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Visual Performance of Refractive Intraocular Lenses within the Human Eye

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HIGHLIGHTS

- Cataract (clouding the eye lens) lead to blindness.
- The refractive IOLs are used to correct this problem.
- It's cheap, available in global markets.

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ABSTRACT

The most effective treatment for cataracts is to remove the cloudy crystalline natural lens and implant an intraocular lens (IOL) in its place. These refractive (IOL) provide the same focusing as do the natural lens. Two refractive IOLs are designed and analyzed in this paper—these IOL are made of (PMMA, and Acrylic). The quality of the retinal image is analyzed and compared with the healthy eye, which is based on the (Liou-Brennan) eye model) LBEM). Polychromatic Point Spread Function (PSF), Modulation Transfer Function (MTF), spot diagram, Encircled Energy (EE), and monochromatic aberration are used as acceptable criteria within the Zemax software.

1. Introduction

The eye is our window to the world. Human vision has been widely studied for a long ago. The human eye sensitive to wavelength from (380-760) nm it's considered the most complex optical structure. The light refracts when entering the eye as it passes the cornea, the aqueous humor, the crystalline lens, the vitreous humor, and finally arrives at the retina [1]. Naturally, the crystalline lens focuses the light on the retina. Any injuries of the lens cause the focusing impossible, and the eye gets vision problems. These vision problems can be corrected by using spectacles lens [2], contact lens [3,4], and intraocular lens [5]. The opacity of the crystalline lens (cataract) is the most publicity reason for losing vision, especially in middle-aged about (45 to 65). In a year, about fifty million people effect by cataracts causes 33 percent of visual impairment and 51 percent of blindness [6]. The effective method for cataracts is to remove the opaque lens and insert the IOL lens in its place [7]. Many IOL materials [8-10] is used recently, such as (PMMA and Acrylic). The use of the PMMA IOLs is limited due to the inability of folding. The Silicone IOL was used more often in the past due to it less convenient for precise incision, Acrylic is the most common material used for IOLs due to the foldable property. There are Many advanced IOL over the years [11], such as spherical IOL [12], aspherical IOL to correct the spherical correction in the previous one [13], multifocal IOL, which provide vision in near and distance vision [14,15], the difference in visual performance of using refractive IOL and Hybrid IOL [16]. The problem of suitable (IOLs) choice implanted within the eye was discussed previously [17]. These discussions are based on the Liou-Brennan eye model (LBEM) for the healthy eye. (LBEM) is considered as one of the best approximations of the healthy human eye [18,19]. The most important part of choosing the implanted IOLs lens is to provide the right image retinal quality. The (LBEM) parameters are given in Table 1 [20].

In this work, the crystal lens was replaced, individually, by two IOL of different material (different refractive index and dispersion). The lens radius of curvature, its thickness, and its conic are used as a degree of freedom to optimized and correct the image aberrations, particularly, the chromatic aberration correction.

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Table 1: (LBEM) parameters

IOL	Material	Index of refraction	* νb	front Radius (mm)	Thickness (mm)	Back Radius (mm)
P359UV	PMMA	1.493	57.4	15.00	1	-15.0
MA60BM	Acrylic	1.552	46.4	32.00	0.8	-15.0

The theoretical section extends the analytical background of the article and develops a new formulation of the problem. Calculations are achieved here using the developed equations and the modifications should be pointed out.

2. Materials and Methods

To estimate the quality of the retinal image formed by an eye with an implanted refractive IOLs, the model of the real human eye developed numerically by (LBEM) is used as a reference to compare and analyze the results. The (LBEM) supposed that the crystalline lens front and back surfaces are of gradient refractive indices. Equation (1) and (2) show the refractive index distribution in three dimensions; the (front and back) surface of a crystalline lens are given by [18]

For the front surface;

$$n_a(r,z) = 1.368 + 0.049057z - 0.015427z^2 - 0.001978\, r^2 \quad (1)$$

and for the back surface given by;

$$n_b(r,z) = 1.407 - 0.006605\, z^2 - 0.001978\, r^2 \quad (2)$$

Where (z, r) are the cylindrical coordinates with the z-axis is oriented along the visual axis of the model eye.

In this paper, two refractive intraocular lenses are designed; the parameters of the refractive lenses are presented in table 2 [20]. The refractive eye models used here are based on (LBEM) but with the replacement of the crystalline lens with two types of the IOL in its place P359UV (Bausch & Lomb) implant made of PMMA [21], AcrySoft MA60BM (Alcon) made of Acrylic [21,22].

The spectral sensitivity depends on the light wavelength in the human eye; it is important to take into account the proper weight function corresponding to photopic spectral sensitivity, the spectral sensitivity (0.07460, 0.4027, 0.8658, 0.4569, 0.0568) corresponding to wavelength (0.455, 0.505, 0.555, 0.605, 0.655) respectively [23]. The eye pupil diameter is 4 mm, with a 5-degree field of view.

3. Results and Discussions

The results of using refractive lenses of two different materials (PMMA and Acrylic) are presented by using Zemax software. The polychromatic PSFs of the healthy eye model with several IOLs are shown in Figure 1. The PSFs for all lenses are worse than the healthy eye (LBEM). The figure shows the Strehl ratio of LBEM (green), P359UV (blue), MA60BM (red) is equal to (0.812,0.195 and 0.378) respectively. These degradations in the Strehl ratio for the IOL lenses with respect to the Strehl ratio of LBEM have happened since all the IOL has spherical surface while LBEM was used aspherical surfaces to reduce the spherical aberration. The shift in the position of the image is caused for the asymmetric lens (MA60BM), while the symmetric lens image position is at the center of the image plane (0,0).

The polychromatic modulation transfer function (MTF) of the refractive lenses are represented in the figure3 its show that two IOLs are worse and curves go down compared with (LBEM) model of the healthy eye that means the image get by using these lenses suffer from blur and little of loss edge fidelity .its seen (MA60BM) is better than other and more contrast and resolution compared with other IOL.

The Longitudinal Chromatic Aberration (LchC) of the (LBEM) model is compared with the refractive intraocular lenses as presented in figure2. It is easy to see the(LchC) of the refractive IOLs within polychromatic wavelength range with 4mm entrance pupil diameter are greater than LchC of the healthy eye model. The magnitude of (LchC) for IOL has to be the same as the healthy eye due to its strong effect on the retinal image and on (accommodation process). The (LchC) for the Liou-Brennan model is equal to about 110µm, and for eyes with lenses made PMMA (P359UV), and Acrylic (MA60BM) are equal to about by(350, and 438)µm respectively. These variations in the LchC have belonged to the high refractive index for the crystal lens used in LBEM (n=1.59) compared with the other IOL refractive indices. The longitudinal chromatic aberration is reduced as the crystal lens power is decreased, and from the lens maker formula shown in equation (3)

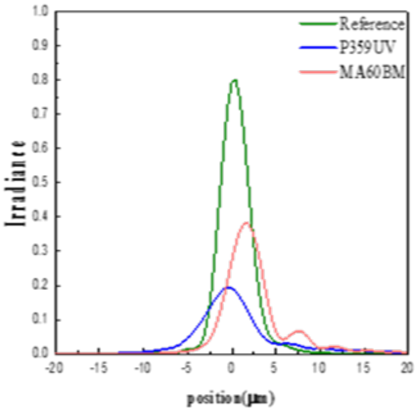
The polychromatic spot diagram of the LBEM eye model is presented in figure 4 with refractive IOLs (with its different materials). The root square (RMS) radius for the healthy eye and lenses made of PMMA and Acrylic are equal to about (2.191, 11.642, and 9.601) µm, respectively. Spot diagrams refer to the aberration effect on the image; the minimum value of the spot diagram refers to the value of the small aberration in the image.

$$\emptyset = (n_1 - 1)\left|\frac{1}{R_1} - \frac{1}{R_2}\right| \quad (3)$$

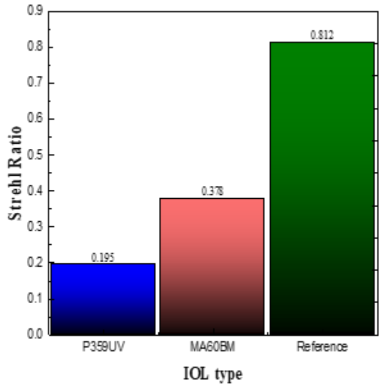
So LchC decreased with refractive index increment.

Table 2: Parameters of refractive intraocular lenses

Surface	Radius (mm)	Conic Constant	Thickness (mm)	Index of Refraction at 0.55um
Cornea	7.71	-0.8	0.50	1.376
Aqueous humor	6.40	-0.6	3.16	1.336
Front Crystalline lens	12.40	-0.94	1.59	$n_a(r,z)$
Back Crystalline lens	Infinity		2.43	np(r,z)
Vitreous body	-8.10	+0.94	16.27	1.336



(a)



(b)

*ν_b refers to the abbe number

Figure 1: a) point spread functions, b) Setrehl Ratio of the refractive IOLs compared with the healthy eye (LBEM) model

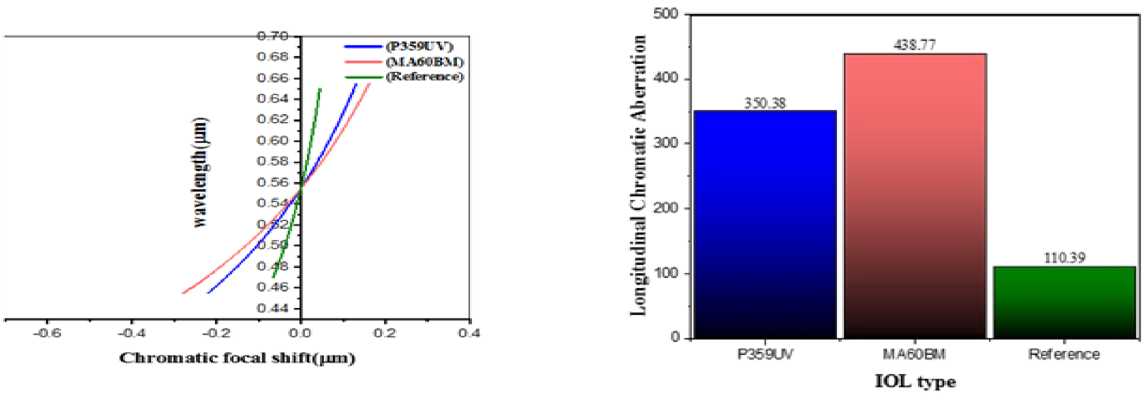


Figure 2: Longitudinal chromatic aberration (focal shift)

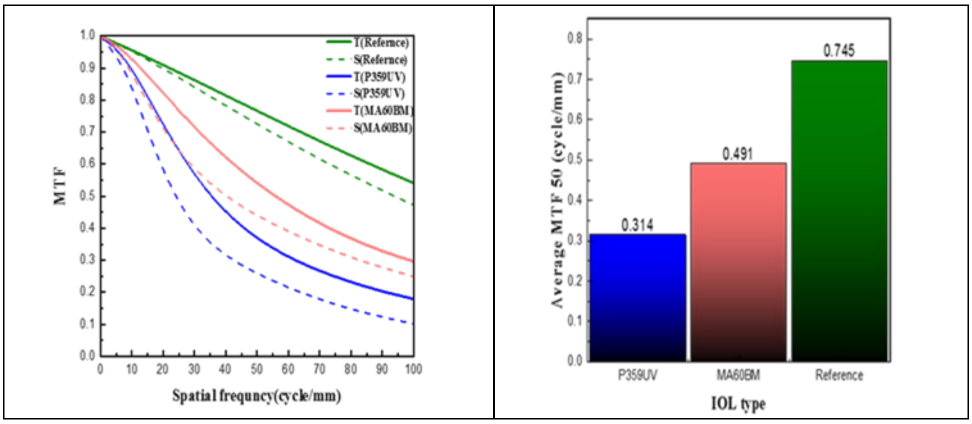


Figure 3: The modulation transfer function comparison between refractive lenses and (LBEM) model, The Average MTF at the spatial frequency (50 cycle/mm)

The energy accumulated by a lens in a circle at the image plane centered at the origin of the image is called the encircled energy. This criteria is important to measure the illumination at the eye retina. The large slop of the curve means a large amount of collected energy. Figure 5 shows that the image illumination with the healthy crystal eye is larger than the energies collected by the other IOLs.

The amount of monochromatic aberration coefficient (spherical, coma, astigmatism, the field of curvature, and distortion) are present in table 3, its show aberration coefficients for (LBEM) and the two refractive implanted IOLs (PMMA and Acrylic). The performance of these lenses is worse than the performance of a healthy eye because of the increase in the number of aberrations, as presented in Figure 6.

Table 3: amount of monochromatic aberration for the healthy eye (LBEM) and refractive IOLs

Liou model and IOLs type	Spherical aberration	Coma aberration	Astigmatism aberration	Field of curvature aberration	Distortion aberration	LchC
LBEM	0.5037	0.3363	0.1678	0.2627	0.1440	110.39
P359UV	1.7635	0.4384	0.4699	0.5859	0.2646	350.38
Acrysoft MA60BM	1.9701	0.1800		0.4722	0.5820	438.77

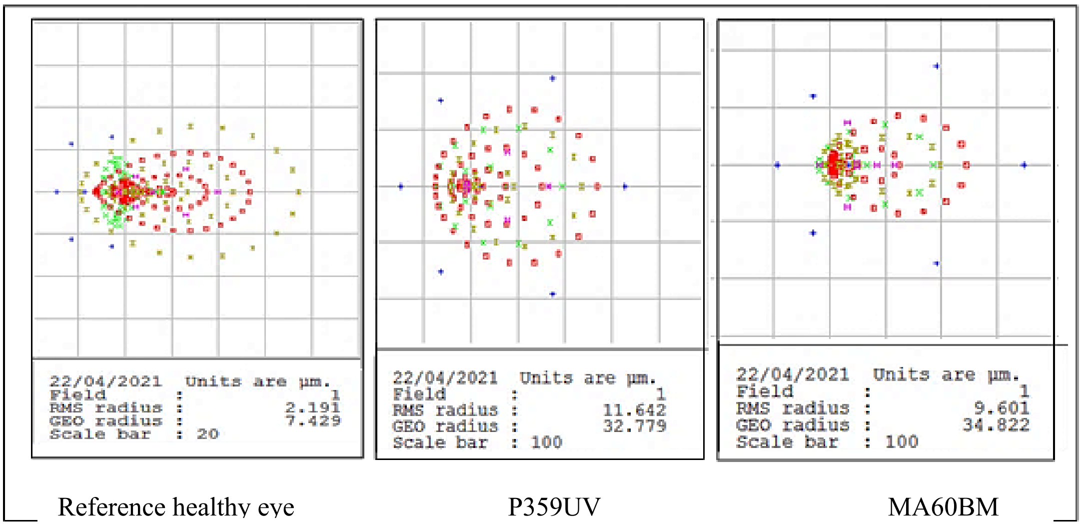


Figure 4: Polychromatic spot diagram for models' eye with refractive IOLs implanted

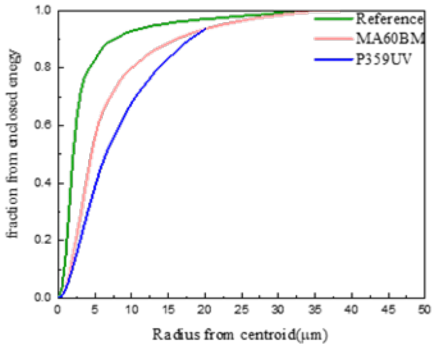


Figure 5: The encircled energy collected by the IOLs compared with the reference LBEM

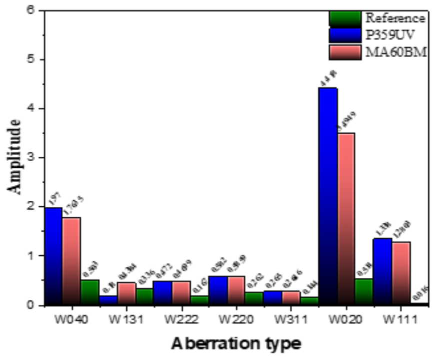


Figure 6: monochromatic aberration of (LBEM) and refractive IOL

4. Conclusions

The most effective treatment for cataracts is to remove the cloudy crystalline natural lens and implant an intraocular lens (IOL) in its place. These refractive (IOL) provide the same focusing as do the natural lens. Two different refractive IOLs were used in this work and compared with the result of the healthy eye as reference results. The analysis and comparison between the results are based on different criteria (MTF, PSF, LchC, and spot diagram) to describe the image quality for the healthy eye(LBEM) model and for the two artificial refractive IOLs made of(PMMA and Acrylic). The results indicate that all the IOLs do not improve the visual performance of the healthy eye performance since the refractive index for all the IOLs less than of the healthy eye. Also, the results indicate that the performance in Acrysoft MA60BM is better than the other IOL. The aberrations concerned with all IOLs are high and degrade the Strehl ratio and the MTF of the eye image. Chromatic aberration is a major parameter that affects polychromatic image quality.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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