Optical modeling and analysis of polyurethane lens for correcting presbyopia by using Zemax program

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النمذجة البصرية وتحليل عدسة البولي يوريثان لتصحيح طول النظر الشيخوخي باستخدام برنامج زيماكس

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Abstract

This study aims to design an optical system based on the model of Liu & Brennan by using Zemax EE2006 program. This model was selected because it more accurately reflects anatomical and visual data as compared to the physiological eye model. Polyurethane lens (Pu) is designed for patients with presbyopia patients by using multi-configuration function in Zemax. According to human eye structure, three distances were defined, namely, far (10.0^{+09}mm), middle (1000mm), and near (500mm), to simulate the position of the body, investigate the difference in image received by the eye, and determine the effect of visual defect on image quality. Several techniques have been adopted in the Zemax program to evaluate the visual design efficiency and the magnitude of the difference in the image before and after lens insertion. Results showed that bi-focal polyurethane lens exhibited good performance for far and intermediate distances.

Keywords: Polyurethane lens, presbyopia, Zemax optical design, Human eye simulation.

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الخلاصة:

تهدف هذه الدراسة إلى تصميم نظام بصري يعتمد على نموذج ليو وبرينان باستخدام برنامج زيماكس EE2006. تم اختيار هذا النموذج لأنه يعكس بشكل أكثر دقة البيانات التشريحية والبصرية بالمقارنة مع نموذج العين الفسيولوجية. تم تصميم عدسة البولي يوريثان (Pu) للمرضى الذين يعانون من مرض طول النظر الشيخوخي باستخدام وظيفة متعددة التكوين في زيماكس. وفقا لبنية العين البشرية، تم تحديد ثلاث مسافات، وهي بعيدة (10.0^{+09}ملم)، والمتوسطة (1000ملم)، وقرب (500 ملم)، لمحاكاة موقع الجسم، والتحقيق في الفرق في الصورة التي تلقاها العين، و تحديد تأثير الخلل البصري على جودة الصورة. وقد اعتمدت العديد من التقنيات في برنامج زيماكس لتقييم كفاءة التصميم البصري وحجم الفرق في الصورة قبل وبعد العدسة الإدراج. وأظهرت النتائج أن عدسة البولي يوريثان ثنائية البؤرة اظهرت الأداء الجيد للمسافات البعيدة والمتوسطة.

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1. Introduction

Refractive errors are vision problems that occur when the shape of the eye prevents light from focusing directly on the retina. Other factors causing refractive errors are length of the eyeball (longer or shorter), changes in the shape of the cornea, and aging of the lens. The most common types of refractive error can be corrected using glasses, contact lenses, or refractive surgery [1]. Presbyopia (aging of the eye, loss of near vision with age), another type of postopia, is associated with aging of the eye and often leads to gradual deterioration in the ability to focus clearly on nearby objects [2]. Hardening of the eye lens causes the eye to focus light back rather than focusing on the retina while looking at nearby objects; the lens cannot change the shape to allow the eye to focus on nearby objects because the housing strength of the eye decreases with aging [3]. In general, the length of puberty usually begins after age 40. Our lenses can change shape easily when we are young but becomes less flexible after the age of 40 [4]. This phenomenon is due to the progressive weakening of the ciliary muscles and diminished elasticity of the crystal lens [2], as shown in (Fig.1) **.**
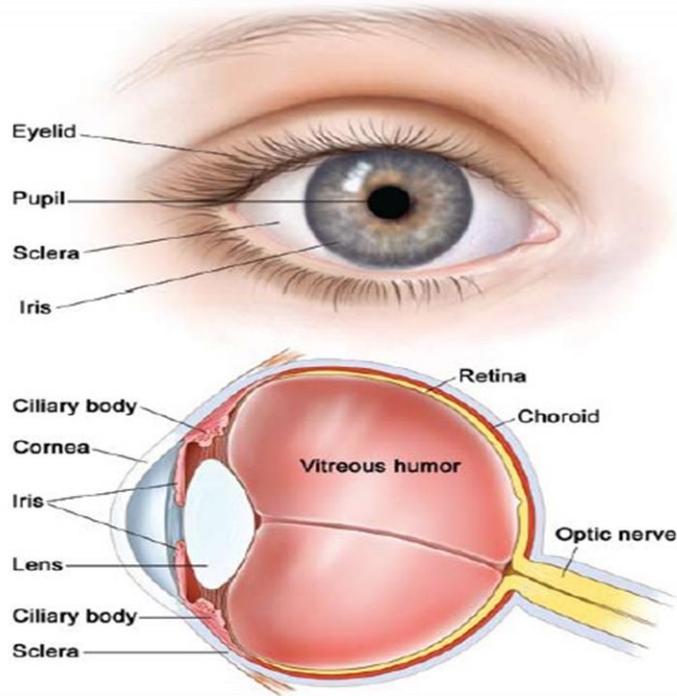
Figure (3): The structure of the eye [5].

The use of glasses is the simplest, safest, least expensive, and the most common method for correcting refrective errors [6]. Medical lenses were classified as follows: the type of materials used, refractive index, color (fixed or variable), and focality (single or multi-focal) [7]. Lenses are used to improve the vision of the eye by bending the light inside the eye to correct refractive errors. Concave lens with a single-focal negative force is used to correct myopia (nearsightedness); this kind of lens is thin in the center and thicker on the edges, thereby diffusing light rays and allowing the lens of the eye to focus directly on the retina. Convex lens with a positive refractive force is used to correct the hyperopia (far-sightedness) because the lens is thick in the center and thinn on the outer edges. This kind of lens converges (concentrates) light rays so that the eye lens can focus on the retina [8]. Simple reading glasses with convex lenses can correct most cases of presbyopia; meanwhile, multifocal lenses are used for individuals suffering from both myopia and hypermetropia. In the multi-focal lens the top part is a concave lens used for distant vision, and the bottom part is a convex lens that can be used for reading [9].

The typical human eye without refractive error has a refractive capacity of about 60 diopters [10]. The force of the lens is measured in optical units called the diopter. This estimation demonstrates how much refractive force the lens must have to focus images directly on the retina; that is, high diopter indicates strong lens [11]. The force of the lens is reciprocal of its focal length and expressed in the equation below [12].

$$\varphi = \frac{1}{F} = (N - 1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(N-1)T}{N\,R_1 R_2}\right] \qquad \qquad \ldots(1)$$

Where: R_1 and R_2 are the radii of the first and second surfaces, respectively;
 T is the thickness of the lens;
and N is the refractive index of the lens material.

2.Optical System Design

The human eye model is established by placing Zemax into Sequential mode, which is the preferred for designing imaging systems, or any system requiring optimization and detailed image analysis. Wavelengths are set within visible rays, and the dimensions used are in millimeter units. The design of the human eye model in Zemax requires eight surfaces starting from the   object surface (Surface 0) to the surface of the retina (image surface) as shown below:

Surface 0: This surface represent the object surface and is labeled "OBJ" in the Zemax Lens Data Editor.

Surface 1: The first surface (after the object) is a dummy plane that represents the input beam.

Surface 2: This is the outer cornea surface.

Surface 3: This surface represents the area between the cornea and the glass liquid.

Surface 4: This surface is labeled "STO" in the Zemax Lens Data Editor and is pupil plane of our eye model's

Surface5: This is the front part of the crystalline lens of our model. We use a surface type (gradient 3) provided by the program Zemax .

Surface 6:This is the back part of our model's crystalline lens.

Surface 7: This Surface represents the interface between the lens and the vitreous body of the eye.

Surface 8: This Surface is labeled "IMA" in the Zemax Lens Data Editor and is the retina of our model.

Based on the eye model of Liou & Brennan (1997) [13], at this point the Lens Data Editor is shown in the figure below:

Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter	
OBJ	Standard	OBJECT	Infinity	1.000000E+009		8.390997E+008	
1	Standard	INPUT BEAM	Infinity	50.000000		1.977588	U
2*	Standard	CORNEA	7.770000	0.550000	1.38,50.2	5.000000	U
3*	Standard	AQUEOUS	6.400000	3.160000	1.34,50.2	5.000000	U
STO#	Standard	PUPIL	Infinity	0.000000	1.34,50.2	1.250000	U
5*	Gradient 3	LENS-FRONT	12.400000	1.590000		5.000000	U
6*	Gradient 3	LENS-BACK	Infinity	2.430000		5.000000	U
7*	Standard	VITREOUS	-8.100000	16.238830	1.34,50.2	5.000000	U
IMA	Standard	RETINA	-12.000000	-		5.000000	U

Figure (2): Optical data of eye model in Zemax optical design software

The 3D Layout of the system is checked, Now, where the first Surface is set to Surface 1(input beam) instead of Surface 0, as the figure (3).
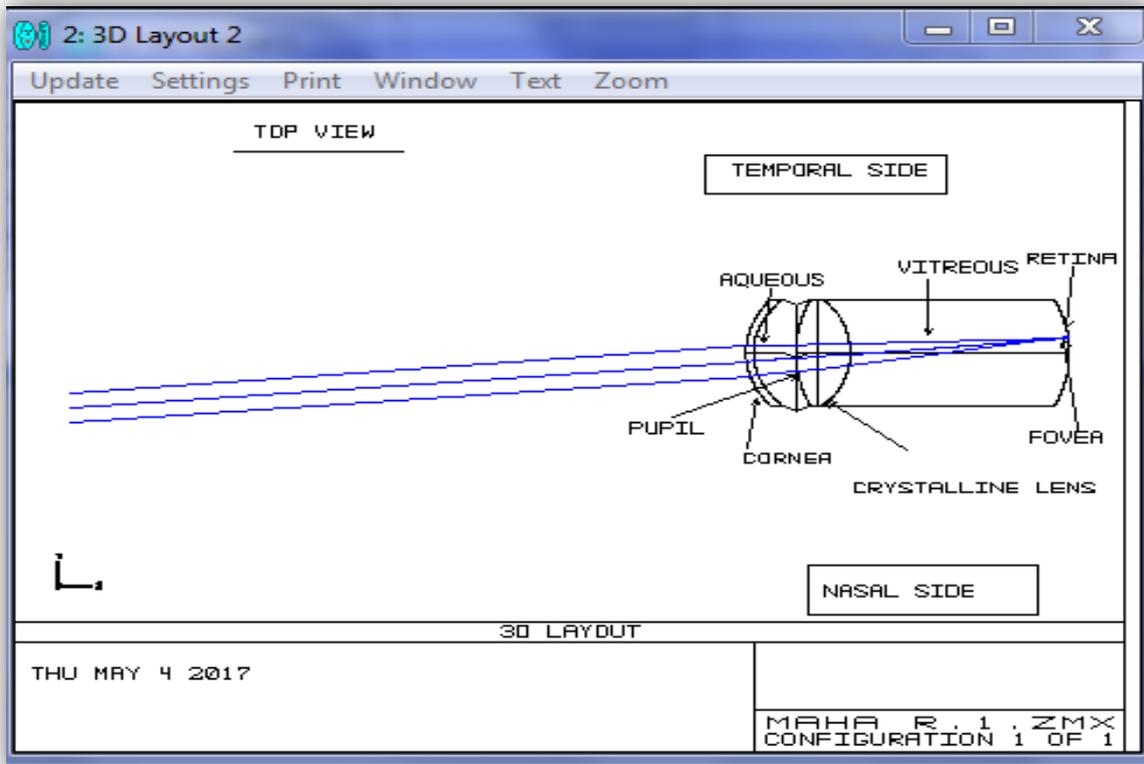

Figure (3): 3D Layout

After successfully designing the eye model in Zemax, it was used to design an eyeglass lens for patients with Presbyopia by using the multi-configuration function in the Zemax optical design program. An eyeglass lens is designed by adding lens to the front of our model and optimize to provide good imaging for, near, middle, and far objects. Thus three surfaces between the Input Beam and the Cornea is inserted. These three surfaces will exemplify the front and rear surfaces of the eyeglass lens, and a coordinate break to tilt the eye below the three new surfaces.

Surface 1 of eyeglass lens: This is the front surface of the eyeglass lens.

Surface 2 eyeglass lens: This is the rear surface of the eyeglass lens.

Surface 3 eyeglass lens: This is the coordinate break placed at the center of the eyeball.

The 3D Layout is rapidly checked to present the side view of the system for the three(far, middle, and object distances), as shown in figure(4).
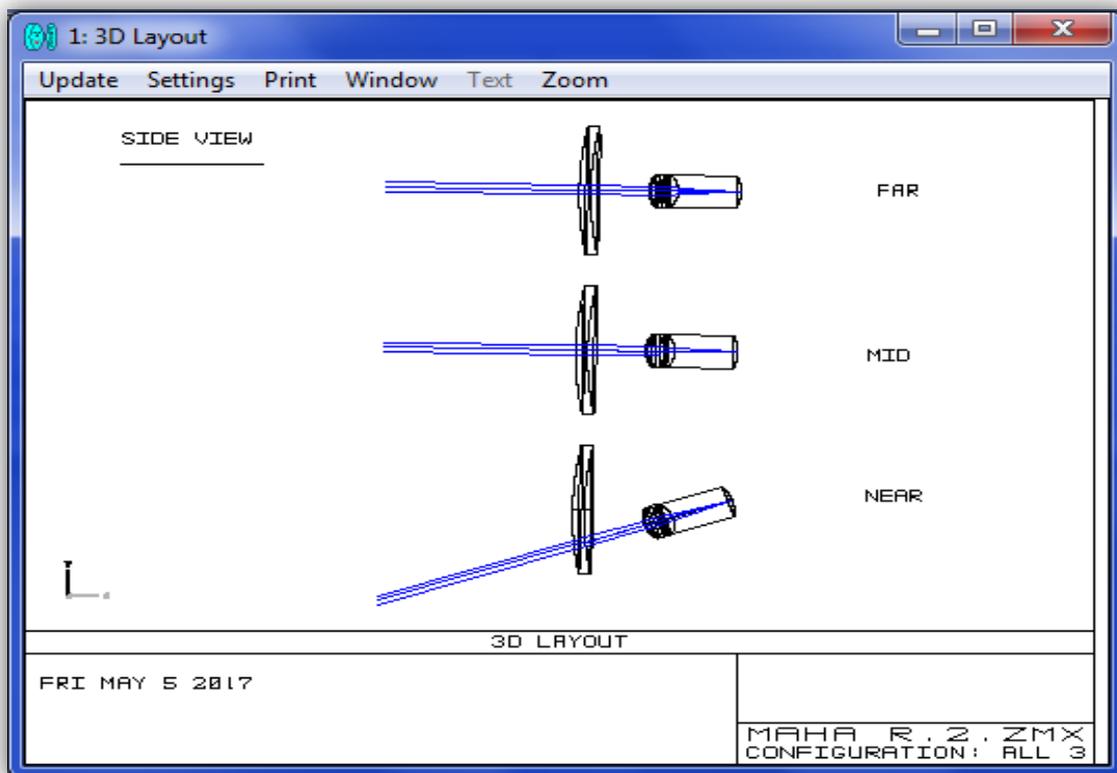

Figure (4): 3D Layout of Trifocal Lens

3. Result and Analysis

The spot diagram for the far, intermediate and near visual range are shown in figures (5), (6), (7) respectively. Which refer to the distribution of points for the wavelength used in the retina affected before and after insertion the Pu lens. Show that the RMS value after inserting Pu lens is less than the RMS radius without Pu lens. Hence, Pu lens improve the human eye performance and reduce the spot size. The results also showed that our design with Pu is suitable for far and middle object distances.

Figures (8), (9), (10) show The MTF plot of the far, intermediate and near distances respectively with and without Pu lens. The contrast, after inserting Pu lens is larger than that without lens for far and intermediate distance.

From figures (11), (12), (13) show that the image designate with and without the Pu lens is clearer than the image before placing the lens, the far distance is clearer than the image in the other distances.

4. Conclusion

The spot diagram indicated that the beam distribution improves after lens insertion, resulting in decrease in optical deviation, reduced aberration and improved image quality. The inclusion function showed an increase in the amount of function after lens insertion, indicating that the picture contrast increases with increasing spatial frequency. The results showed the effect of lens insertion on correcting the vision of the affected eye by obtaining a clearer picture, in contrast to the blurry image before lens insertion.

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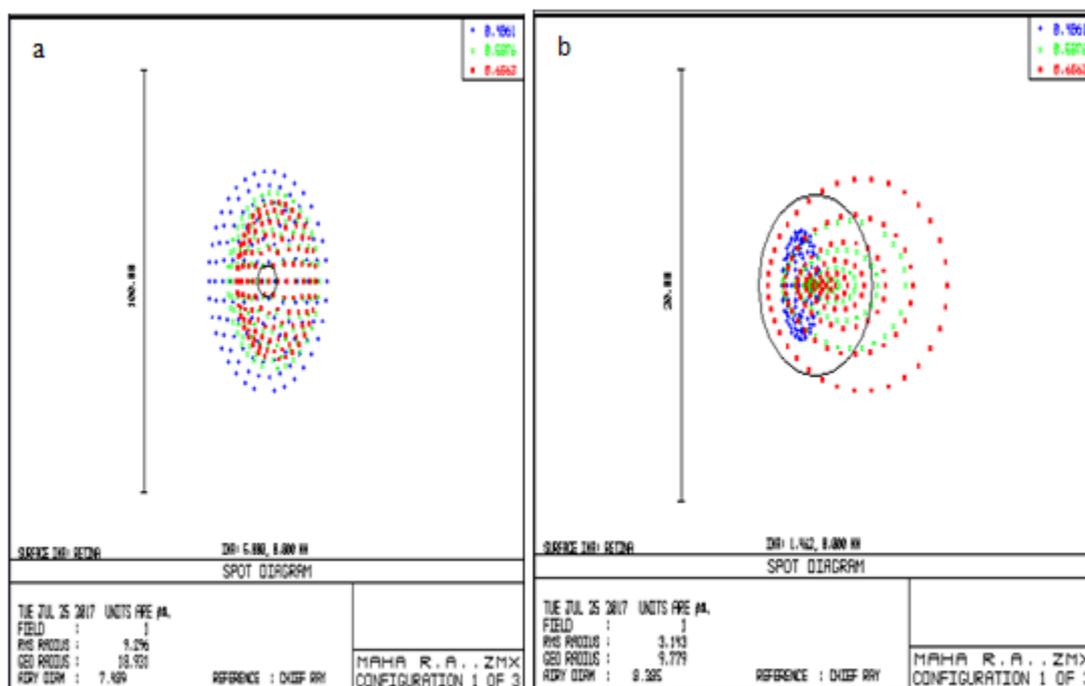

Figure (5): Root-Mean-Square of far distance (a: before, b: after the Pu lens insertion respectively).
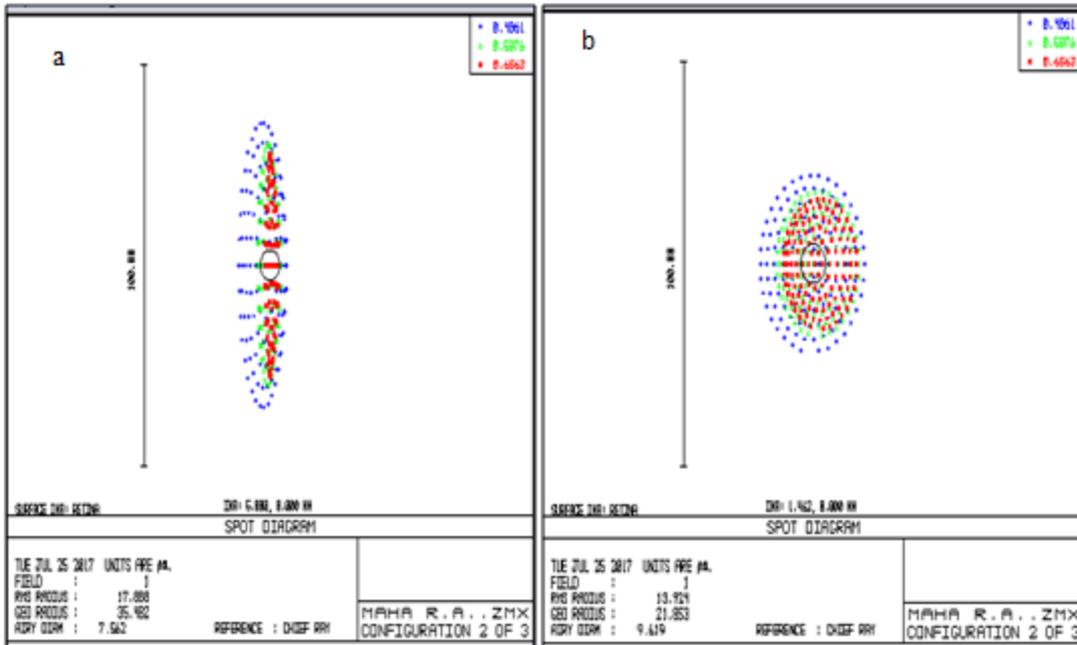
Figure (6): Root-Mean-Square of intermediate distance (a: before,
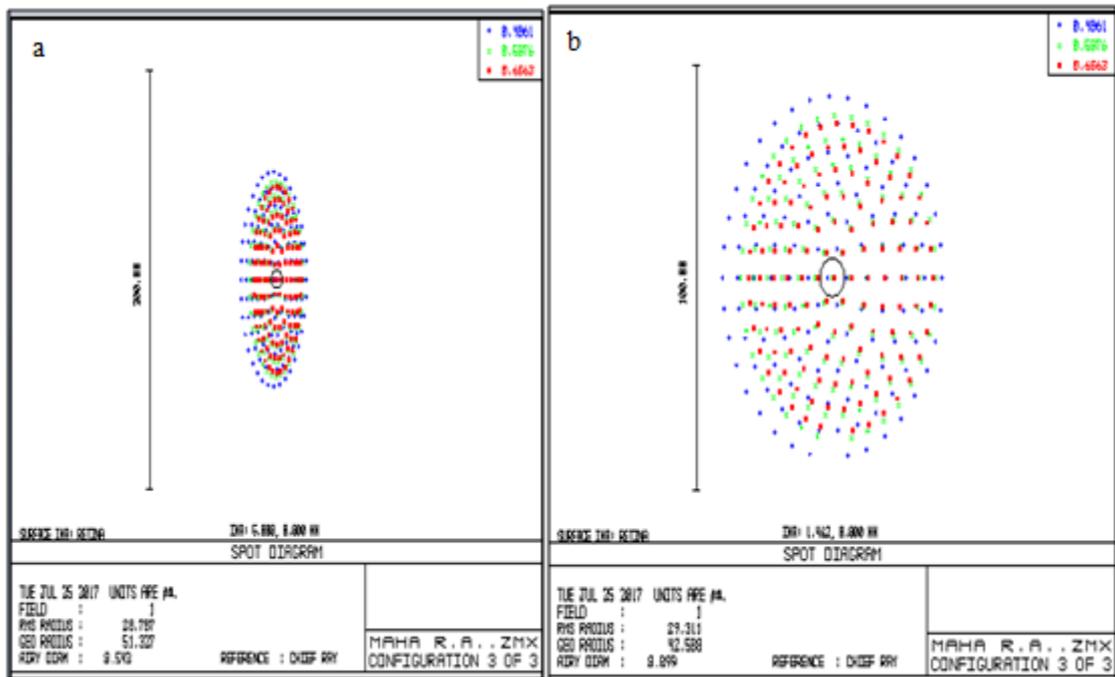b: after the Pu lens insertion respectively).

Figure (7): Root-Mean-Square of near distance (a: before, b: after the Pu lens insertion
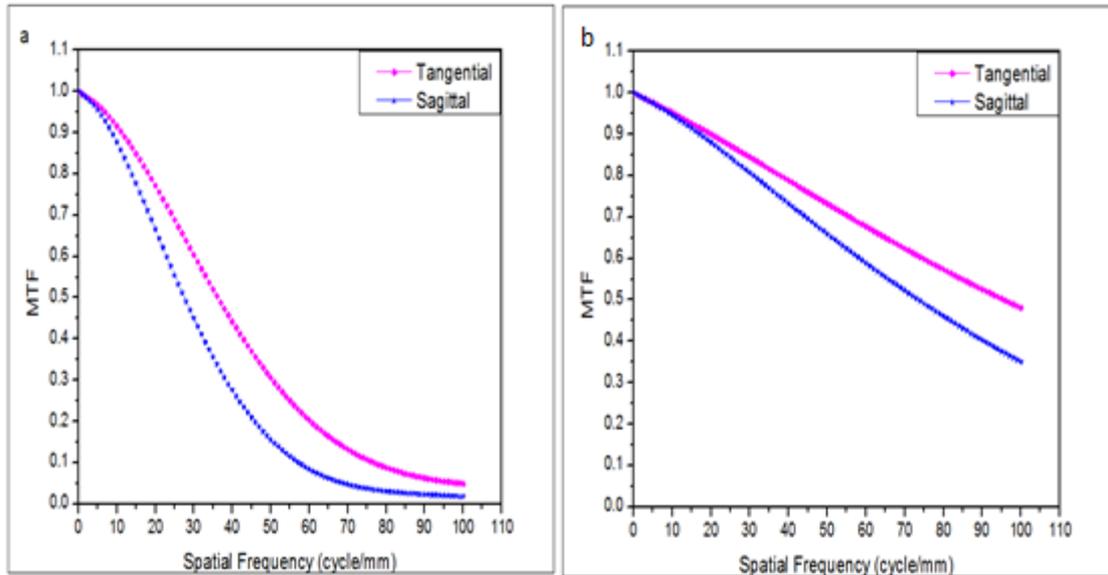respectively)

Figure (8): The Modified transfer function of far distance (a: before, b: after the Pu lens insertion respectively).
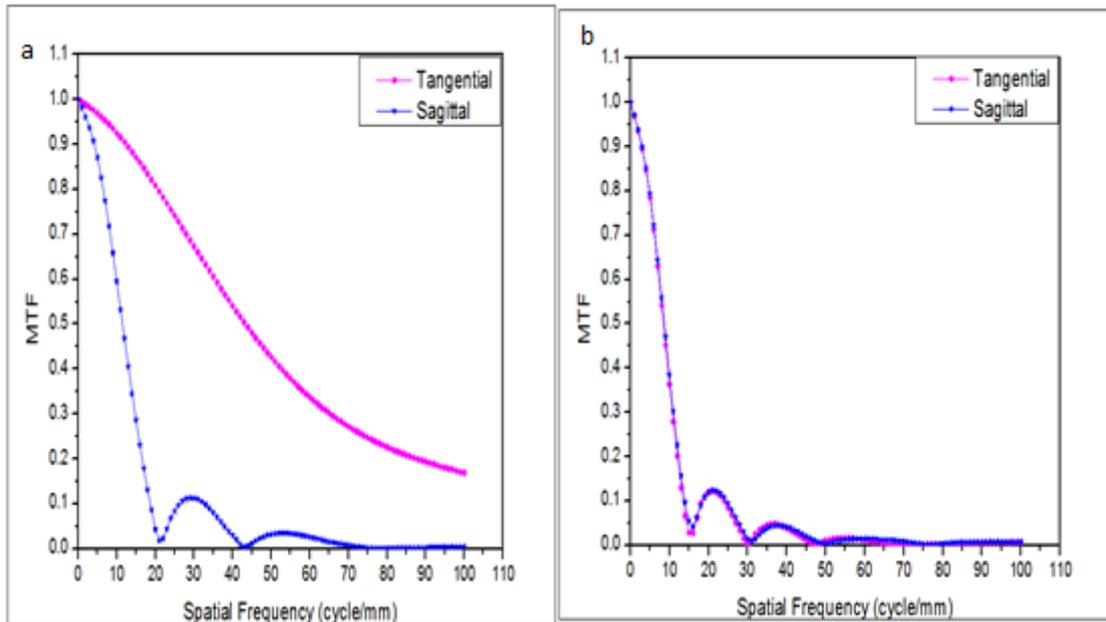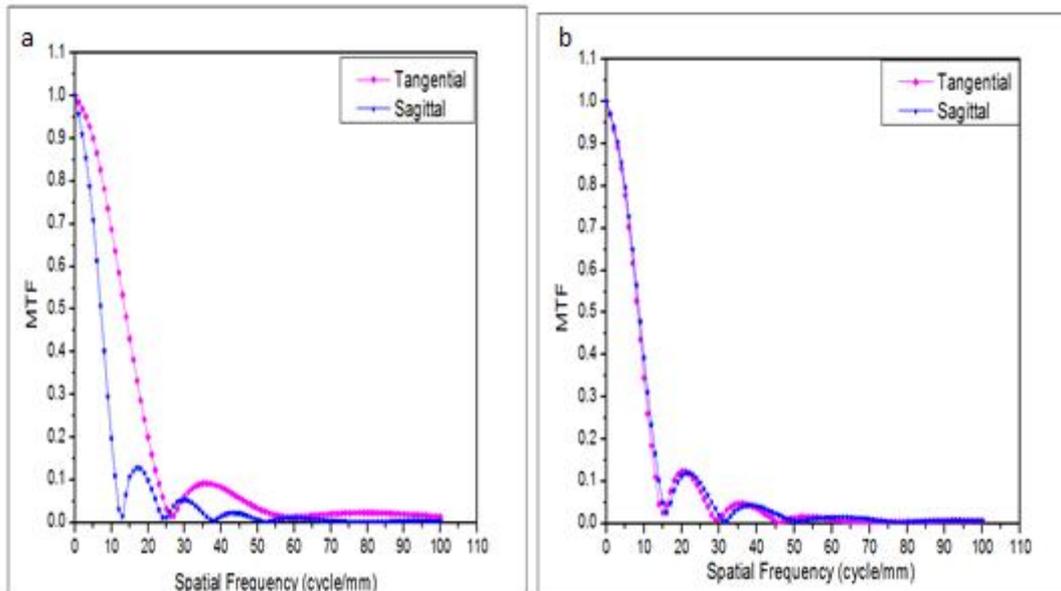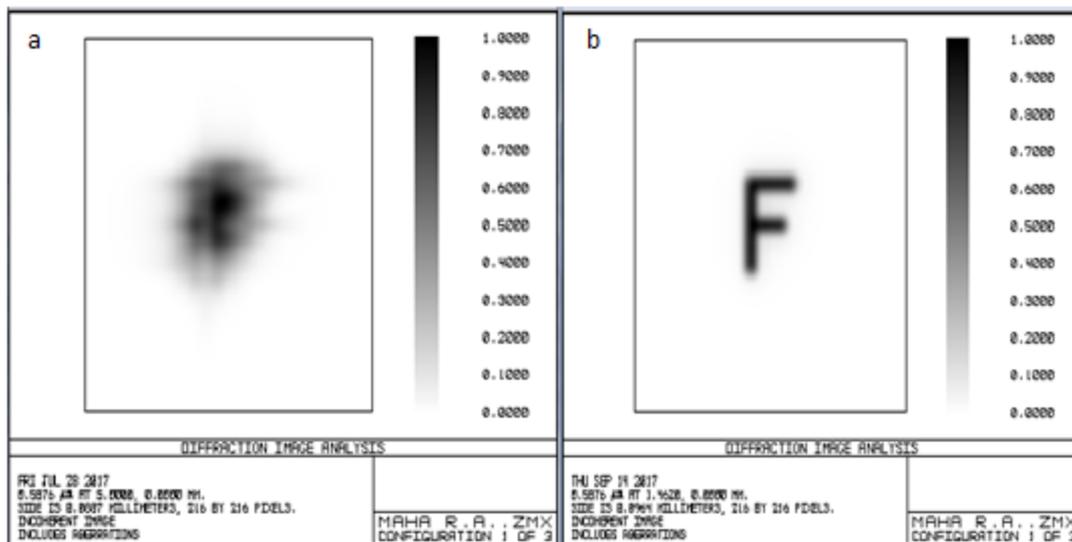

Figure (9): The Modified transfer function of intermediate distance (a: before, b: after the Pu lens insertion respectively).

Figure (10): The Modified transfer function of near distance (a: before, b: after the Pu lens insertion respectively).

Figure (11): The Modified transfer function of far distance (a: before, b: after the Pu lens insertion respectively)
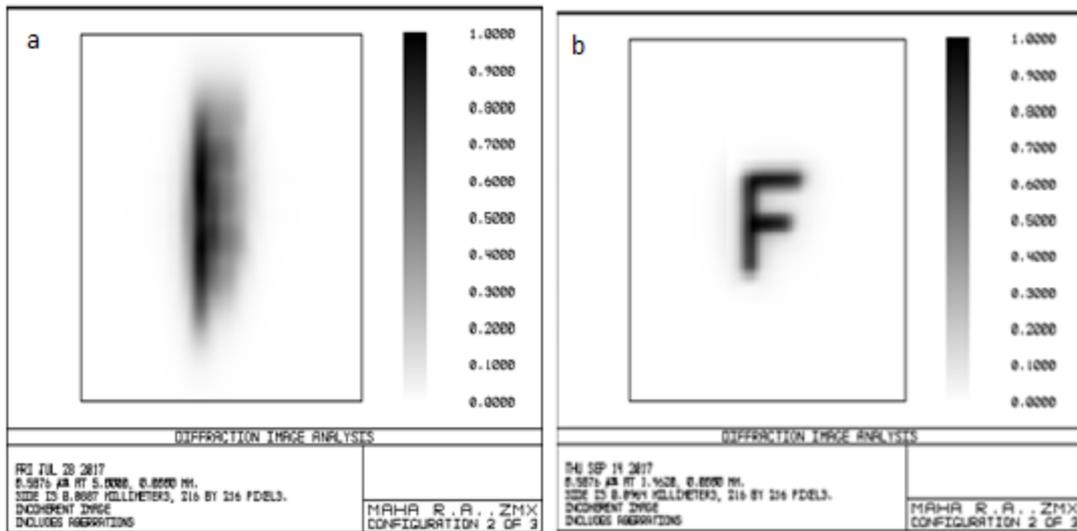
Figure (12): The Diffraction image of intermediate distance (a: before, b: after Pu the lens insertion respectively).
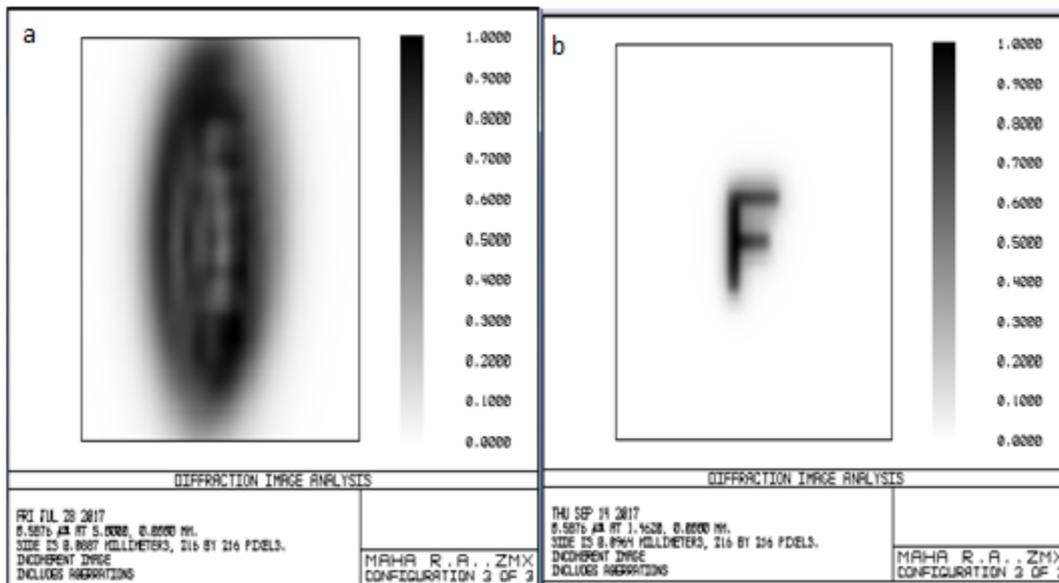

Figure (13): The Diffraction image of near distance (a: before, b: after the Pu lens insertion respectively).