Evaluation of the Impact of Intraocular Lens Tecnis Z9000 Misalignment on the Visual Quality Using the Optical Eye Modeling

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Abstract

***Purpose*:** The aim of this study was to investigate the effect of misalignment (tilt & decentration) of IOLs in cataract surgery using Liu-Brennan optical eye model in a simulation.

***Methods*:** A phantom with the real eye parameters –Liu-Brennan model– and Tecnis Z9000 IOL were used for simulation.

***Results*:** Results showed that with 0.4 mm decentration and more the modulation transfer function (MTF) and contrast were reduced continuously in the ±X Axes. IOL decentration in ±Y axes showed a symmetrical reduction of MTF and contrast with increasing the decentration. In the ±X and ±Y axes, 1º to 8º IOL tilts had no significant effect on the MTF and contrast of the eye.

***Conclusion*:** It can be said that the decentration of Tecnis Z9000 IOL in the ±X and ±Y axes will reduce the optical quality of the person, specially for decentration more than 0.4 mm this effect is very significant. Therefore using the compensation methods for improvement of the optical quality is essential. But up to 8º IOL tilt in vertical and horizontal axes had no significant effect on the visual quality of the patient.

***Keywords*:** Intraocular Lens, Misalignment, Tecnis Z9000, Zemax, Modulation Transfer Function, Optical Quality

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Introduction

Nowadays, intraocular lens (IOL) implants have become a standard method for visual rehabilitation after cataract surgery. Among the significant developments, several complications related to surgical techniques and IOL designs are available after surgery. These IOLs may cause some aberrations after surgery due to misalignment (tilt and decentration) and so reducing the visual acuity (VA) after surgery. IOL misalignment, including tilt and decentration is one of the most common complications, even occurs after successful and perfect implantation. The rate and extent of these complications have decreased with improved of IOL designs and surgical techniques. However, various studies reported that many of these complications still persist.[1,2]

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Aspheric lenses can reduce the spherical aberration of the eye and can improve contrast sensitivity. Despite the improvements in VA, patients who undergo cataract surgery have been experienced the reduction of resolution, contrast and a dazzling aura. Contrast sensitivity of the visual system following the use of IOLs, are not desirable. The possible causes may be IOL material composition and spherical or aspheric IOL misalignment during or after cataract surgery.[3,4]

Theoretical studies showed that even a small shift in modern aspheric IOLs can reduce their performance considerably. Thus the increase in ocular aberration correction technology requires double precision for IOL centration and placement.[5] Altmann and colleagues imposed displacement on three different types of intraocular lenses. They concluded that conventional lenses with spherical surfaces, may induce defocus, astigmatism, and coma.[6] Baumeister et al examined the tilt and decentration of some spherical and aspheric IOLs and they have shown that the effect of tilt and decentration is very important even for non-spherical IOLs.[4] Given the importance of tilt and decentration of IOL after cataract surgery on visual quality, we have tried to simulate a different value of tilt and decentration of aspheric IOL Tecnis Z9000- which has the approval from the U.S. Food and Drug Administration and widely used. This investigation is done with Zemax code using a proper eye visual model that can better simulate the real eye.[7] The effect of tilt and decentration on visual quality is analyzed after each simulation by modulation transfer function (MTF) and E-letter. Finally, the amount of IOL tilt and decentration that does not have a considerable impact on the quality of vision was determined.

Methods

For simulating the effect of IOL misalignment on the image quality of the eye in the computer we used the complete optical model of the eye and ray tracing procedure in the mathematical environment. There are different software's in the field of optics each has a specific capabilities and applications. Zemax software has numerous applications in various fields, specially in the field of optical design. This code has various optical analysis and depending on the requirements of research each of these analyzes are used. So 2003 version of Zemax was used in this study.

The optical model used in this study was the Liu-Brennan schematic eye model that is the most similar to the human eye and is capable of predicting in vivo optical performance of the eye.[8-10] It is intended that the pupil diameter for the model was 2.5 mm and is tilted and decentered along the -X direction. Initially a phakic eye was modeled using a Liu-Brennan eye model. Then a pseudophakic eye based on this model was simulated. The data used for the simulation are given in table 1.

For definition of the IOL in the eye model the geometry of anterior and posterior surface of IOL (Tecnis Z9000) - provided by the manufacturer- as standard surface with a specific refractive index was modeled in the schematic eye model.[3,10,11] In the next step, tilt and decentration of IOL in the ±X and ±Y direction was applied. The range of IOL decentration was considered from 0 to 1 mm in ±X and ±Y directions, with an accuracy of 0.2 mm. IOL tilt in ±X and ±Y direction was performed from 1º to 8º, with the accuracy of 1º. Zemax ray tracing code was used to simulate the aberrations due to IOL misalignment in its all situations. According to various studies, the maximum tilt observed in the eyes of most peoples who have used IOL were less than 10 degrees so the effects of more than 8º tilt, because of its impossibility, for all IOLs has not been investigated in this study.[12-16]

To evaluate the image quality of an optical system MTF and the point spread function (PSF) of an image and their effects on the E-letter were used.

Table 1. Optical data of LBME phakic eye used for simulation

Surface	Radius (mm)	Conic constant	Thickness (mm)	n (λ=555 nm)
Anterior cornea	7.77	-0.18	0.50	1.376
Posterior cornea	6.40	-0.60	3.16	1.336
Iris	Infinity	-	0.00	1.336
Anterior lens	12.40	-0.94	1.59	1.368-1.407
Posterior lens	Infinity	-	2.43	1.407-1.368
Vitreous	-8.10	+0.96	16.27	1.336
Retina	-12.00	0.00	-	-

λ=wavelength, n=refractive index

Results

IOL Tecnis Z9000 decentration effect in +X direction:

The effect of IOL decentration in the +X (nasal) direction of the eye on the optical quality, the MTF plot, can be seen in figure 1. As can be seen, the vertical and horizontal axis show, respectively, the MTF of the optical system and the spatial frequency in terms of cycles per degree for different values of IOL decentration. It is clear that with increasing IOL decentration, MTF drops more severely so that the MTF of 0.6, 0.8, 1 mm decentration were less than 50% at 6 cycles per degree. This indicates that the visual quality of the eye in these values at the +X axis was not desirable.

IOL Tecnis Z9000 decentration effect in -X direction

The effect of IOL decentration in the -X (temporal) direction of the eye on the optical quality, the MTF plot, can be seen in figure 2. It is clear that increasing the IOL decentration is associated with reduced MTF, but not so strongly as in +X, so that at 6 cycles per degree, MTFs for all values of tilt (0.2, 0.4, 0.6, 0.8 and 1 mm) were more than 50%. Therefore despite the visual quality which was declined, the MTF results of decentration in the -X, in comparison to +X direction was more desirable.

Statistical analysis of MTFs of figures 1, 2 with original centered IOL by K-S Test is shown in table 2. As can be seen, all decentration of Tecnis Z9000 have significant effect on MTF in X, Y directions ($p<0.05$), except for 0.2 mm in ±Y and -X directions.

IOL Tecnis Z9000 decentration effect in ±Y direction

The results for tilt of the IOL in ±Y were plotted in figure 3. As can be seen, the variations in the Y-axis in both positive and negative directions were less than the X axis. Figure 3 shows that the MTF is reduced with increasing decentration in +Y, -Y. All the MTF were more than 50% in 6 cycles per degree.

Statistical analysis of MTFs of figure 3 with original centered untilted intraocular lens by K-S test showed in table 3. As can be seen in this table, 0-8 degrees tilts of Tecnis Z9000 have no significant effect on MTFs in X,Y directions ($p>0.99$).

IOL Tecnis Z9000 tilt effect in ±X, ±Y directions

Figures 4, 5 show the MTF graphs of IOL tilt in ±X, ±Y axes. As can be seen the MTF of IOL tilt was approximately similar to normal IOL, in both directions. This shows that the optical system has a good performance in this range of tilt and its visual quality is acceptable.

The effect of IOL decentration on E letter

The figures of 6, 7, 8, 9 show the E-letter analysis of IOL decentration in ±X and ±Y and IOL tilt in ±X and ±Y directions, respectively. As can be predicted from MTF analysis, the IOL decentration in +X has greater influence on optical image quality of the eye. However, it can be seen that IOL decentration in -X also has a negative effect on visual image quality, but not as severely as in +X. Figure 7 shows that the IOL decentration in ±Y direction results in the reduction of the optical quality of the image. Elongation and distortion of the image was clearly seen on IOL decentration in Y direction and IOL decentration has symmetric effects in two directions (+Y, -Y).

Figures 8, 9 show that IOL Tecnis Z9000 tilt in ±X and ±Y directions have no significant effect on visual quality of the eye in Liu-Brennan eye model.

Table 2. P-values for modulation transfer function of Tecnis Z9000 decentrations in ±X, ±Y directions comparison to original centered intraocular lens in Schematic eye

Decentration X (mm)	p-value	Decentration Y (mm)	p-value
0.2	0.0001	0.2	1.0000
0.4	0.0001	0.4	0.0260
0.6	0.0001	0.6	0.0001
0.8	0.0001	0.8	0.0001
1.0	0.0001	1.0	0.0001
-0.2	0.3760	-0.2	0.1280
-0.4	0.0001	-0.4	0.0001
-0.6	0.0001	-0.6	0.0001
-0.8	0.0001	-0.8	0.0001
-1.0	0.0001	-1.0	0.0001

Table 3. P-values for modulation transfer function of Tecnis Z9000 tilts in ±X , ±Y directions comparison to original centered untilted intraocular lens in Schematic eye

Tilt in X (degree)	p-value	Tilt in Y (degree)	p-value
1	1.00	1	1.00
2	1.00	2	1.00
3	1.00	3	1.00
4	1.00	4	1.00
5	1.00	5	1.00
6	1.00	6	1.00
7	1.00	7	1.00
8	1.00	8	1.00
-1	1.00	-1	1.00
-2	1.00	-2	1.00
-3	1.00	-3	1.00
-4	1.00	-4	1.00
-5	1.00	-5	1.00
-6	1.00	-6	0.99
-7	1.00	-7	0.99
-8	1.00	-8	0.99

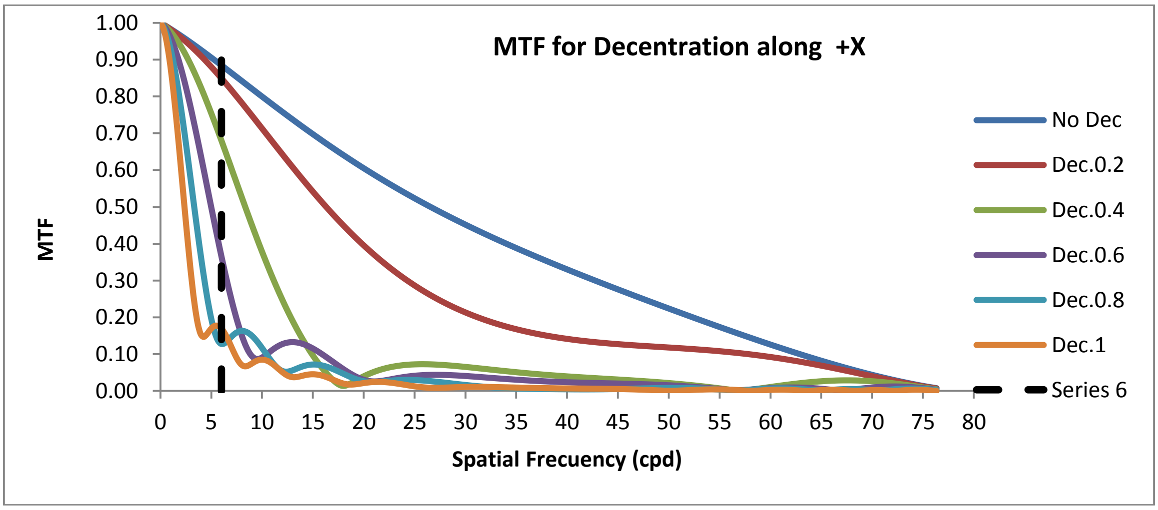

Figure 1. The effect of intraocular lens decentration on +X direction

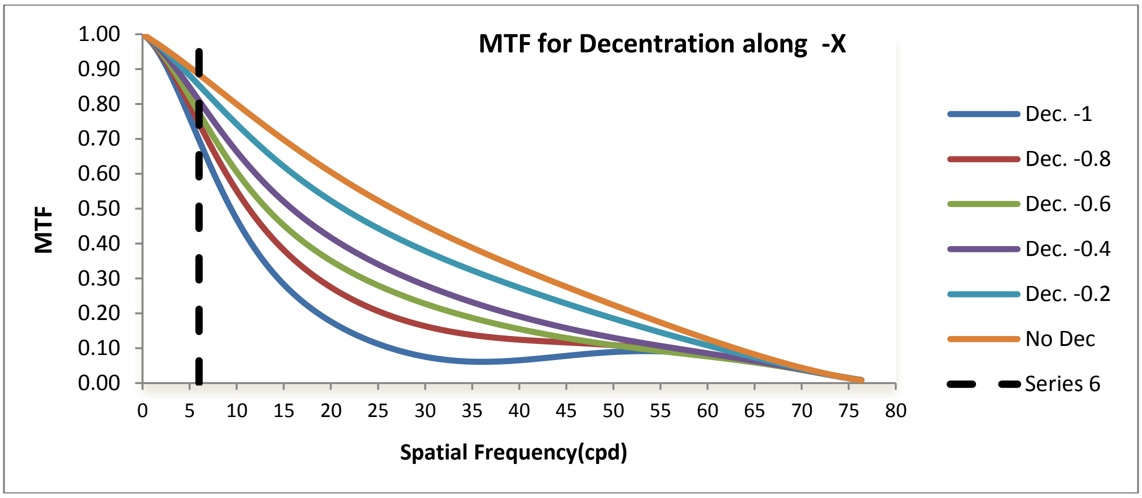

Figure 2. The effect of intraocular lens decentration on -X direction

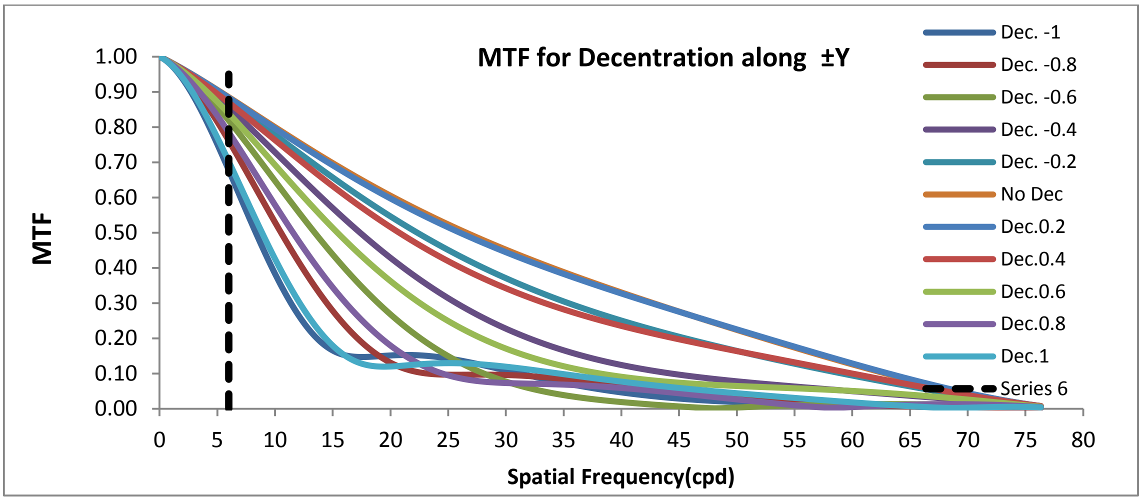

Figure 3. The effect of intraocular lens decentration on ±Y directions

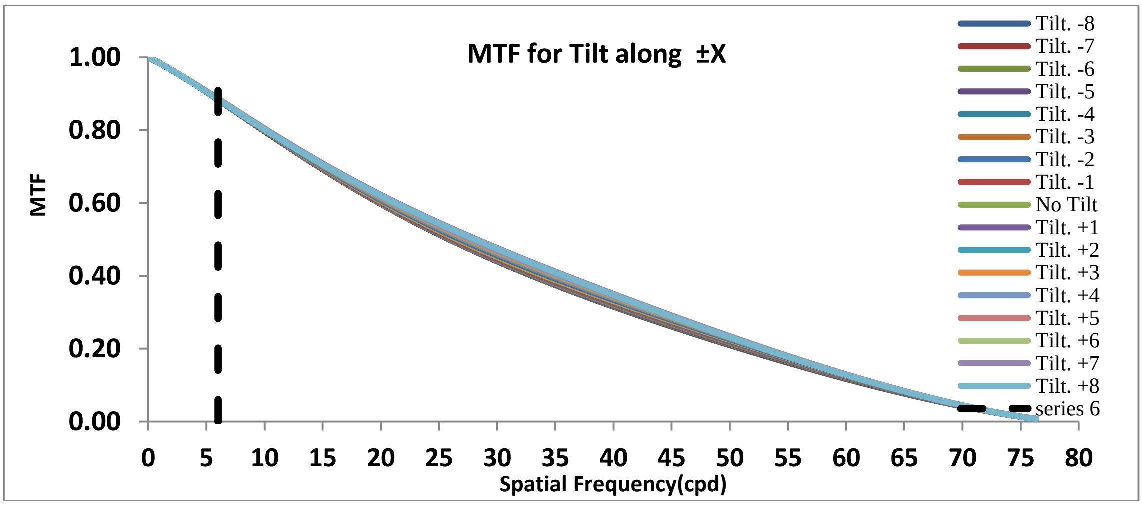

Figure 4. The effect of intraocular lens tilt in ±X directions

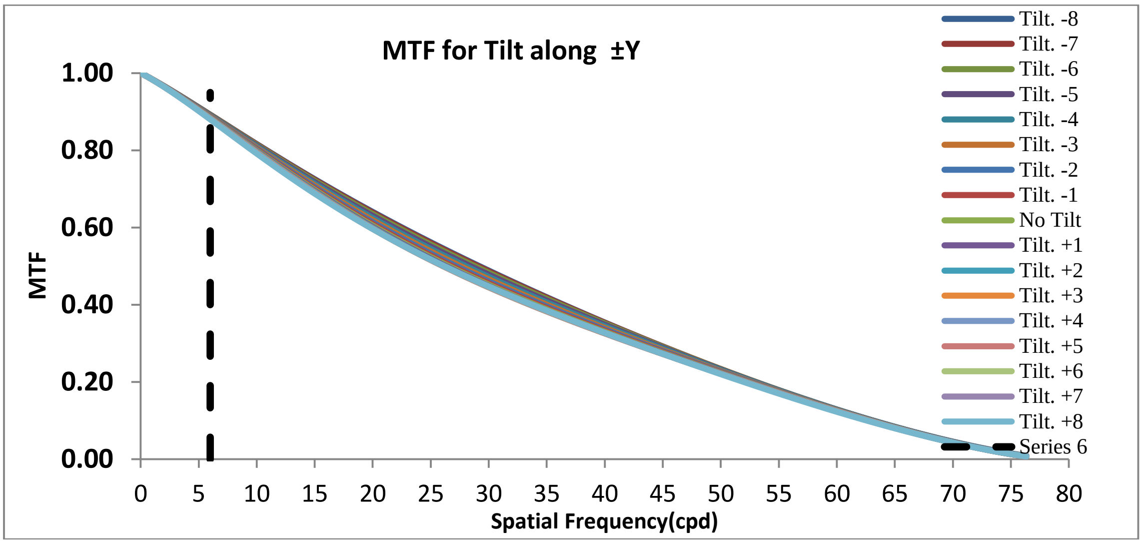

Figure 5. The effect of intraocular lens tilt in ±Y directions

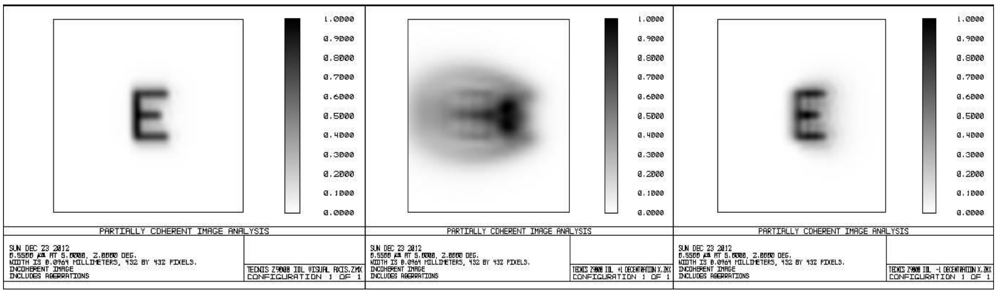

Figure 6. E-letter analysis. Normal, +1 mm decentered, -1 mm decentered in X axis, left to right respectively

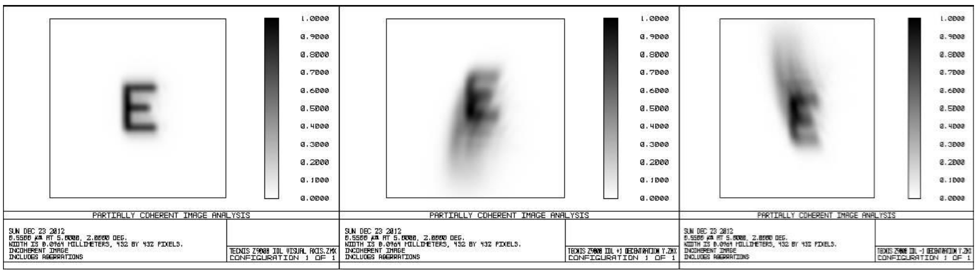

Figure 7. E-letter analysis. Normal, +1 mm decentered, -1 mm decentered in Y axis, left to right respectively

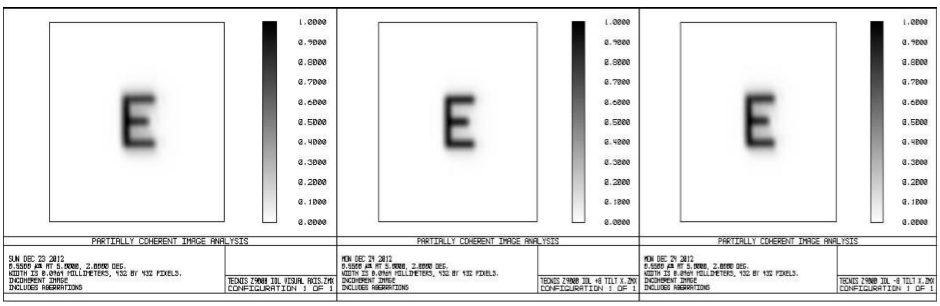

Figure 8. E-letter analysis. Normal, +8º tilt, -8º tilt in X axis, left to right respectively

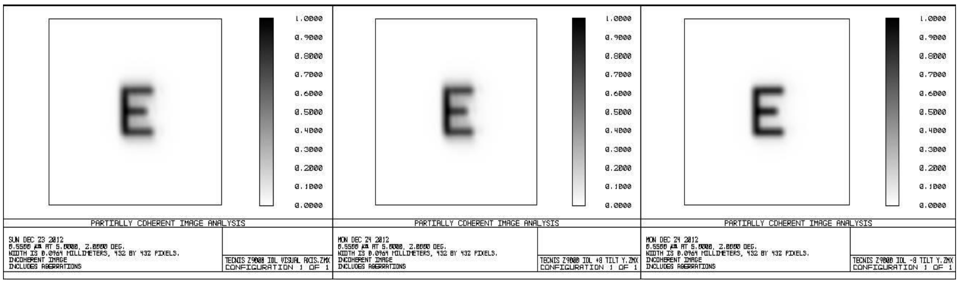

Figure 9. E-letter analysis. Normal, +8º tilt, -8º tilt in Y axis, left to right respectively

Discussion

In this study the effect of IOL misalignment on optical quality of the eye using the MTF for monochromatic light was studied. MTF is the ratio of image contrast to object contrast, so the significant improvement in the MTF leads to improve the image contrast. Statistical analysis of Tecnis Z9000 IOL decentration in this study showed that with increasing the amount of decentration in ±X and ±Y direction, specially after 0.4 mm, MTF decreased. This reduction was approximately symmetric in the ±Y direction but the slope of this reduction in -X was clearly less than +X. This difference can be due to the Liu - Brennan eye model used in this study. In this model like a real eye optical axis was not coincide with the visual axis and was tilted and decentered in the -X direction. Also the pupil was decentered in this direction. Therefore it can be said that the effect of decentration in Liu-Brennan model in X direction was not symmetric.

Comparison of MTF curves for different values of decentration with the reference curve using the K-S test showed that IOL decentration in each direction results in reduction of visual quality but this reduction for various decentrations in different directions were not equal. Using these results, we can say that up to 0.2 mm decentration has no significant effect on the overall MTF of the eye - the criteria of the optical performance of the eye is negligible. Also the results showed that the IOL Tecnis Z9000 tilt has no significant effect on MTF in ±X and ±Y directions.

Since one of the main parameters of the optical system is the PSF, optical system of the eye can be interpreted according to the width of PSF and its effect on E-letter.

$$PSF_{width} = 1.22\frac{f\ \lambda}{nD}$$

(*λ=wavelength, f=focal length, n*=refractive *index, D=pupil diameter)*

The results of this study showed that the decentration of IOL changed the effective focal length of the eye, resulted in lengthening the PSF width. Increasing the width of the PSF curve showed the reduction of image resolution and quality. This effect can be seen clearly in the E-letter. According to the definition of the MTF, with the wider width of the PSF, the MTF is reduced for different frequencies, this represents a reduction in image quality.[15,17,18]

PSF equations and its curve width can be applied to investigate the reasons for the lack of the effect of tilt on the optical performance of the eye. The IOL tilt up to 8º has no significant effect on the effective focal length. However, other parameters in the width of the PSF equation (the wavelength of light, refraction index and pupil diameter) for all tilt values were considered unchanged, therefore the IOL tilt has no significant effects on PSF width and image quality. The width of the PSF on image quality for different values of tilt is clearly visible with the E-letter analysis.

In addition to the above findings it can be concluded that with the tilt of the IOL its position is unchanged and so its effect on parameters such as the anterior part of the eye (ACD) was negligible.[19] Therefore because the other eye parameters were fixed, IOL tilt had no considerable effect on the effective focal length so the image quality will be constant.

Comparing MTF curve in this study with other investigations showed the good correspondence between these results. The results of the current study agreed with the Madrid-Costa and colleagues for IOL decentration effects on optical quality of the eye.[20] Holladay et al report was also consistent with the current study since they reported that less than 0.4 mm decentration and 7º tilt of IOL has no significant effect on optical quality of the eye.[21]

The results of the current study also agreed with the results of Altmann et al on Tecnis Z9000, SofPort AO and spherical IOLs[22] and Portney et al for image quality on the retina with the IOL misalignment (tilt and decentration).[23] Lopez-Gil NL et al in 2007, like the results of current study, showed that more than 0.4 mm IOL decentrations significantly affect the average MTF of the optical system.[24] Holladay and associates also found that a wide ranges of IOL tilt provide a stable image quality but spherical IOLs may be sensitive to decentration.[21] Lopez-Gil et al showed that some of the aspheric IOL - like Tecnis-have little sensitivity to lesser values of tilt but at higher levels the tilt effects on image quality increased. These are consistent with the results of the current study and confirmed ineffectiveness of tilt up to 8 degrees on the optical performance of the eye.[24]

Finally the declination and loss of vision after IOL implantation of aspheric Tecnis Z9000 IOL can often be due to IOL decentration rather than its tilt. Other studies on various lenses also have suggested that the effects of IOL tilt and decentration has not the same effect on the visual quality of the eye.[7,15]

Conclusion

Results of this study for the effect of IOL Tecnis Z9000 tilt up to 8 degrees has no substantial effects on the image quality of the eye. But more than 0.4 mm decentration in this type of IOL resulted in significant reduction of the image quality of the eye. Therefore the evaluation of the visual performance of the eye based on a potentially misalignment of the IOL and compensation approach for this type of patients, is essential. However, based on previous studies, the reduction in MTF at different decentrations strongly dependent on the unique design of IOL and the better design of IOL resulted in less sensitivity to misalignment and improve the visual quality of patients after cataract surgery 15. In summary, this study showed that under normal conditions, decentration effect of Tecnis Z9000 aspheric IOLs on retinal image quality was more than the tilt.

In cases where the IOL alignment in the eye was not guaranteed, non-aberration IOLs can probably be a good choice for these patients – with the acceptable agreement between the image quality and good design that is resistant to tilt and decentration. It is recommended that when appropriate alignment of the IOL cannot be guaranteed, surgeons should use the IOLs resistant to misalignment.

References

1. Mello MO Jr, Scott IU, Smiddy WE, Flynn HW, Feuer W. Surgical management and outcomes of dislocated intraocular lenses. Ophthalmology 2000;107(1):62-7.
2. Montés-Micó R, Cerviño A, Ferrer-Blasco T. Intraocular lens centration and stability: efficacy of current technique and technology. Curr Opin Ophthalmol 2009;20(1):33-6.
3. Jafarinasab MR, Baghi AR, Karimian F, Yaseri M. Comparison of visual outcomes between aspheric IOLs tecnis Z9000 and acrys of IQ. Bina J Ophthalmol 2008;13(2):186-91.
4. Baumeister M, Kohnen T. Scheimpflug measurement of intraocular lens position after piggyback implantation of foldable intraocular lenses in eyes with high hyperopia. J Cataract Refract Surg 2006;32(12):2098-104.
5. Kirschkamp T, Dunne M, Barry JC. Phakometric measurement of ocular surface radii of curvature, axial separations and alignment in relaxed and accommodated human eyes. Ophthalmic Physiol Opt 2004;24(2):65-73.
6. Altmann GE, Nichamin LD, Lane SS. Lane, Pepose JS. Optical performance of 3 intraocular lens designs in the presence of decentration. J Cataract Refract Surg 2005;31(3):574-85.
7. Faklis D, Morris GM. Spectral properties of multiorder diffractive lenses. Appl Opt 1995;34(14):2462-8.
8. Almeida MSd, Carvalho LA. Different schematic eyes and their accuracy to the in vivo eye: a quantitative comparison study. Braz J Phys 2007;37(2A):378-87.
9. Abolmasoomi M, Keshavarzi K, Nikkhou M, Jafarzadeh Pour E. Study of optical models

regarding the human eye. Iran J Med Phys 2011;8(30):73-88.

10. Bellucci R, Scialdone A, Buratto L, Morselli S, Chierego C, Criscuoli A, et al. Visual acuity and contrast sensitivity comparison between Tecnis and AcrySof SA60AT intraocular lenses: A multicenter randomized study. J Cataract Refract Surg 2005;31(4):712-7.
11. Geary JM. Introduction to lens design: with practical ZEMAX examples. Willmann-Bell, 2002, 462 p.
12. Fasih U, Ahmed I, Shaikh A, Fahmi MS. Comparison of complications after primary and secondary anterior chamber intraocular lens implantation. Pak J Ophthalmol 2010;26(2):57-64.
13. Artal P, Benito A, Tabernero J. The human eye is an example of robust optical design. J Vis 2006;6(1):1-7.
14. Charman WN. Optics of the Human Eye. In: Cronly Dillon, J. (ed.) Visual Optics and Instrumentation 1991:1-26.
15. Tan B. Optical modeling of schematic eyes and the ophthalmic applications. University of Tennessee, Knoxville, 2009.
16. Morris GM, Nordan LT. Phakic intraocular lenses. Optics and photonics news 2004;15(9):26-31.
17. Davison JA, Chylack LT. Clinical application of the lens opacities classification system III in the performance of phacoemulsification. J Cataract Refract Surg 2003;29(1):138-45.
18. Chang DF. Spotlight on IOL Complications. Eye Net 2011:47-60.
19. Nowakowski M. Study of ocular aberrations within a 10 deg central visual field. Ireland: Science Faculty, National University of Ireland; 2011.
20. Madrid-Costa D, Ruiz-Alcocer J, Pérez-Vives C, Ferrer-Blasco T, López-Gil N, Robert Montés-Mico R. Visual simulation through different intraocular lenses using adaptive optics: effect of tilt and decentration. J Cataract Refract Surg 2012;38(6):947-58.
21. Holladay JT, Piers PA, Koranyi G, van der Mooren M, Norrby NE. A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. J Refract Surg 2002;18(6):683-91.
22. Altmann GE, Edwards KH. The aberration-free IOL: advanced optical performance independent of patient profile. Symposium on Cataract, IOL and Refractive Surgery, San Diego, Colif, May 2004.
23. Portney V. New bi-sign aspheric IOL and its application. Optom Vis Sci 2012;89(1):80-9.
24. López-Gil N, Montés-Micó R. New intraocular lens for achromatizing the human eye. J Cataract Refract Surg 2007;33(7):1296-302.