



Tilt and decentration with various intraocular lenses: A narrative review

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Abstract

We find that tilt and decentration of intraocular lens (IOL) commonly cause visual quality deterioration after cataract surgery. Multiple factors affect IOL tilt and decentration in the pre-, mid-, and post-operation phases. Moreover, the tilt and decentration of 1-piece IOL are less correlated with internal ocular HOAs than those of 3-piece IOL. Aspherical IOLs are more sensitive to decentration or tilt than spherical IOLs. Furthermore, the optical performance of toric IOLs with an accurate axis remains stable irrespective of tilt and decentration. The optical quality of asymmetric multifocal IOLs varies significantly after decentration and tilt in different directions. The image quality enhances or deteriorates in the direction of the decentered IOL. An extended depth of focus IOL can achieve good visual acuity in the distant, intermediate, and near range. Additionally, its tilt and decentration have less impact on the vision than bifocal and trifocal IOL. This is the first review that compares the effect of IOL tilt and decentration on image quality for various IOL designs. The result indicates that a deeper understanding of tilt and decentration of various IOLs can help achieve a better visual effect to visually improve refractive cataract surgery.

Key Words: Intraocular lens; Tilt and decentration; High order aberration; Visual quality

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Core Tip: The tilt and decentration of intraocular lens (IOLs) definitely affect the effect of refractive cataract surgery, we review the contemporary literature on the IOL tilt and decentration. Furthermore, we explore the effects of IOL tilt and decentration on visual quality indicators, such as visual acuity, high-order aberration, point spread function, and modulation transfer function, for different IOL types. Moreover, we propose surgeon with refractive surgical skills performs the refractive cataract surgery with IOL.

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INTRODUCTION

Tilt and decentration of intraocular lens (IOL) commonly cause visual quality deterioration after cataract surgery. They restrain the peripheral part from casting an image on the retina, resulting in glare, astigmatism, visual halo, and monocular diplopia. Studies have shown that an IOL with up to 2 – 3 tilt and 0.2 mm – 0.3 mm decentration does not disturb the image quality[1,2]. However, more than 5° of tilt or more than 1 mm of decentration causes substantial visual loss. However, clinical statistics show that human eyes are very sensitive to IOL tilt and decentration. Large aberrations are induced with less than 0.5 mm of decentration, leading to noticeable visual symptoms[1,3]. Statistically, 10% of patients have IOL tilt and decentration greater than 5° and 0.5 mm, respectively, after cataract surgery. This implies that they are very common, causing an obstacle in refractive cataract surgery. Therefore, their impact on postoperative visual quality cannot be underestimated and require intensive studies.

IOL tilt represents the angle between the IOL axis and the standard axis-pupil axis. IOL decentration denotes the vertical distance between the IOL center and the standard axis. The main existing measurement methods, including the Purkinje method, Scheimpflug method, ultrasound biomicroscopy (UBM), and anterior segment optical coherence tomography, generally use the pupillary axis under mydriasis as a reference to assess the tilt and decentration of the IOL. The Purkinje method measures the four midpoint positions on the anterior and posterior surfaces of the cornea and IOL *via* mydriasis. However, it is sensitive to pupil shape and IOL surface curvature. UBM measurement—especially in the supine position—may deepen the anterior chamber, causing inaccurate measurements of anterior chamber depth and pupil axis. All these methods result in the deviation of the pupil center due to pupil dilation. The corneal topography axis is a reference line connecting the corneal vertex to the fixation point on the corneal topographer irrespective of the pupil shape. Kimura *et al*[4] used the corneal topographic axis to measure preoperative and postoperative lens tilt and decentration in 100 eyes. They did not find a significant difference in IOL tilt and decentration before and after mydriasis. However, they found a significant correlation between the two, proving that the accuracy and stability of IOL tilt and decentration measurements can be improved by considering the corneal topographic axis as the reference axis.

Therefore, the scientific community gradually realized the importance of the impact of IOL tilt and decentration on their quantification and the precision improvement of measurement methods. The usage of multifocal IOLs (MIOLs) and extended depth of focus (EDOF) IOLs is significantly higher than that in the past owing to the improvement in the quality of life. Therefore, it is necessary to clearly identify the causes of IOL tilt and decentration and their effects on the postoperative visual quality of different IOL eyes, especially trifocal and EDOF IOL eyes, to further provide guidance for selecting a proper IOL and determine the effective lens position for improving the postoperative visual effect of cataract patients.

CAUSES OF IOL TILT AND DECENTRATION

It is essential to identify the factors affecting the position of IOL and diminishing the visual acuity and visual effect of patients in pre-, mid-, and post-operation phases.

Preoperative causes of IOL tilt and decentration

There are several factors contributing to IOL tilt and decentration[5,6]. Among those, the patients' ocular condition is an important factor affecting IOL position. In the univariate analysis of IOL tilt, the IOL tilt is significantly associated with a shorter axial length (AL)—the IOL tilt decreases by 0.228° for every 1 mm increase in AL. Furthermore, a greater IOL decentration is correlated with a longer AL. This

means that the position of IOL is more likely to tilt in patients with high myopia decenter postoperatively and with high hyperopia or microphthalmia. Additionally, the position of the crystalline lens is a critical determinant of postoperative IOL tilt and decentration. Research has indicated that the mean tilt and decentration of the crystalline lens were 4.90° and 0.21 mm, and those of postoperative IOL were 4.75° and 0.21 mm, respectively. Moreover, no significant differences were found between the two. Hence, we must consider the influence of the crystalline lens position and an abnormal AL. The studies of IOL position and previous intraocular surgery have shown that pars plana vitrectomy has a statistically significant effect on the IOL tilt, causing it to increase; this effect was considered to be related to the enlargement of ocular volume. Additionally, IOL tilt and decentration were found to have no significant correlation with basic information such as sex, age, diabetes, and hypertension.

Zonular instability has been proven to be an essential factor affecting surgical procedure and IOL stability[7]. Pseudoexfoliation, primary angle-closure glaucoma, trauma, surgical complications, and chronic uveitis are the major associated conditions for zonular dehiscence. The zonular weakness leads to not only IOL dislocation, but also marked IOL tilt and decentration. Furthermore, Takimoto *et al*[7] found that a capsular tension ring (CTR) could prevent IOL dislocation from zonular weakness, reducing the risk of marked anterior capsule contraction.

Intraoperative causes for IOL tilt and decentration

Well-behaved zonules can make manual continuous curvilinear capsulorhexis easier and facilitate the symmetry of continuous curvilinear capsulorhexis in cataract surgery. Meng *et al*[2] evaluated the influence of the size and shape of manual continuous curvilinear capsulorhexis on the postoperative tilt and decentration of IOLs. They divided patients into groups based on the capsulorhexis shape and size: Symmetrical capsulorhexis between 4.5 mm and 5.5 mm in size; capsulorhexis smaller than 4.5 mm in size, termed the small group; and all other types of capsulorhexis, which were termed the eccentric group. They statistically found that the capsulorhexis group hardly influences the distribution of tilt and decentration. Therefore, they believed that the size and shape of capsulorhexis have little effect on modern IOLs. However, no further clinical observation has been conducted to verify the effects of eccentric and symmetric capsulorhexis on IOL decentration and tilt and on postoperative visual quality. Therefore, our understanding of the effect of capsulorhexis—a key surgical procedure—on IOL is limited.

The effect of anterior capsule polishing is controversial. Wang *et al*[8] compared the IOL tilt, decentration, and area after 1, 3, and 6 postoperative months in patients who underwent 360° anterior capsular polishing in one eye and no polishing in the contralateral eye. They found that the two groups had a significant difference in IOL tilt and decentration. Moreover, they concluded that 360° anterior capsule polishing prevents anterior capsule contraction and increases the stability of IOL.

Postoperative causes for IOL tilt and decentration

Posterior capsular opacification (PCO) has been widely considered as the most common cause of vision loss after cataract surgery. The clinical observation of Uzel *et al*[9] demonstrated that PCO is associated with visual acuity impairment as well as the tilt and decentration of IOL. The PCO group showed vertical tilt up to 3.78° and decentration up to 0.55 mm compared to the control group. Laser capsulotomy decreased IOL tilt when the vertical tilt was 3.15°. However, no effect on decentration in both vertical and horizontal meridians was found—the vertical and horizontal decentration remained at 0.71 mm and 0.74 mm, respectively. The angle of tilt and decentration at both the meridians remained significantly higher after capsulotomy in the PCO group, implying that the YAG laser treatment of PCO could not adequately compensate for the tilt and decentration effect of PCO on IOL. Mastropasqua *et al* [10] applied CTR in a normal population without zonular abnormalities and found that the internal trefoil and coma aberrations were significantly lower in the CTR group in a 1-year follow-up. The IOL tilt and decentration in the CTR group a year later were also lower than those in a control group without any statistical significance. Mastropasqua *et al*[10] emphasized that CTR can help keep the anterior capsule distant from the anterior optic surface. Furthermore, they showed that it could reduce the distance between the posterior optic surface and posterior capsule, discontinuing the capsule band. Finally, it inhibits myofibroblastic lens epithelial cells metaplasia and migration, reducing the incidence of PCO. Zhang *et al*[11] defined the space between IOL and posterior capsule as IOL-PC space in 2020 and demonstrated that IOL-space had no significant correlation with IOL tilt and decentration. Furthermore, they showed that the thickness of IOL affects the IOL-space; however, a difference in IOL-space did not affect the stability of IOL.

We conclude that multiple factors affect IOL tilt and decentration in pre-, mid-, and post-operation phases. Preoperative ocular conditions of patients, such as crystalline lens position and zonular stability, are important for IOL tilt and decentration. Furthermore, anterior capsule polishing, CTR, and other relevant measures during the operation can avoid marked IOL tilt and decentration and are of great significance to the long-term stability of IOL.

INFLUENCE OF DIFFERENT IOL TILTS AND DECENTRATIONS ON POSTOPERATIVE VISUAL QUALITY

There are many studies on the effects of IOL tilt and decentration on postoperative visual acuity and visual effect. However, there are various types of IOLs, such as spherical IOL and aspheric IOL, monofocal IOL and MIOL, MIOL and EDOF IOL, that make tilt and decentration appear differently. A comprehensive understanding of the differences among these would help understand patients' visual symptoms and further guide the selection and application of IOL.

Single-piece and 3-piece aspheric IOLs

The influence of tilt and decentration on high-order aberrations (HOAs) varies between single-piece and 3-piece aspheric IOLs[12]. For example, the single-piece ZCB00 (Tecnis ZCB00, AMO) and 3-piece ZA9003 (Tecnis ZA9003, AMO) both have a correct spherical aberration of $-0.27 \mu\text{m}$; hence, the influence of different IOL aberrations can be excluded. We found significant differences in that the mean tilt of 90° (vertical) and 135° of the 1-piece ZCB00 group were lower than those of the 3-piece ZA9003 group. The defocus (Z4), astigmatism (Z5), third-order coma (Z8), and fourth-order spherical (Z12) in the 1-piece ZCB00 group were also lower than those in the 3-piece ZA9003 group at 5.0 mm pupil diameter. Consequently, the tilt and decentration of the 1-piece IOLs are not significantly correlated with internal ocular HOAs, while the those of the 3-piece IOLs are more correlated with internal ocular HOAs.

Spherical and aspheric IOLs

The optical part of spherical IOLs has positive spherical aberrations that increase the total HOAs postoperatively, theoretically deteriorating the optical quality. Aspheric IOLs are designed to be free of aberration or have negative spherical aberrations. A negative spherical aberration can improve the patient's contrast sensitivity and visual quality by completely or partially correcting or preserving within limits, they do not affect the ability to correct spherical aberrations with satisfying visual quality[14,15]. However, the ability of the aspheric IOLs to correct for spherical aberrations is limited when the decenter or tilt exceeds a certain threshold, possibly causing greater astigmatism and coma than spherical IOLs. Pérez-Gracia *et al*[15] found that the effect of IOL tilt and decentration on root mean square (RMS) astigmatism and coma, especially horizontal coma, is positively related to the spherical aberrations of the IOL[15-18]. At a certain decentration, larger negative spherical aberrations result in a stronger influence of the decentration on the retinal image quality[15,19]. Pérez-Merino *et al*[18] compared 10 Vivinex XY1, 4 Tecnis 1P ZCB00V, and 4 Acrysof 1P SN60WF lenses with spherical aberration corrections of $-0.18 \mu\text{m}$ (V-0.18), $-0.27 \mu\text{m}$ (T-0.27), and $-0.17 \mu\text{m}$ (A-0.17), respectively, to evaluate the effect of IOL decentration on optical aberrations. Moreover, they found that V-0.18 was the design most immune to optical degradation caused by decentration. Similarly, the human eye model confirmed that the modulation transfer function (MTF) was found to be lower than 0.43 when negative spherical aberration IOLs tilted by more than 3° and 5° and decentered by 0.5 mm and 0.75, respectively. The decentration increased with increasing negative spherical aberrations at a certain MTF.

Moreover, the RMS astigmatism and coma in spherical IOLs were comparable with negative spherical aberration IOLs when aspheric IOLs decentered from 0.75 mm to 1.00 mm. Furthermore, Pérez-Merino *et al*[18] proved that a 0.7 mm decentration of negative spherical aberration IOLs decreased MTF significantly. Hence, the correction of spherical aberration was limited.

Therefore, we conclude that aspherical IOLs are more sensitive to decentration or tilt than spherical IOLs. The tilt and decentration of aspheric IOLs markedly increase the wavefront aberration and have remarkable effects on visual quality.

Later, Rosales *et al*[20] calculated the IOL tilt and decentration of customized computer eye models. They proposed that 58.3% of patients are unaffected by misalignment of aspherical IOLs because ocular HOAs are compensated for by the aberrations due to IOL tilt and decentration, especially for spherical aberration and horizontal coma. Therefore, there are many ways the tilt and decentration of aspheric IOLs influence HOAs.

Aspheric IOLs are more sensitive to tilt and decentration and have a limited compensating effect on spherical aberrations. Moreover, designing IOLs to correct for negative spherical aberrations can affect the influence of the IOL tilt and decentration on HOAs and retinal image quality.

Toric IOLs

The anterior surface of a toric IOL is spherical, whereas its posterior surface is toric. The posterior surface of toric IOLs is designed by applying different refractive forces on the torus to compensate for regular astigmatism of the cornea to reduce or eliminate ocular astigmatism and improve the visual quality. The tilt and decentration of the toric IOL increase the HOAs and decrease the visual quality. He *et al*[21] evaluated the effect of decentration and tilt on the image quality in AcrySof IQ Toric SN6AT3, SN6AT4, and SN6AT5. They found that the decentration of toric IOLs induces a markedly increased coma. However, toric IOLs provide superior image quality as long as the decentration is less than 0.6 mm. Kim *et al*[22] also arrived at similar conclusions. Moreover, the decentration significantly affects

aspheric IOLs with more negative aberrations. However, an aberration-free aspheric toric IOL (Precizon and Torbi 709M, Carl-Zeiss Meditec AG) has better tolerance to decentration and provides good image quality with decentration. Furthermore, Zhang *et al*[23] used the Zemax ray-tracing program to analyze the optical performance of toric IOLs with an accurate axis. The optical properties of AcrySof IQ Toric SN60T5 and SN60AT were found to be similar. Moreover, MTFs were decreased under a 4 mm or 5 mm pupil diameter. However, the optic quality was not influenced by the decentration direction of the toric IOL with an accurate axis; hence, the tolerance of toric IOLs to decentration was found to be similar to that of spherical IOLs.

MIOLs

Schrecker *et al*[24] examined 55 eyes with monofocal IOLs. They showed that the mean tilt and decentration were 1.8° and 0.02 mm, respectively. Furthermore, the correlation between decentration and aberrations was not significant, and tilt influenced only ocular coma-like aberrations. Therefore, we conclude that the tilt and decentration of monofocal IOLs are not related to HOAs statistically.

However, MIOLs are more susceptible to the influence of tilt and decentration than monofocal IOLs. Moreover, decentration has a greater influence than tilt[25]. MIOLs are based on the refraction and diffraction of light. They have a far-dominant optic design to minimize the degradation of visual function while retaining near focus. The effect of tilt and decentration on MIOLs are complicated and variable because there are diverse MIOLs such as refractive MIOLs, diffractive MIOLs, and mixed MIOL. Hayashi *et al*[26] evaluated the correlation between IOL tilt and decentration with postoperative LogMAR visual acuity (VA) in the Allergan Medical Optics Array IOL (Allergan, Irvine, CA). They observed significant positive associations between the degree of IOL decentration and LogMAR VA at 5.0, 3.0, 2.0, 1.0, and 0.7 m. Moreover, the distant mean LogMAR VA at 5.0 m did not reach 0.10 at a decentration greater than or equal to 0.7 mm. Furthermore, the mean LogMAR VA did not reach 0.20 when the degree of decentration was greater than or equal to 0.9 mm. This implies that a decentration of less than or equal to 0.7 mm has little effect on distant VA. On the other hand, the decentration and tilt of monofocal IOLs are not related to LogMAR VA at any distance. The near, intermediate, and distant focus MTF values of aspheric diffractive bifocal IOLs (LISA 809M; Carl-Zeiss-Meditec) and trifocal IOLs (LISA 839M; Carl-Zeiss-Meditec) decrease significantly within the decentration range of 0.5-0.75 mm, especially with a 4.5 mm aperture size rather than 3.0 mm. Hence, MIOLs are positively affected by decentration with dilated pupils[25].

Additionally, rotationally asymmetric MIOLs (SBL-3) are sensitive to tilt and decentration. However, they are different from diffractive MIOLs. Liu *et al*[27] illustrated the change in optic performance of SBL-3 in specific directions. The optic quality improved at near focus for a near-horizontal decentration and decreased at distant focus. The image quality deteriorated more for a 3.0 mm aperture than for a 4.5 mm aperture. The opposite results were obtained for far-horizontal decentration. Unlike the decentration, the optic quality decreased at near focus and improved at distant focus for a near-horizontal tilt, with a greater tendency for the 4.5 mm aperture than for the 3.0 mm aperture. However, the opposite results were found for distance-horizontal tilt[27]. Therefore, the optical quality of the asymmetric MIOL varied significantly after decentration and tilt in different directions. The image quality enhanced or weakened at specific directions with a decentered IOL, while a poor image quality was attained with tilt in any direction.

Overall, human eyes have different responses to IOL tilt and decentration due to the diversity of MIOL designs, suggesting that different types of MIOLs must be considered under different ocular conditions to achieve the best postoperative visual effects.

EDOF IOLs

EDOF IOL is designed with a special diffraction grating system and achromatic technique with an aspheric surface to lengthen the focus and expand the depth of field for the patient to obtain clear vision and better imaging quality. Studies have shown that Toric-EDOF IOL has high rotational stability and concentration, helping patients to achieve better distant, intermediate, and near vision with reduced astigmatism. This provides high patient satisfaction[28].

Bellucci *et al*[29] explored the effect of decentration and tilt of EDof IOL (Mini WELL; SIFI, Catania, Italy) on visual effect in 2017. They showed that the values of distant and intermediate MTF are not influenced by tilt up to $\pm 2.5^\circ$ or by decentration up to ± 0.5 mm with pupil diameters of 3 mm and 4.5 mm. Good VA was also achieved from near (0.5 m) to distant (4 m) vision. Ben Yaish *et al*[30] arrived at the same conclusions by studying EDof decentration. They obtained clear and focused near, intermediate, and distant vision. Moreover, they achieved the capability of correcting astigmatism of up to 1.00 diopter when the decentration of the EDof IOL was lower than 0.75 mm. Moreover, Ben Yaish *et al*[30] studied an aspheric toric IOL (Mini WELL; SIFI, Catania, Italy) with positive spherical aberration in the central 2-mm zone and negative spherical aberration in the pericentral 1-mm annulus. They found that IOLs do not have a refractive annulus that produces lower unwanted optical phenomena than current MIOLs. Xu *et al*[31] retrospectively analyzed and compared the effects of IOL decentration on the optical quality of monofocal, bifocal, and EDof IOL implantation. Research has shown that HOAs, coma, point spread function, and glare perception in monofocal and EDof IOLs are better than those in the ZMB00 IOL with a decentration greater than 0.25 mm. Therefore, monofocal and EDof IOLs are

more immune to optical quality degradation caused by IOL decentration than the ZMB00 IOL. Breyer *et al*[32] proved that EDOF IOLs are more stable under decentration than bifocal IOLs by comparing an EDOF lens with AcrySof ReSTOR SA60D3 Lens (Alcon Laboratories Inc).

The above results imply that an EDOF IOL can achieve good visual acuity in the distant, medium, and near range. The tilt and decentration of EDOF IOLs have less impact on the vision than those of bifocal and trifocal IOLs. Therefore, they are highly important for improving the visual quality of patients after surgery.

DISCUSSION

In this review, we reviewed more than 30 articles focusing on the effects of different IOL tilt and decentration on postoperative visual quality.

With the development of IOL technology and the diversification of IOL types, the aspirations of patients undergoing cataract surgery have gradually shifted from simply being able to see towards pursuing lens removal, after achieving clear vision in the near, immediate, and distant range as well as considerably reduced visual interference. However, IOL tilt and decentration can negatively affect patients' postoperative visual ability. We have also realized that the effect of tilt and decentration is closely associated with the IOL type. Therefore, choosing an accurate IOL based on ocular conditions would reduce the probability and impact of IOL tilt and decentration after surgery.

It should be noted that IOLs are designed based on the average state of the cornea. However, with the development of refractive surgery techniques, an increasing number of cataract patients undergo corneal refractive surgery earlier to correct myopia, hyperopia, and astigmatism. The surgical procedure results in changes in the cornea and overall spherical aberrations. Research has confirmed that myopia laser-assisted in situ keratomileusis (LASIK) surgery induces changes in the anterior and total aberrations[33]. However, hyperopia refractive surgery results in negative spherical aberrations of the cornea[34]. Therefore, it is of great significance to further study the effect of different IOL designs and IOL positions on the visual quality of patients undergoing refractive surgery. Studies have shown that when the IOLs are centered, IOLs with aberration correction design can compensate for the ocular aberrations of patients with low and high myopia after refractive correction[35]. However, a decrease in visual quality is expected when IOLs are decentered or tilted. Moreover, the accurate implantation of negative aberration IOLs in patients with previous refractive surgery is vital, and aberration-free IOLs provide a consistent image quality[35,36].

CONCLUSION

In summary, it is very important to define the type of IOL implantation based on spherical corneal aberrations. Aspheric IOLs with a free-aberration design are a better choice for patients for whom position accuracy cannot be guaranteed. Additionally, refractive surgery guided by the HOA of the affected eye has been widely applied, and it is more suitable for IOLs designed based on the standard eye model. Therefore, a deep understanding of IOL tilt and decentration would help achieve the visual effect in refractive cataract surgery and make a significant visual improvement after refractive cataract surgery.

FOOTNOTES

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