Engineering and Technology Journal 40 (08) (2022)1029-1034

Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

The Visual Quality of Healthy Eye Lens for Different Tilt Effects

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HIGHLIGHTS

- Tilting beyond 5 degrees worsens vision.
- Increased tilt increases visual aberration.
- Study of tilt tolerance increases treatment accuracy.

ARTICLE INFO

Handling editor: Ivan A. Hashim
Keywords:
Tilt
Tolerance area
RMS spot size
Modulation Transfer Function (MTF)

ABSTRACT

The importance and accuracy of the human visual system have led scientists and researchers to do their best to study it, know its problems, and how to treat them. The eye lens tilt is possibly due to a specific accident such as a blow or the like. So, this manuscript was submitted to study the human eye lens tilting effect on visual performance and determine the tolerance tilt values. Using (ZEMAX-EE) software program and relying on the Liou and Brennan model Eye (LBME), one of the most accurate models for studying the eye, and some basic criteria used to describe the image formed in an optical system, such as Modulation Transfer Function (MTF), Root Main Square-spot size (RMSS), and simulated image including aberration, the study of the lens tilt effect on visual quality was conducted. The calculation of the area under the MTF curve was also used to determine the tolerance tilt values. Where the lens was tilted from (-5 to 5) degrees by (1 degree) on the (X and Y) axes, for zero decentering, with visible wavelength (0.486, 0.587, 0.656) µm, pupil diameter (2.5 mm), and field of view (5^o).The results were that vision worsened when the lens was tilted due to reduced MTF. Sagittal MTF was less sensitive than Tangential due to the nature of the lens structure. The area under the MTF curve results also proved that the tilt is less than (5) degrees does not affect the visual much, so it was necessary to determine the tilt tolerance values.It was concluded that the visual quality was inversely proportional to the tilt increase. Exceeding the tilt (5) degrees led to visual deterioration due to increased optical aberration where the tolerance tilt ranges were (± 5.1) degrees and (- 5.9 to 9) degrees on the (x and y) axes, respectively.

1. Introduction

Any problem, even a small one that occurs in the visual system represented by the eye, leads to problems with the visual performance due to the infinite precision of this system [1]. The crystalline lens is one of the eye's main parts that collect the light coming from the cornea and focuses it on the retina to form the clearest image [2]. Its center is a fibrous gel, which is gradual towards the edges [3]. The most important characteristic is the refractive index, which ranges between 1.420 in the middle and 1.383 at the edges [4]. The lens is connected to the ciliary muscle through ligaments to be fixed in place [5]. The wavefront of the retinal image depends on the precise alignment of the visual elements, so it is very important to evaluate the tilt effect on visual performance [6]. The tilt represents the angle between the optical element and the optical axis [7], see figure (1), [8], and it appears in the eye as a result of a specific disease or accident [9]. So any deviation of the lens causes a change in the light direction and thus a decrease in vision [10] due to the optical aberration appearance (spherical, coma, astigmatism, and defocus) [11]. There is a very close relationship between the tilt effect and the lens design and the amount of its aberration [12]. Many clinical studies [13, 14, 15] and engineering [16] were presented to study the tilt effect on many optical elements such as contact lenses [17], implantable lenses [18], and the pupil as well [18].

Where (Ali H. Al-Hamdani et al.) made an electro-optic design to test the tilt and decenter, depending on the Liou and Brennan model Eye (LBME) and the use of pupillary aperture (3 and 4.5) mm. They concluded that tilt and decentration

http://doi.org/10.30684/etj.v40i8.2197
Received 28 May 2021; Accepted 16 August 2021; Available online 20 May 2022
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showed high image deterioration in aberration corrective lenses [20]. Also (Pe´rez-Gracia J et al.) presented a study on the relationship between vision and tilt of an implanted aspherical lens. They proved that tilt increased wavefront errors due to increased optical aberration [21].

This work includes a study on the crystalline lens tilt effect in the eye on the visual quality and retinal image contrast and knowing the acceptable tilt range depending on the area under the MTF curve, as the image is not affected much at the tilt values within the permittivity space. Still, it is greatly affected when passing these values.

2. Method

To study and analyze the eye lens tilt effect on the retinal image quality, the design software (ZEMAX-EE) was used, depending on the Liou and Brennan model Eye (LBME), which is considered one of the most accurate models [22], with the parameters mentioned in Table 1:

Table 1: Optical design data of the LBME [23]

Surf: Type		Comment	Radius (mm)	Thickness (mm)	Glass	Semi-Diameter		Conic
OBJ	standard	Object	Infinity	1.00E+009		8.749E+007		0.000
1	standard	Input beam	Infinity	20.000		1.978	U	0.000
2	standard	Cornea	7.770	0.550	1.38, 50.2	5.000	U	-0.180
3	standard	Aqueous	6.400	3.160	1.34, 50.2	5.000	U	-0.600
4	standard	Pupil	Infinity	0.000		1.250	U	0.000
5	Gradient 3	Lens-front	12.400	1.590		5.000	U	-1.086
6	Gradient 3	Lens- back	Infinity	2.430		5.000	U	-1.086
7	standard	Vitreous	-8.100	16.238	1.34, 50.2	5.000	U	0.960
IMA	standard	Retina	-12.000	-		5.000	U	0.000

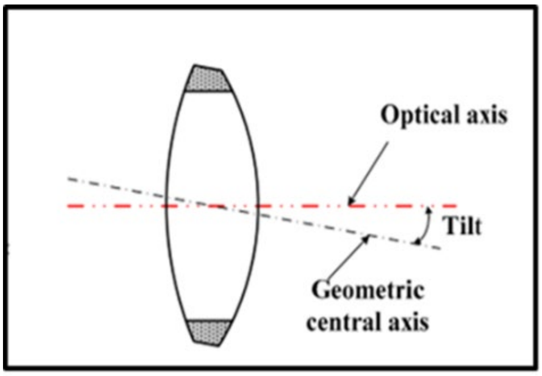


Figure 1: the concept of lens tilting around the optical axis [8]

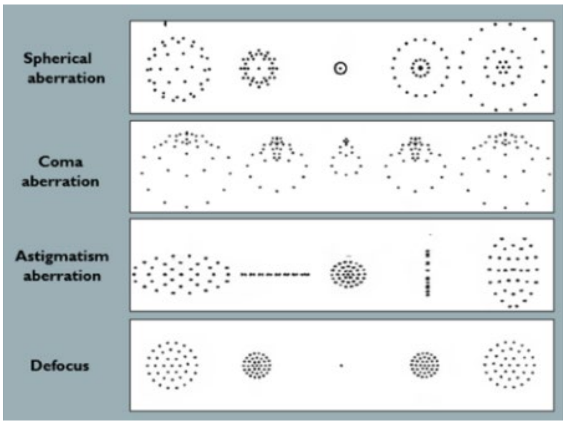


Figure 2: Types of aberration appear in RMS spot size [26]

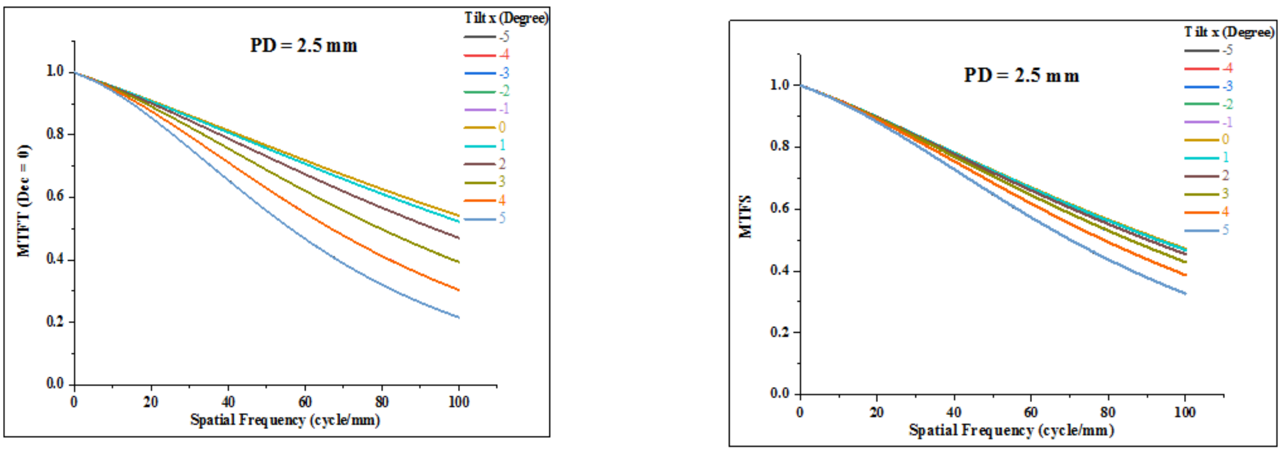


Figure 3: The MTF of eye lens with different tilt (-5 to 5) on X-axis; decenter =0.0, (a) MTFT, and (b) MTFS

Eye lens tilted from (-5 to 5) degrees, step (1 degree), on (X and Y) axes. The field of view (5º), pupil's diameter (2.5 mm), and visible wavelengths (0.486, 0.587, 0.656) µm were used.

Any optical system can be described and analyzed by the basic and important criteria as the Modulation Transfer Function (MTF) as in Eq. (1) [24].

$$MTF = \frac{I_{max}-I_{min}}{I_{max}+I_{min}} \quad (1)$$

Where (I_{max} and I_{min}) are the peak and irradiance of the sinusoid, respectively.

Because any optical system is exposed to the optical aberration problem, especially when some of its elements are tilted, as in this work, it was possible to rely on the root mean square spot size (RMSS) to analyze the image clarity and what will accompany the tilt process [15]. Where its shape-changing is according to the aberration type that appears in the image, as shown in the Figure (2) and Eq. (2) [25]

$$RMSS = \frac{\sqrt{(x_i-x_0)^2+(y_i-y_0)^2}}{n} \quad (2)$$

Where n is the total number of rays considered, (x_i and x_0), (y_i and y_0) are the reference points and the ray intersection points, respectively. Also, to simplify the calculations, the area under the MTF curve was used in eye image quality studies, as in Eq. (3) [6].

$$\text{Area}= \int_0^{100} MTF(vf)\, df \quad (3)$$

Where (v) is the spatial frequency (from 0 to100) cycle/mm, which is equivalent to (30 cycle/degree) and is considered the normal vision of the human eye, and (df) is the differential of the variable(f). There was a significant difference in mean visual acuity when the area under the curves differed by at least 25%, which is the tilt tolerance in the eye [27].

3. Results and dissuasion

The eye lens tilted on the (X and Y) axes, respectively, from (-5 to 5) degrees, step (1) degree for zero decentering. Figure (3) represents the tilt effect on the X-axis. Reading the Tangential (MTFT) and sagittal (MTFS), the similarity of the tilt effect between the negative and the positive directions was observed.

Although the tilt effect was not very significant within (± 5) degree, it was observed that MTF decreased with increasing tilt. But MTF decreased a lot when crossing this range, and the tolerance values proved this in the latter, see Figure (5).

Also, the sagittal MTF sensitivity was less than divergent, and this difference is due to the design nature of the eye lens. Figure (4) represents the tilt effect on the Y-axis. The tilt effect was asymmetric in the positive and negative directions. The tilt effect was so small that it appeared through the curves very close, especially in the positive direction. In contrast, the effect appeared large at the high tilt values (-4 and -5) degrees in the negative direction, so the MTF worsened a lot. It was also noted that the Sagittal and Tangential MTF sensitivity was different from the tilt values , which is as indicated due to the design of the lens. It is very necessary to determine the tolerance tilt values, and this helps a lot during the treatment to know the lens's maximum tilt so that it cannot be crossed; otherwise, this causes visual distortion and perhaps its absence, and this is shown in the figure (5)

In this figure, the area under the MTF curves was calculated using equation (3). The red dashed curve and the solid black curve represent the area under the MTFS and MTFT. The horizontal dashed green line represents the curved area of the eye at zero tilt. Figure (4 a and b) shows that this value was (76.808), and the area under the curve after the tilt (blue area between vertical black solid lines) is equal to (57.606), which accounts for 25% of the two regions (green and blue dashed lines).

Accordingly, the tolerance tilt range was (± 5.1) degrees and from (- 5.9 to 9) degrees on the (X and Y) axes, respectively. These values cannot be crossed because the image will deteriorate a lot or maybe be lost permanently. Figure (6) shows the reason for the MTF decreasing. The spot radius increasing indicated the defocus presence, which caused the image distortion. In addition, the spot shape-changing showed the optical aberration emergence, especially (coma and spherical) were two main reasons for the image deterioration and low contrast. Also, chromatic aberration appeared as a result of using polychromatic wavelengths, which reduced the visual quality.

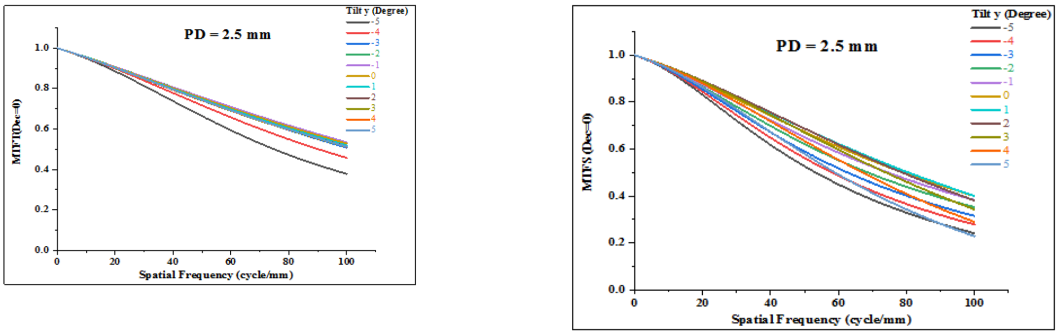
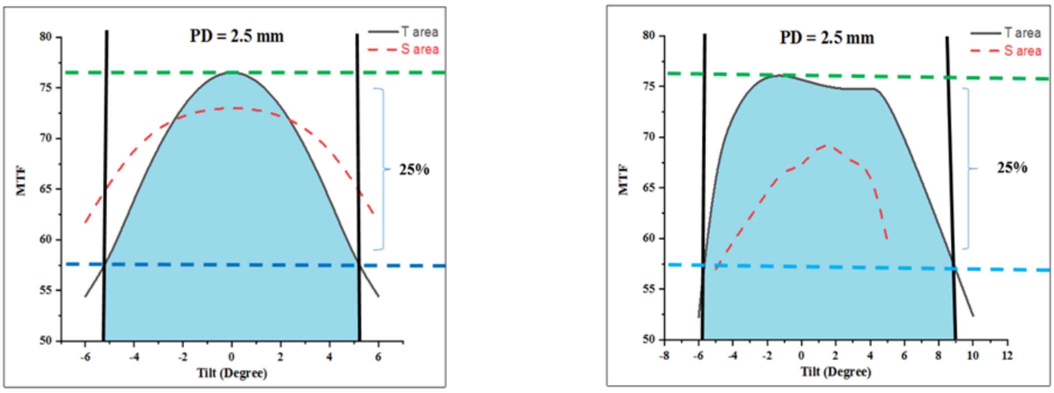


Figure 4: The MTF of eye lens with different tilt (-5 to 5) on Y-axis; decenter =0.0, (a) MTFT, and (b) MTFS



(a) **(b)**

Figure 5: MTFT and MTFS area of eye lens tilt, (a) on the X-axis, (b) on the Y-axis. The MTF area is shown with the Tangential MTF (black solid curve) and Sagittal MTF (red dashed curve). The MTF of the LBME without tilting (horizontal dashed green line) is plotted as a reference

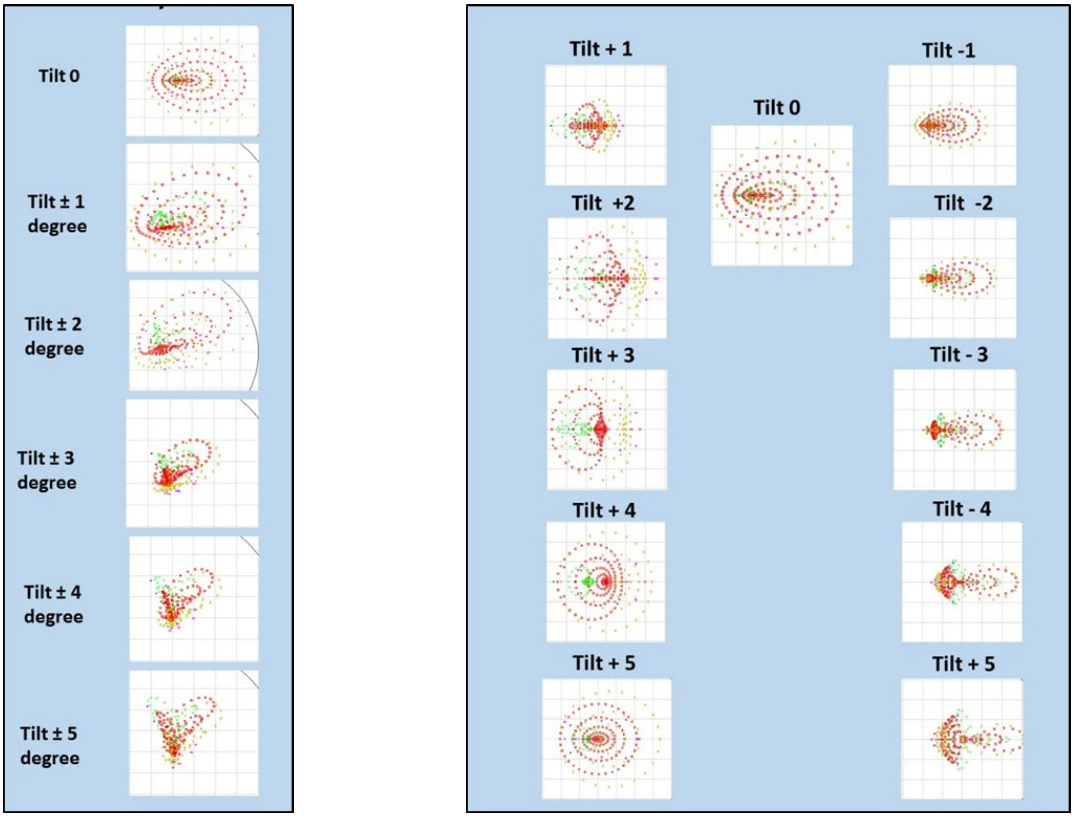


Figure 6: RMS spot size for tilt effect, (a) on X-axis and (b) on Y-axis

4. Conclusion

In this paper, the eye lens tilt effect was studied. The pupil diameter used was (2.5) mm, the field of view was 5º, and the wavelengths were (0.486, 0.587, 0.656) micrometers.

Tangential and Sagittal MTF were analyzed by the ZEMAX software program and depending on LBME. The conclusion was that the tilt effect on the eye lens was not great. But, this did not prevent the image from becoming bluer when it passed the tolerance ranges equal to (± 5.1) degrees on the X-axis and (- 5.9 to 9) degrees on the Y-axis. This is because of the optical aberration appearance, such as spherical and coma, and the chromatic aberration due to the use of polychromatic wavelengths. In addition, the defocus increment caused image distortion, and lack of clarity has the main role. It was observed by increasing the spot radius and changing its shape according to the optical aberration.

Author contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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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