the evolution of cataract surgery from visual rehabilitation to refractive surgery, aspheric intraocular lenses (IOLs) are being increasingly used in the field of ophthalmology. This increased use can be attributed to negative or zero spherical aberrations with unique optical designs, which counteract some of the positive spherical aberrations of the cornea. These alterations reduce the total spherical aberration of human eyes and improve the visual acuity in patients with cataract postoperatively. At present, various types of aspheric IOLs are used worldwide. Although the implantation of aspheric IOL is beneficial to the patients who need correction of spherical aberrations, much controversy is still associated with ocular residual spherical aberrations that facilitate the best visual quality for patients postoperatively. In order to provide reference for future clinical work and scientific research, this report reviews the relationship between the ocular residual spherical aberration of human eyes and visual quality.

• KEYWORDS: corneal spherical aberration; aspheric intraocular lens; visual quality

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INTRODUCTION

Cataracts are the leading cause of preventable blindness worldwide[1-2]. Epidemiological surveys show that the number of people with blindness or visual impairment caused by cataracts has declined annually during the period 1990-2010[3]. However, the total number of cataract surgeries has increased more than three times worldwide and the frequency of surgeries is also increasing owing to a reduction in surgical complications, especially in Asia[4]. With the increase in surgical treatment, the expectations of patients regarding postoperative outcomes is also increasing. The 2016 clinical survey of the European Cataract and Refractive Surgery Association reported that 43% of cataract surgery has a refractive target that achieves monocular vision[5]. The ideal intraocular lens (IOL) should be able to restore vision, with or without complications, and without any complaints of distant, medium, or near vision[6]. In most cases, the use of different types of IOLs can achieve an emmetropia status in patients after surgery. At present, the mainstream artificial lenses include monofocal IOLs, multifocal IOLs, and astigmatism-corrected IOLs.

The human eye is the most sophisticated optical instrument; however, its optical performance does not always equate to that of optical instruments[7]. In addition to defocus aberrations and astigmatism, normal visual quality is also affected by ocular spherical aberrations and coma aberrations. The demand for superior postoperative visual quality among patients with cataract is increasing, as they seek to achieve independence from spectacles and favorable visual outcomes at both near and far distances to meet the needs of daily life and work[8]. Visual quality refers to the ability to distinguish the details and sharpness of an object[9].

High-order aberrations of the human eye are the most important factors that affect visual quality. With improved living standards, the requirements for visual quality are also increasing. However, the reason for the objective visual acuity of the patient reaching 20/20 vision, and the subjective vision remaining blurred has not yet been determined. This requires an evaluation of the visual quality of the human eye with more accurate and comprehensive examination. The use of wavefront aberration technology in cataract surgery and IOL design is a considerable milestone in the history of IOL development. This technology can sensitively and objectively detect the visual quality of patients with cataract postoperatively, and evaluate the quality of cataract surgery[10].

DISTRIBUTION OF CORNEAL SPHERICAL ABERRATION IN THE NORMAL POPULATION AND ITS RELATIONSHIP WITH VISUAL QUALITY

Although the shape of the cornea, as part of the refractive

medium of the eye, is aspheric, the spherical aberration can still be measured by specific instruments. Wei *et al*[11] measured the higher-order aberrations (HOAs) in the central 6-mm zone of the cornea using an iTrace wavefront analyzer, and found that the corneal spherical aberration ranged from 0.015 to 0.726 μm, with a median value of 0.258 μm. Nemeth *et al*[12] investigated one healthy eye of 227 subjects using the Pentacam HR system on automatic mode, and concluded that corneal root mean square of the HOA shows a significant growth with increasing age. Among the HOAs, primary and secondary spherical aberrations, vertical coma, and vertical trefoil are significantly increased with age, whereas other HOAs show no correlation with aging. Beiko *et al*[13] used the Oculus Easygraph (Oculus Optikgeraete GmbH) to measure the corneal spherical aberration of 696 healthy subjects. They found that the mean spherical aberration was 0.270±0.089 μm, and the fluctuation range was between +0.041 and +0.632 μm. As a result of the various principles applied, including ray tracing, Hartmann-Shack, Tscherning, and automatic retinoscopy, wavefront aberration values may differ[14]. Furthermore, corneal spherical aberration is also influenced by microfluctuations in accommodation, instability of the tear film, and small eye movements. In addition to corneal spherical aberration, the study of other corneal aberrations is also worthy of consideration. A previous study reported that coma aberrations of the cornea are correlated with age, whereas spherical aberrations show no significant correlation with age[15]. In contrast, another study has demonstrated a negative correlation between axial length and corneal spherical aberration[16]. The reason for the disparity in results could be attributed to the differences in sample size. Philip *et al*[14] studied the total ocular HOAs and corneal topography of myopic, emmetropic, and hyperopic eyes of 675 adolescents (aged 16.9±0.7y) and found no significant difference in anterior corneal spherical aberration. Although it is widely accepted that the visual quality of the human eye is age-related, the fundamental cause of its decline is an increase in the number of age-related HOAs[17]. Oshika *et al*[18] found that the total number of corneal aberrations are also increased with age (measured at a pupil diameter of 7 mm), but corneal spherical aberration showed no significant change with age. Some researchers postulate this is because accommodation can influence the corneal curvature, and especially reduce corneal HOAs[19]. However, the results of these studies were not sufficient to explain the reduction in visual quality with age. Thus, the change in visual quality is likely due to lens aberrations.

VISUAL QUALITY WITH ASPHERIC MONOFOCAL IOLS AND MULTIFOCAL INTRAOCULAR LENS IMPLANTATION

In the past, the focus of cataract surgery was on the material of IOLs, distance visual acuity and prevention of posterior capsular opacification. The main purpose of cataract surgery today is not only to focus on distance vision of the naked eye but, more importantly, to pay attention to the postoperative visual quality and patient comfort and satisfaction. The initial function of IOLs was to compensate for changes in the lens diopter of patients after cataract surgery[20]. However, this is not sufficient to improve the postoperative visual quality of patients. This can only be achieved by using accurate IOL calculations to compensate for defocus and low-order aberrations to obtain the best corrected vision. Song *et al*[21] concluded that in cases of aspheric IOL implantation, ocular vertical coma may be a major HOA associated with better near visual acuity. Although corneal aberrations are major determinants of ocular aberrations after cataract surgery, aberrations from internal optics may still play an important role in visual performance.

At present, mainly monofocal IOLs and multifocal IOLs are available. Although multifocal IOLs can facilitate distance, medium, and near vision for patients, some studies have shown that multifocal IOL implantation can cause a 50% decline in contrast sensitivity[22]. Researchers investigated three types of IOLs (Tetraflex, ZMA00, and Akreos Advanced Optics) in 128 eyes of 86 patients with age-related cataract who underwent phacoemulsification, and found that all three types allowed greater distance visual acuity. The only exception was observed in patients of the ZMA00 group, who had more adverse effects, such as halos and glare, compared to patients in the other two groups[23]. Moreover, any disturbance in optical phenomena is considered the most severe problem after multifocal IOL implantation[24].

Studies have shown that monofocal IOLs produce similar effects of distance vision as multifocal IOL implantation postoperatively[25]. Shah *et al*[26] compared the visual outcome between multifocal and monofocal IOLs, and showed that the percentage of patients who achieved uncorrected distance visual acuity of 20/40 or better at 6mo was 92% in the multifocal group and 97% in the monofocal group.

Monofocal IOLs were also associated with better patient-reported scores for glare[26]. Compared with multifocal IOLs, monofocal IOLs are less affected by optical phenomena, such as halo and flash[27]. Furthermore, the probability of IOL replacement after monofocal IOL implantation is lower[28]. Implantation of aspheric monofocal IOLs changes the overall spherical aberration of the whole eye after surgery by conferring zero spherical or negative spherical aberration, and thereby improving the postoperative visual quality of patients to a certain degree. Chen *et al*[29] used the Optical Quality Analysis System (OQAS) to show that the objective visual quality of aspheric IOLs is better than that of the spherical

lens. Many studies have been conducted on the visual quality of aspheric IOLs. Scialdone *et al*[30] studied 72 eyes in which either the SN6AT IOL or AT Torbi 709M IOL were implanted, and found that both IOLs had similar clinical effectiveness in terms of astigmatism correction, rotational stability, and optical quality. A systematic review and Meta-analysis demonstrated that aspheric monofocal IOL implantation resulted in less ocular spherical aberration and fewer ocular HOAs than spherical IOLs, and aspheric IOLs can provide better contrast sensitivity[31].

Although the implantation of aspheric IOLs can reduce spherical aberration, achieve superior functional vision, and shows widely accepted optical advantages, visual quality after their implantation can also be affected by pupil diameter, and IOL depth of focus. Researchers investigated the difference in visual quality between spherical and aspheric IOLs with various pupil diameters in patients with cataract, and showed that at pupil diameter of 3 mm, the modulation transfer function (MTF) was significantly different between the two groups only when spatial frequency was 30 c/d (P=0.05). At a pupil diameter of 5 mm, the MTF was significantly different (P=0.05) at 15 c/d, 30 c/d, and 60 c/d[32].

A study[33] has shown that although the ocular spherical aberrations are significantly lower in eyes with implanted aspheric IOLs, the quality of vision determined by the MTF and point spread function (PSF) shows no significant differences in subjective and objective parameters. Although the current indications for the implantation of aspheric IOLs remain controversial[34], the reduction in total ocular aberration can indeed lead to improved contrast sensitivity and visual quality[35].

Thus, the implantation of aspheric IOLs can improve the best corrected distance vision after surgery, and improve the postoperative contrast sensitivity to some extent. Nevertheless, the postoperative tilt and eccentricity of the lens, the size of the pupil after surgery, corneal astigmatism, and high-order aberrations of the cornea caused by surgery will, to a large extent, affect the postoperative visual quality. Therefore, to achieve the maximum benefit of surgery, the state of the IOL should be regularly evaluated after surgery.

RESIDUAL SPHERICAL ABERRATION AND OPTIMAL VISUAL QUALITY AFTER ASPHERIC INTRAOCULAR LENS IMPLANTATION

Various studies report different opinions concerning residual spherical aberration following the implantation of aspheric IOLs. However, the recent study[36] has revealed that defocus and HOAs have an interactive relationship. Some studies have shown that positive spherical aberration improves the visual quality of patients who have both myopia and cataract, and negative spherical aberration improves the visual quality of patients who have both hyperopia and cataract. Some researchers believe that maintaining a certain spherical aberration after surgery can improve the postoperative visual quality of all patients with cataract. Jia and Li[37] found that customized selection of aspheric IOL implants improved mesopic contrast sensitivities at high spatial frequencies. Another study reported that the implantation of an aspheric aberration-correcting monofocal IOL (Tecnis ZCB00, Abbott Medical Optics) after cataract surgery resulted in very low residual HOA and normal straylight[38].

The existence of spherical aberration is not only related to contrast sensitivity, but also the depth of focus. A recent study showed that positive spherical aberrations introduce myopic shifts relative to the best subjective focus for dark letters on a bright background, whereas negative spherical aberrations introduce hyperopic shifts in optimal focus[39]. Studies have also been conducted on the implantation of a monofocal spherical IOL, which resulted in an increased depth of focus without significant degradation of distance visual acuity or contrast sensitivity[40]. Gharaee *et al*[41] compared the depth of focus of Tecnis and Akreos AO IOLs after implantation, and found that a specific residual spherical aberration can increase the depth of focus after surgery. Mu *et al*[42] found that personalized aspheric IOL implantation based on preoperative corneal spherical aberration is feasible. This technique can reduce total ocular aberrations postoperatively and lead to aberrations that are close to the predictive value.

Thus, the main challenge of how to balance the postoperative total ocular aberration and postoperative depth of focus following aspheric IOL implantation, to provide the best visual quality for patients, remains the focus of current research in refractive surgery.

CONCLUSION

At present, the implantation of personalized aspheric IOLs based on corneal spherical aberrations improves the patient's best corrected distance vision after surgery, preserves the spherical aberration, and improves the contrast sensitivity. However, we know that the HOAs of the cornea consist of not only spherical aberrations but also other HOAs such as coma and trifoliate aberrations. Therefore, more precise implantation of personalized IOLs based on HOAs of the cornea would remain the focus of clinical and scientific research in the future.

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