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Designing of Progressive Lens to Remove Presbyopia of the Human Eye Using ZEMAX Program

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ABSTRACT: In this research, an optical system has been designed to simulate human eye, according to Liou & Brennan model, using ZEMAX program for optical systems. The same data of the human eye anatomy dimensions was adopted for the components of refraction coefficients such as lens, vitreous, retina, etc. A trifocal lens has been designed that positioned in front of the eye to correct presbyopia of eye vision. The simulation of object position, with appropriate positions and dimensions, was conducted to know resulted difference in the received image by the eye and the effect of optical defect on quality of the image. The progressive lens was used for correcting this defect through simulating eye accommodation for all used dimensions of the object by using a progressive surface in the lens appropriating with the distance of object to the lens. Modified Transfer Function (MTF), available by ZEMAX, has been adopted to evaluate the design efficiency and the variation magnitude occurred in the image before and after inserting the lens in front of the eye. The spot diagram showed that there was an obvious improvement in ray distribution after inserting the lens indicating decrement in the optical aberration then improvement in the image quality which was the purpose of lens use to remove the optical defect. The results showed increment in MTF magnitude at inserting the lens which explained increasing image contrast when spatial frequency increased.

KEYWORDS: Keywords: Progressive lens, presbyopia, human eye, ZEMAX

I. INTRODUCTION

Progressive lens is a corrective used in eyeglasses to correct presbyopia and other disturbance in eye accommodation. It characterized by a gradual increment in the lens power, in addition to correcting other refractive errors. Upon reaching the age of forty years, the natural process of aging starting to effect on vision in which the thickness of the eye lens enlarging and gradually losing flexibility then reaching a point where the focus on objects in the near vision was lost causing a presbyopia. Thus, it is natural that people who suffering presbyopia need to correct their vision by wearing progressive lenses. People often uses single vision lenses to correct this problem. Although it can provide a very good vision of the near areas, but people need to lens gives them a good vision of the far areas [1].

Progressive lens design and industry had occupied a wide interesting by specialists due to the thought virginity and the effect on optical defect correction to meet human needs for development of the design across the time in term the efficiency, shape and cost.

Edwards et al. had conducted an experiment to determine whether the use of progressive lens might gradually reduce myopia for Hong Kong children (7 – 10 years old) for two years [2]. The results, obtained by Sheedy showed that there were wide ranges of optical characteristics across progressive lens used in his study. He explained that near, intermediate and far vision as well as astigmatism evaluation could be used for appropriate lens selection to meet patients' optical needs [3].

Yang et al. used two groups of lenses: progressive lens had near vision of +1.5 D and single vision lens to evaluate their effect on gradual myopia for 178 Chinese children for two years study [4].

Andre study the characteristics of progressive lens, found that the evaluation of the progressive lens optical characteristics showed big differences in the general power and astigmatism distribution across lens designs indicating that some design probably were more suitable for certain patients according to their unique optical needs [5].

The study of Gwiazda et al. aimed to determine whether progressive lens to single vision lens had an ability to make myopia development slow for children suffering the high accommodation late that closed to strabismus [6].

II. PROGRESSIVE LENS

Bifocal lenses was invented in 1826 by J. I. Hokins, it consisted from two parts: the first for Intermediate vision with half addition, and the second for near vision with full addition. This type of lens was made by compact bifocal lenses technology. Easily, the equations, used to calculate the effect of image jump and lenses prismatic the trifocal lenses (Fig 1), were circulated. The major obstacles of trifocal lenses and annoying dividing lines were reduced so there are three areas in the trifocal lenses: the upper for the distant vision, the intermediate for the intermediate vision, and the lower for the near vision [7].

Fig 1: Trifocal Lens

III. THE POWER OF PROGRESSIVE LENSES

The values indicated in the sphere and cylinder columns of an eyeglass prescription specify the optical power of the lenses in diopters, abbreviated D. The higher the number of diopters, the more the lens refracts or bends light. A diopter is the reciprocal of the focal length in meters. If a lens has a focal length of 1⁄3 meters, it is a 3 diopter lens. A +10 diopter lens, which has a focal length of 10 centimeters, would make a good magnifying glass. Eyeglass lenses are usually much weaker, because eyeglasses do not work by magnifying; they work by correcting focus. A typical human eye without refractive error has a refractive power of approximately 60 diopters. Stacking lenses combines their power by simple addition of diopter strength, if their separation is negligible. A +1 diopter lens combined with a +2 diopter lens forms a +3 diopter system (Fig 2a) [8].

Lenses come in positive (plus) and negative (minus) powers. Given that a positive power lens will magnify an object and a negative power lens will make it look smaller, it is often possible to tell whether a lens is positive or negative by looking through it. Positive lenses caused light rays to converge and negative lenses caused light rays to diverge. A −2 lens combined with a +5 lens forms a +3 diopter system (Fig 2b). A −3 lens stacked on top of a +3 lens looks almost like flat glass, because the combined power is 0 (Fig 2c).

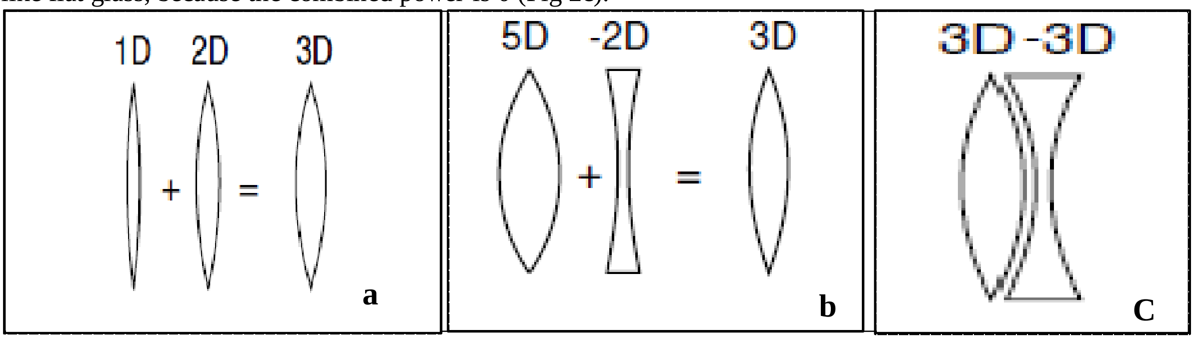

Fig 2: Lenses Combination

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In the case of an eyeglass lens, this means that the lens should be roughly shaped like a cup with the hollow side toward the eye, so most eyeglass lenses are menisci in shape. The most important characteristic of a lens is its principal focal length, or its inverse which is called the lens strength or lens power. The principal focal length of a lens is determined by the index of refraction of the glass, the radii of curvature of the surfaces and the medium in which the lens resides. For a thin double convex lens, all parallel rays will be focused to a point referred to as the focal length of the lens. For double concave lens where the rays are diverged, the principal focal length is the distance at which the back-projected rays would come together and it is given a negative sign. For a thick lens made from spherical surfaces, the focal distance will differ for different rays, and this change is called spherical aberration. The focal length for different wavelengths will also differ slightly, and this is called chromatic aberration [9].
To design a progressive lens, the optical power is one of two conclusive design parameters for optical engineers according to the patient property. In general, progressive lens optical power was determined by the shape of front and back surfaces with the material of the lens. In optics, optical power can be expressed according to the following equation [10]:

$$p = (1-n)^{p^b} + \frac{(n-1)^{p^f}}{1-d\left(1-\frac{1}{n}\right)p^f} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, p^b is the rate of back surface curvature, p^f is the rate of front surface curvature, d is lens thickness, and n is the refraction coefficient of the lens material.
Assuming that the lens is very thin, through making d=0 we obtain approximate formula:

$$p = (n-1)(p^f - p^b) \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

IV. Optical System Prototypes that Used in ZEMAX

In this study, a model of human eye was designed in ZEMAX according to Liou & Brennan [11] which was more modern and inclusive in which many real factors can be calculated that so difficult to be calculated by other models such as pupil balance, curved retina surface, pointing to the inner of eye ball, and crystalline lens with two different sections of progressive refraction index. After the successful design of human eye by ZEMAX, it will be used to design the free shape of progressive lens.

V. HUMAN EYE DESIGN

ZEMAX sequential ray-tracing was used to design the human eye due to it most appropriate. Wavelengths, used in the light source within vision rays, were inserted. Millimeter units were used for dimensions calculation. ZEMAX human eye design needs to insert 8 surfaces starting from Surface 0 to retina surface as the follow:

- **Surface 0** : In fact, this surface doesn’t fall in the lens editor as surface 0, but it calles as OBJ surface.
- **Surface 1** : The first surface (after the Object) is just a dummy plane, and we used it to make our layout drawings easier to understand.
- **Surface 2** : This is the outer cornea surface (Table 3). ZEMAX provide inserting any optical characteristics of specific material such as refraction coefficient if not inserted in the library of the program.
- **Surface 3** : This is the interface between the cornea and the aqueous humor in which the last coefficient (Conic) indicating aspherical surfaces (parabola, hyperbola, or ellipse), its value of 0 for spherical surface and ≠0 for aspherical surface.
- **Surface 4** : This surface is not actually labeled surface 4 in the ZEMAX lens data editor, it is labeled "STO" and it's the aperture stop of the system. This is our eye model's pupil plane.
- **Surface 5** : This is the interior (front) portion of our model's crystalline lens The surface type "gradient 3", which provided by ZEMAX, was used. Gradient 3 simulates the eye lens which has gradient refraction coefficient.
- **Surface 6 :** This is the posterior (rear) portion of our model's crystalline lens
- **Surface 7** : This is the rear surface of the crystalline lens (that is, it is the interface between the crystalline lens and the vitreous body of the eye)
- **Surface 8** : This surface is not actually labeled surface 8 in the ZEMAX lens data editor, it's labeled 'IMA" and it's the image surface and the retina of our model

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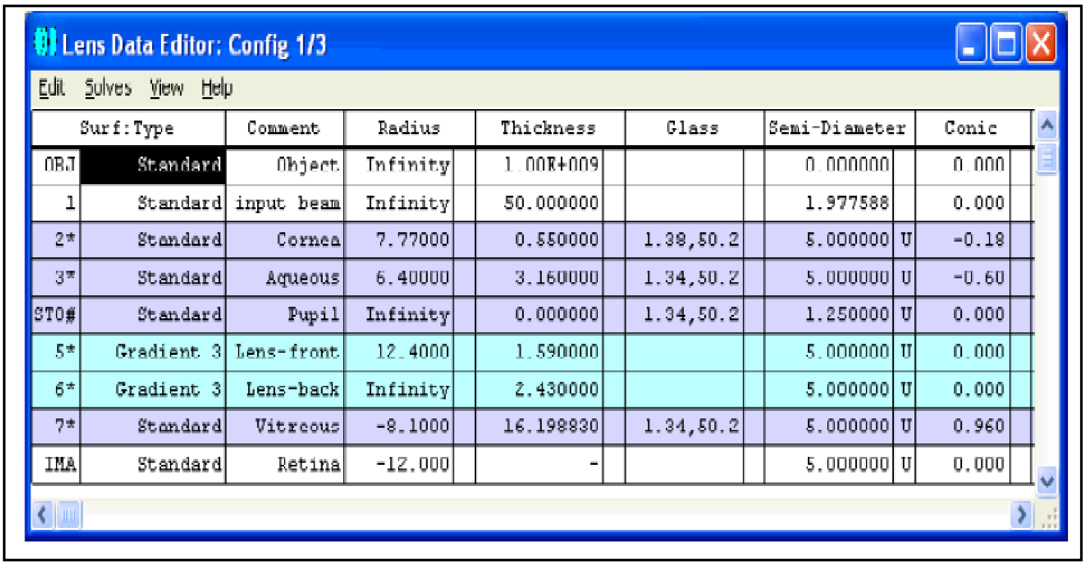
After inserting the surfaces of eye design, the Lens Data Editor is as it shown in Fig 3:



Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter		Conic
OBJ	Standard	Object	Infinity	1.00E+009		0.000000		0.000
1	Standard	input beam	Infinity	50.000000		1.977588		0.000
2*	Standard	Cornea	7.77000	0.550000	1.38,50.2	5.000000	U	-0.18
3*	Standard	Aqueous	6.40000	3.160000	1.34,50.2	5.000000	U	-0.60
STO#	Standard	Pupil	Infinity	0.000000	1.34,50.2	1.250000	U	0.000
5*	Gradient 3	Lens-front	12.4000	1.590000		5.000000	U	0.000
6*	Gradient 3	Lens-back	Infinity	2.430000		5.000000	U	0.000
7*	Standard	Vitreous	-8.1000	16.198830	1.34,50.2	5.000000	U	0.960
IMA	Standard	Retina	-12.000	-		5.000000	U	0.000

Fig 3: Lens Data Editor

VI. PROGRESSIVE LENS DESIGN

At this point, with a good human eye model set up in ZEMAX, it's possible to add external elements to the design. We will be designing a Progressive Addition Lens (PAL) and we'll start by adding an eyeglass to the front of our model. We'll optimize this PAL to provide good imaging for near, midrange, and far objects. To ensure a realistic modeling of the eye's movement as the "patient" moves his eye up and down, we will want to keep the eyeglass in place, and have the eye model rotate about its center. That is, we will have to place a coordinate break at the center of the eyeball, and then have the entire eye model rotate about this point. To do this, we first place the eyeglass lens into the Lens Data Editor (LDE), and then we will move forward an appropriate amount of thickness to get to the center of the eye.
First, insert three surfaces between the input beam (Surface 1) and the Cornea (Surface 2). These three surfaces will represent the front and rear surfaces of the eye glass lens, and a coordinate break to tilt the eye. You'll notice that we've chosen to place the eyeglass lens 15 mm from the eye. This way, the eye will rotate about its center, in way that mimics the actual motion of a human eye. Below is a guide to setting up these three new surfaces.

- **Surface 2** : This is the front surface of the eyeglass lens .
- **Surface 3** : This is the rear surface of the eyeglass lens .
- **Surface 4** : This is the coordinate break located at the center of the eyeball .

To design this kind of lenses, we add a couple of new configurations. Open the Multi Configuration Editor (MCE), and hit Ctrl Shift Insert twice. There should be nine empty cells in the MCE. We're going to make the first Configuration represent the eye looking straight ahead through the lens, at an object located faraway. The second Configuration will represent the eye looking slightly down through the lens, at midrange object. Finally, the third Configuration will represent the eye looking far down, at very near object.
Changing the object distance is handled with THIC operand (changing the thickness of surface 0) and changing the eye's up down angle is handled by changing the Tilt bout X. We have set the eyeball so that it rotates in a realistic manner. Figure 4 showed that the eyeglass lens staying in place, while the eyeball rotates.

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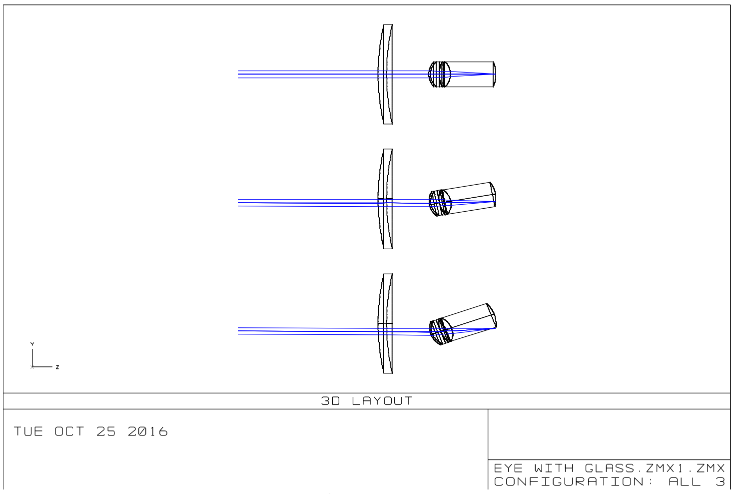

Fig. 4: Trifocal Lens Design

VII. RESULTS

Polycarbonate material was inserted in this kind of lenses to evaluate the performance of this material as well as many techniques were used to evaluate the design of progressive lens such as Spot Diagram, Modified Transfer Function (MTF), Fan-Ray Aberration, and Image analysis due to these techniques are the optimal to give inclusive thought on image quality by different pathways, and give a graphic digital and visual evaluation of image quality formed on the retina before and after inserting the lens. A comparison among the previous criteria, before and after inserting lens, were conducted to evaluate the performance of designed lenses to reach the optimum values of design data.

This kind of lenses contains three visual fields: far, intermediate, and near field. These type of lenses was tested using spot diagram, MTF, fan-ray aberration, and image analysis to evaluate the effect of using trifocal lens to correct the eye optical defect. Polycarbonate material was inserted into lens design and evaluated using the previous evaluation pathways and to know the effect of the lens to correct the optical defect as the follow:

Fig. (5), (6), and (7) show the evaluation of far, intermediate, and near visual field, respectively, using spot diagram before and after the trifocal lens. A bad image can be seen through diffusion of points in a large amount out of airy disk before inserting the lens (a), while the good quality of image can be seen through gathering these points inside the airy disk after inserting the lens (b).

Fig. (8), (9), and (10) showed the evaluation of far, intermediate, and near visual field, respectively, using Modified Transfer Function MTF before and after inserting the trifocal lens. The image had a good quality through increased value of graphic line in case of inserting the lens (b) compared with the absence of the lens (a), and this will confirmed the modification of image in term of contrast and clarity.

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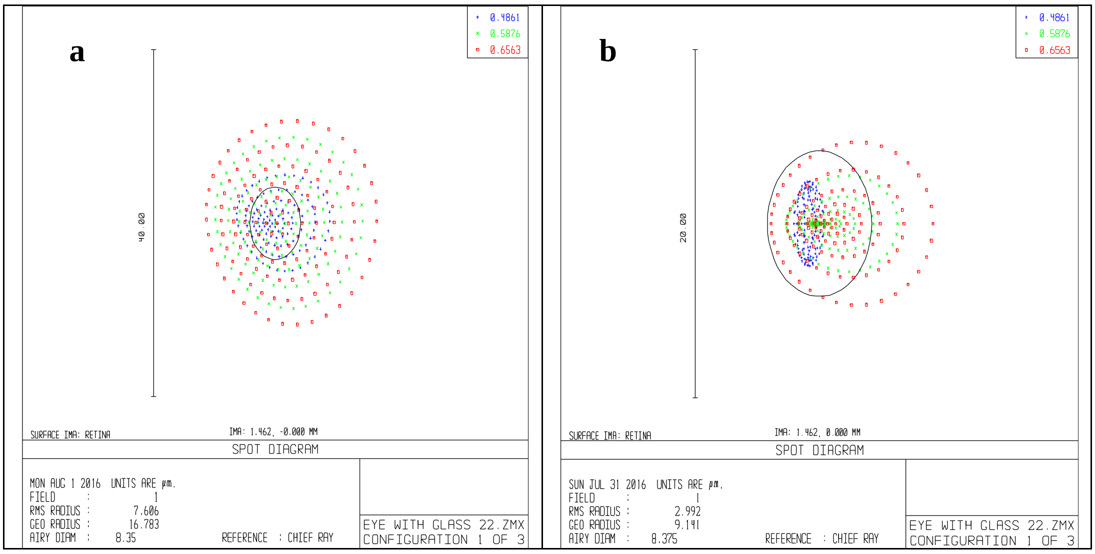

Fig. (5): Spot diagram of far field vision (a: before, b: after the lens insertion respectively)

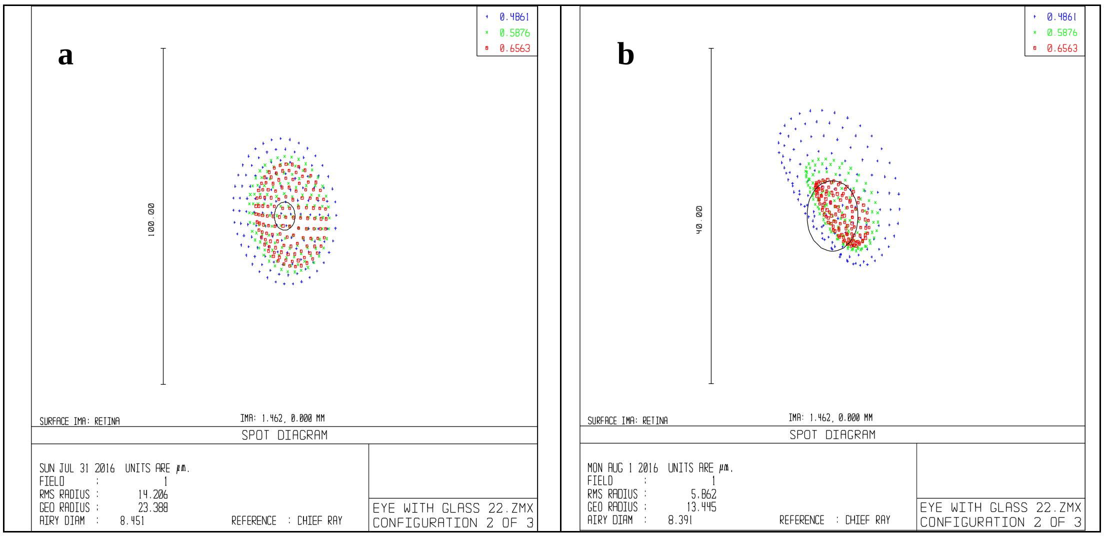

Fig. (6): Spot diagram of intermediate field vision (a: before, b: after the lens insertion respectively)

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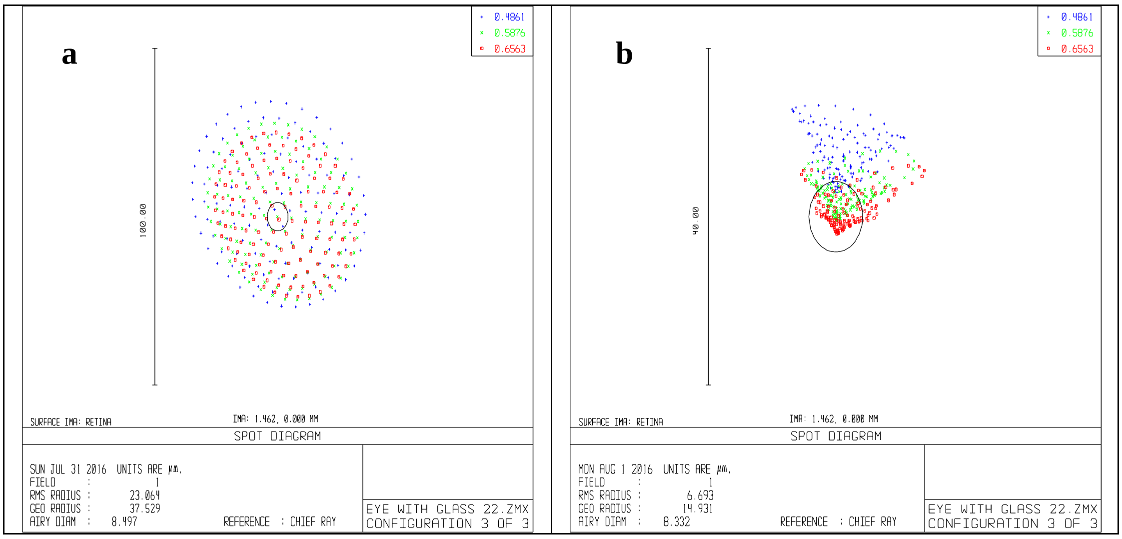

Fig. (7): Spot diagram of near field vision (a: before, b: after the lens insertion respectively)

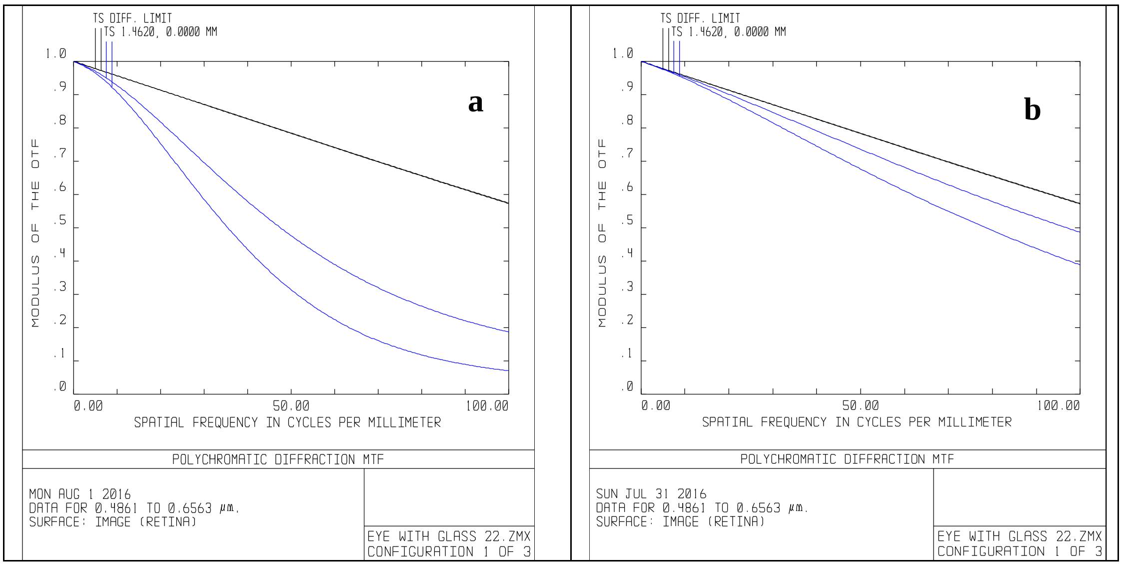

Fig. (8): MTF of far field vision (a: before, b: after the lens insertion respectively)

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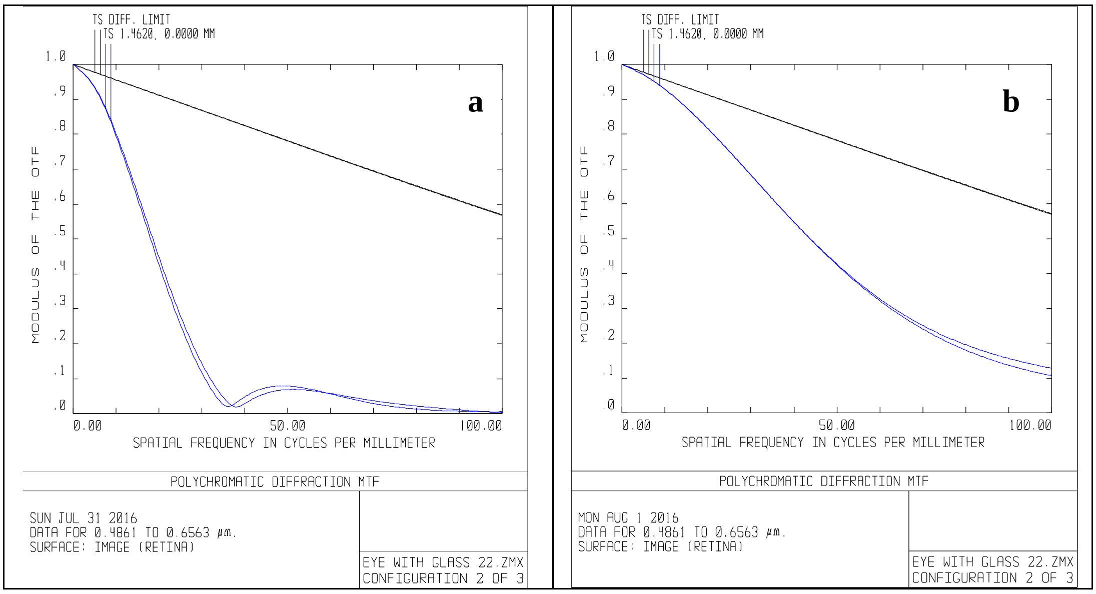

Fig. (9): MTF of intermediate field vision (a: before, b: after the lens insertion respectively)

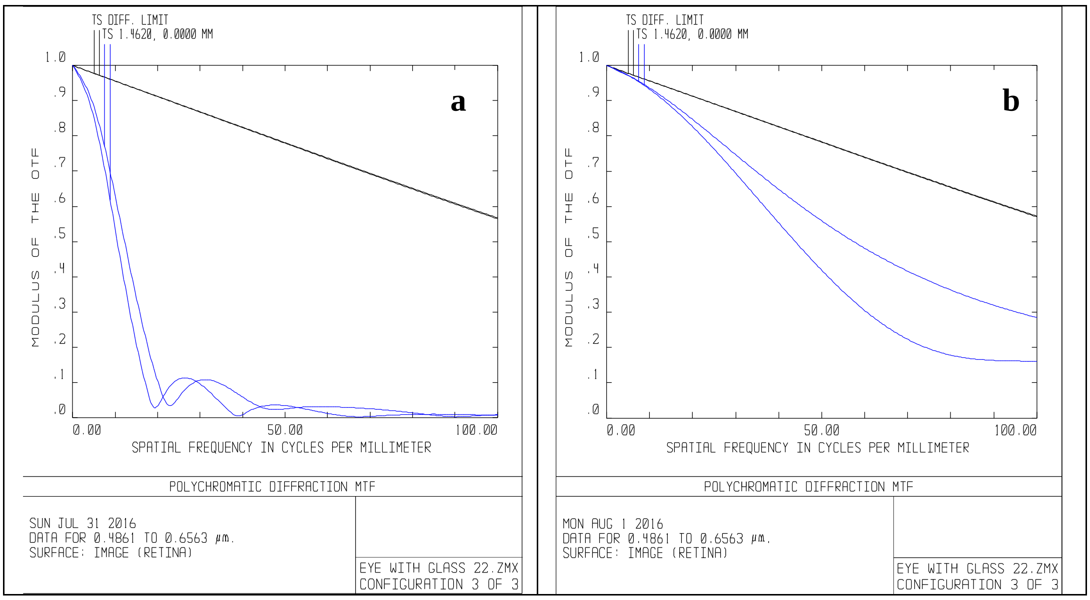

Fig. (10): MTF of near field vision (a: before, b: after the lens insertion respectively)

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VIII. CONCLUSION

We have obtained an improvement in optical system that represented by human eye when using attachment element (progressive lens), which has improvement in ray distribution of spot diagram and image contrast of modified transfer function (MTF).

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