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Review article

Analysis of visual quality after multifocal intraocular lens implantation in post-LASIK cataract patients

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ABSTRACT

With the development of refractive corneal surgery, excimer laser in situ keratomileusis (LASIK) has become a common refractive surgery procedure. However, post-LASIK patients are at increased risk of developing cataracts as they age and often require IOL implantation. The choice of IOLs is particularly important for these patients, who have smaller residual refractive error and have higher requirements for post-cataract vision recovery and visual quality than the general population. Multifocal IOLs are widely used in clinical practice for patients with high visual acuity needs, such as cataract patients after refractive keratomileusis, due to their advantages of providing excellent near and distance visual acuity; however, compared to monofocal IOLs, multifocal IOLs can lead to postoperative problems related to visual quality such as increased higher order aberrations and decreased contrast sensitivity. Therefore, whether multifocal IOLs have advantages for post-LASIK cataract patients, such as improving the visual quality of such patients, has attracted attention. In this paper, we analyze the current status of research on the implantation of multifocal IOLs in post-LASIK cataract patients by domestic and foreign experts, review and summarize the relevant literature, and propose further discussion in the context of the actual situation of postoperative visual quality and vision recovery.

1. Introduction

Laser-assisted in situ keratomileusis (LASIK) is a procedure that uses an excimer laser to make refractive cuts to the stromal layer under the flap to adjust the corneal refractive power and ultimately correct myopia, hyperopia or astigmatism. However, LASIK fails to address problem of glare, halos, higher-order aberrations and contrast sensitivity (CS) reduction [1,2] while improving central visual acuity and eliminating lower-order aberrations. Post-LASIK patients also are at increased risk for cataracts as they age, which often requires IOL implantation and further compromises visual quality. The quality of vision will be further affected. In order to ensure the quality of life of these patients, the correct choice of IOLs is crucial. In recent years, multifocal intraocular lenses (MIOL) have been widely used in cataract surgery [3]. However, many studies have shown that MIOL also has limitations, such as leading to suboptimal uncorrected eye mid-distance visual acuity and adverse visual symptoms such as halos, starbursts, and glare [3–6]. Therefore, the visual quality of post-LASIK cataract patients with MIOL implantation is more unpredictable than that of patients without a history of refractive surgery, and it is more clinically relevant to assess the effect of MIOL on visual quality in such patients. There are several methods of visual quality evaluation in clinical practice, which enable a comprehensive and accurate evaluation of the clinical effect

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after IOL implantation. The commonly used indexes for evaluating visual quality mainly include wavefront aberration, modulation transfer function, point spread function, contrast sensitivity, visual acuity, etc. This paper reviews the value of MIOL implantation in post-LASIK cataract patients from the perspective of visual quality.

2. Wavefront aberration

2.1. *Concept of wavefront aberration*

According to the doctrine of fluctuation of light, light is a forward fluctuating electromagnetic wave, and when it propagates to a certain position, the surface composed of equiphasic surfaces is called wavefront. Theoretically, wavefront aberration is the aberration that occurs when the matrix trajectory of the light forms a wavefront, compared to an ideal sphere. In actual life, each part of the human eye refractive medium is not an ideal optical system, and the light emitted from each point, especially from the peripheral visual field, is not in the near-axis region, so the light path passed by the human eye refractive medium deviates from the ideal path in more ways, and the image formed on the retina is not a point, but a diffuse spot, and the image formed by the object is a surface, leading to the aberration The formation of aberration is called wavefront aberration in physics.

2.2. *Low-order aberration and high-order aberration using wavefront aberration function*

The wavefront aberration can be decomposed into multi-order components by calculating the wavefront aberration function. The commonly used Zernike polynomial is of order 7 and 35 terms, and each coefficient represents the corresponding aberration amount, where the low-order aberration corresponds to the conventional aberration phase. The root means squares (RMS) is used to represent the overall aberration and the size of each order aberration that constitutes the total aberration. According to the aberration size, there are low order aberrations and high order aberrations, among which, low order aberrations include: tilt, out of focus and astigmatism; high order aberrations include: coma, spherical aberration, second order spherical aberration, trefoil, clover and irregular astigmatism.

2.3. *Analysis of wavefront aberration after MIOL implantation in cataract patients after LASIK*

Conventional LASIK surgery mainly corrects low-order aberrations, and this process can cause an increase in high-order aberration (HOA), and these changes are especially obvious in patients with high astigmatism and irregular corneas, leading to more complex HOA after surgery [7,8]. It was found that diffractive MIOL implantation in myopic post-LASIK cataract patients showed higher 3rd-4th order aberrations and total intraocular aberrations at 3–6 mm pupils than in patients without a history of refractive surgery, indicating that HOA increases and visual quality continues to be compromised after MIOL implantation in post-LASIK cataract patients [9,10]. In addition, MIOLs have different design types; aspheric MIOLs have negative or zero spherical aberration designs, and several studies have shown that whole-eye spherical aberration is reduced or unchanged after implantation of such MIOLs in cataract patients [11–16]. This is because under physiological conditions, the human cornea has a positive spherical aberration and the lens have a negative spherical aberration, and the two play a role in compensating each other to a certain extent, thus maintaining good visual quality. The negative spherical aberration of the lens gradually changes to positive spherical aberration as we age, while the corneal spherical aberration remains basically unchanged. The implantation of negative or zero spherical aberration aspheric IOL can offset some of the positive spherical aberration in the eye, thus improving the visual quality. Studies have shown that aspheric IOLs can compensate for the changes in corneal positive spherical aberration produced after myopic LASIK, and the former provides better visual quality for patients after myopic LASIK compared to spherical-type IOLs [10,17]. However, Alfonso et al. [18] found that implantation of diffractive spherical MIOL 3 mm and 6 mm subpupillary corneal HOA, coma and fourth-order corneal spherical aberration were not statistically significant in IOL implantation patients with a history of hyperopic LASIK and those with no history of refractive surgery, indicating that diffractive spherical MIOL implantation after hyperopic LASIK resulted in good visual quality and produced more negative spherical aberrations after this surgery, and that implantation of spherical IOL had better visual outcomes than aspheric one. However, the number of studies mentioned above is currently small, and future studies of MIOL implantation in patients with previous post-farsighted LASIK cataracts should also include more methods to assess visual quality and a larger number of patients.

3. Modulation transfer function

3.1. *Concept of modulation transfer function*

The modulation transfer function (MTF) is an estimate of the loss of image contrast, that is, the ratio of the contrast of the sinusoidal grating image formed by the object on the retina to the contrast of the sinusoidal grating image of the original object at different spatial frequencies. The higher the ratio of the image contrast of the object on the retina to the original object contrast, the higher the MTF value, the better the image quality and the better the visual quality [19]. The low frequency part of the MTF curve reflects the contour transmission of the object, the medium frequency part reflects the level transmission of the object, and the high frequency part reflects the detail transmission of the object. The MTF value is not affected by subjective factors and can objectively reflect the entire refractive system.

3.2. Analysis of MTF after MIOL implantation in post-LASIK cataract patients

Several studies have concluded that aspheric MIOL implanted eyes have higher MTF values than spherical MIOL implanted eyes [14,15,20]. Fernánde et al. [10] found no statistically significant MTF values for aspheric or spherical type MIOL implanted in cataract patients after LASIK at 3 mm pupil, but 0.1 MTF values for aspheric MIOL at 6 mm pupil were higher than those spherical MIOL, and the former group of 0.1 MTF value differed very little from that of the control group (patients with no history of refractive surgery and no cataract).This study demonstrated that aspheric MIOL provided better visual quality compared to spherical MIOL at 6 mm pupil and was similar to that of the normal population. This suggests that the imaging quality of the retina of aspheric and spherical MIOL implanted eyes differs between pupil diameters. In daytime or bright light, when the pupil diameter is less than 2–3 mm, the defects in the optical system of the eye are masked, and the imaging quality of spherical and aspheric IOLs implanted in the retina is close; in dark or nighttime conditions, when the pupil diameter exceeds 5 mm, the light passing through the peripheral part of the refractive system of the eye increases, the spherical aberration increases significantly, and the aspheric MIOL reduces the whole-eye aberration significantly, and the imaging quality is higher. The effect of aspheric MIOL on reducing the whole-eye aberration is obvious and the imaging quality is higher. In summary, doctors can recommend the appropriate MIOLs according to the lifestyle habits of post-LASIK cataract patients.

4. Point spread function

4.1. Concept of point spread function

The point spread function (PSF) is the distribution of light intensity in the image plane after an object point has passed through the optical system, and the ocular PSF is the distribution of light intensity of a point-like object in retinal imaging. Any object can be considered to be composed of numerous point light sources, so the PSF image can be used to understand the imaging quality, that is, the PSF image is the imaging situation when viewing a point light source, the smaller the area of the formed spot, the better the retinal imaging quality. The Strehl ratio (SR) is a commonly used criterion for point spread function. SR is the ratio of the peak PSF center with aberration to the peak PSF center without aberration and diffraction limitation at the same pupil diameter, which is an objective indicator of retinal imaging quality, generally between 0 and 1. SR greater than 0.8 indicates good imaging quality.

4.2. Analysis of PSF after MIOL implantation in post-LASIK cataract patients

Anera et al. [21] found that the SR of patients undergoing corneal knife flap making LASIK surgery decreased at 3 months after standard spherical cut or aspheric cut, respectively, compared to the preoperative period, indicating that LASIK surgery affects the ocular PSF. In addition, SR is widely used in the assessment of visual quality after cataract surgery. SR improved after implantation of refractive MIOL (SBL-3), diffractive refractive MIOL (Zeiss809), diffractive trifocal IOL (AT LISA tri839MP) and bifocal IOL (ReSTOR +3D) compared with preoperative SR and was higher in the diffractive trifocal group than in the refractive group [22,23]. The difference in SR between the two groups may be due to the fact that the negative spherical aberration design of diffractive trifocal IOL can neutralize some of the corneal spherical aberration and make the whole-eye aberration close to zero, while the zero spherical aberration design of the regional refraction group IOL cannot compensate for the corneal spherical aberration, so the whole-eye performance is positive spherical aberration, resulting in the visual quality being affected. According to the above, it can be seen that SR decreases after LASIK and increases after implantation of MIOL in cataract patients. Then, the specific change of SR after MIOL implantation in cataract patients after LASIK deserves further study, which will help to enrich the choice of MIOL for such patients.

5. Contrast sensitivity

5.1. Concept of contrast sensitivity

Contrast sensitivity (CS) is the ability of the visual system to recognize sinusoidal gratings of different spatial frequencies in the presence of changing dark contrasts, and is a test of the ability to contrast between the edge of the visual target and the background illumination. For each spatial frequency, there is a threshold value. The minimum contrast that can be recognized by the human eye at the same spatial frequency is called the contrast sensitivity threshold, and the reciprocal of the threshold is the contrast sensitivity. The contrast sensitivity function (CSF) can be derived by combining the viewing angle and contrast and measuring the contrast that can be distinguished by the human eye at different spatial frequencies. The low-frequency region mainly reflects visual contrast, the mid-frequency region mainly reflects visual contrast and central vision, and the high-frequency region mainly reflects visual acuity.

5.2. Analysis of CS after MIOL implantation in cataract patients after LASIK

It was reported that the CS at all spatial frequencies decreased in the early postoperative period after LASIK with both conventional LASIK and femtosecond laser flap making, resulting in poor visual symptoms such as reduced dark vision, glare, halos, and difficulty driving at night [24]. The reasons may be related to the small cutting diameter of the surgical design optical zone, intraoperative corneal eccentric cutting, postoperative corneal edema, interlaminar photorefraction, irregular healing and slight creasing of the corneal flap, and tear film instability. In addition, several studies have demonstrated that CS decreases in cataract patients after MIOL implantation [25,26]. This may be due to the distribution of light to different focal points. Chang et al. [27] found that the CS of patients with a history of LASIK was inferior to that of patients without a history of LASIK with the implantation of the same diffractive MIOL (TecnisZMA00/ZMB00), which may be due to the fact that the increased corneal spherical aberration after LASIK was not fully compensated. However, there was no statistically significant difference in CS after implantation of continuous-range IOL (Tecnis Symfony) or monofocal aspheric IOL (Tecnis ZCB00) in cataract patients after LASIK compared to preoperative [28,29]. It indicates that the above two groups of IOLs can provide good CS in post-LASIK cataract patients.

6. Visual acuity

6.1. Concept of visual acuity

Visual acuity is the ability of the human eye to see objects and distinguish their shapes, and is the most basic and important part of visual function and the main means of assessing form perception. It can simply and intuitively reflect the good or bad visual acuity of the patient's macular area center. Depending on the measurement distance, there are distance visual acuity chart and near visual acuity chart. The most commonly used distance visual acuity chart in China including international standard visual acuity chart and standard logarithmic visual acuity chart and the most commonly used distance visual acuity measurement in foreign countries include Snellen visual acuity chart and Landolt C-ring visual acuity chart. Near visual acuity chart include standard near vision chart, Snellen near vision chart, LogMAR near vision chart, Jaeger near vision chart, etc. Regardless of the type of visual acuity chart, the information contained in the measurement results is very limited and subjective. In real life, the human eye needs to recognize objects located at different distances and under different light and dark conditions, and in clinical work, there are often cases of "symptom-sign discrepancy", such as patients with good measured visual acuity but complaining of heavy blurred vision, or less cloudy lens but more impaired vision. Therefore, the visual acuity examination needs to be combined with subjective and objective findings such as contrast sensitivity and wavefront aberration to better assess visual quality.

6.2. Analysis of visual acuity in post-LASIK cataract patients after MIOL implantation

The best corrected distance visual acuity (DCVA) after implantation of aspheric diffractive MIOL (Acri. LISA 366D) or spherical MIOL (AcrySof ReSTOR SNA60D3/SN60D3) in post-LASIK cataract patients under 100% contrast light conditions was 0.1 logMAR or better, however, distance corrected near visual acuity (DCNVA) and DCVA under intermediate visual conditions were inferior to controls (patients with LASIK history without cataract) [10,17,18], indicating that these MIOLs provide superior distance visual acuity acceptable near visual acuity. In addition, post-LASIK cataract patients implanted with a diffractive MIOL (Tecnis ZMA00/ZMB00) showed a decrease in distance corrected intermediate visual acuity (DCIVA) compared to preoperative [27] and uncorrected intermediate visual acuity (UIVA) [28] was inferior to the diffractive trifocal IOL (AT LISA tri 839 MP) group [30,31], but compared to the above studies [10,17,18], DCVA did not deteriorate under intermediate vision, demonstrating that compared to MIOL with partially corrected corneal spherical aberration (Acri. LISA 366D), the aspheric-enhanced MIOL (Tecnis ZMA00/ZMB00) provided better visual acuity under intermediate vision. In summary, it was shown that the aspheric-enhanced MIOL provided good distance visual acuity while the trifocal diffractive IOL provided good intermediate visual acuity in patients with post-LASIK cataract. Furthermore, the outcomes of the present study [32] show that a trifocal IOL(AT LISA tri 839 MP) provides good visual acuity in high myopic eyes, being worse for nasal-inferior staphyloma eyes. Whether such patients with a history of LASIK have additional visual acuity effects after trifocal IOL implantation has not been reported. The quality of vision after implantation of multifocal IOLs in patients with a history of LASIK who have problems with their retinal status also needs further study. In a study by Vrijman et al. [33], it was found that the diffractive MIOL (Acrysof Restor SN6AD1/SN6AD3) implanted in patients with post-LASIK cataract, the uncorrected distance visual acuity (UDVA) was improved compared to the preoperative level. After implantation of continuous-range diffraction MIOL (Tecnis Symfony) in cataract patients with and without history of LASIK, there was no statistically significant difference in UDVA, UIVA and uncorrected near visual acuity (UNVA) between the two groups, and the former UIVA and UNVA were higher than the aspheric monofocal IOL (Tecnis ZCB00) group [30]. It indicates that for post-LASIK cataract patients implantation of continuous-range diffraction MIOL (Tecnis Symfony) provides good distance-medium-near visual acuity. It has been reported that highly myopic post-LASIK cataract patients implanted with refractive MIOL (SBL-3) have no symptoms of night vision, glare, halos or double vision and do not need glasses for distance, mid, and near vision [34]. Alfonso et al. [18] found that DCVA improved in hyperopic post-LASIK cataract patients implanted with spherical diffractive MIOL compared to preoperative, but UNVA and DCNVA decreased compared to preoperative. This indicates that spherical MIOL implantation after farsighted LASIK is better for distance vision and worse for intermediate and near vision. In conclusion, the postoperative far-medium-near visual acuity results of cataract patients after LASIK are different when different IOLs are implanted, and doctors can provide the best IOL choice according to the patients' eye distance habits in clinical practice.

7. Summary and prospect

Some previous studies have shown that MIOL can reduce the visual quality of cataract patients after refractive correction; therefore, the value of routine MIOL implantation for post-LASIK cataract patients is controversial. The application of different examination methods can evaluate the visual quality of MIOL implantation in cataract patients after refractive surgery from multiple perspectives, thus reflecting the visual outcome of patients in a comprehensive and detailed manner, and ultimately providing a reference basis for ophthalmologists to select the most suitable IOL for patients in clinical practice. By combining different examination methods to analyze the visual quality of MIOL implantation in post-LASIK cataract patients, we can discuss the advantages and shortcomings of MIOL implantation after refractive surgery, provide accurate and reasonable treatment plans for such patients, and provide a broader space for personalized MIOL implantation design. However, the existing analysis of the visual quality of MIOL implantation in post-LASIK cataract patients is scarce and needs to be discussed in more prospective or retrospective studies with longer follow-up periods.

Author contribution statement

BG contributed to the design of the study and wrote the manuscript. LG contributed to the material support of the study and manuscript review. BG, LX, ZS, and WQ responsible for collection of the related data. All authors read and approved the final manuscript.

Data availability statement

No data was used for the research described in the article.

Declaration of interest's statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

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