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Systematic Design of Myopic Ophthalmic Lens

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ABSTRACT

The aim of this research is to design a myopic ophthalmic lens by using ZEMAX optical design software. The myopic ophthalmic lens is designed by integrating the effects of myopic eyes. The first design started from adjusting the design of purely using lens making formula by ZEMAX's simulation, named "eyeglass 1" of -0.93D myopic ophthalmic lens for -1D myopia . It then shows that the lighter power of the myopic ophthalmic lens is more suitable for the -1D myopia. This verifies that spectacle design should take into account the effects combined effects of the ophthalmic lens and the eye. If the lens is viewed to match the three configurations named far, middle, and near view points according to the human eye structure, an aspheric surface is introduced to the lens "named eyeglass 2", which gives more freedom to correct the aberrations. At the end of this study, we show that the choice of "far distance" gives an even more suitable ophthalmic lens for myopia, and this is shown by "eyeglass 3 & 4". The MTF values show that it is about 0.3 when spatial frequency is 83lp/mm "20/20 vision".

Key words: human eye, diopter, ophthalmic lens, optical design, optimization.

1. INTRODUCTION

Myopia is due to the eye axis being too long so that the object is imaged in front of the retina. Ophthalmic lens design must take into account the characteristics of the human eye (Jose Alonso & Javier Alda, 2003). The eye can be considered as an optical system with a positive power of about 58 D (D is the reciprocal of focal length measured in meters) (Bennett & Rabbetts, 1985; Legrand & El Hage, 1980; Pedrotti, L. S. & Pedrotti, F. L., 1998). The cornea bulges in front of the eyeball and, because its first surface is in contact with air, it bears most of the eye (about 45 D).

On average, if the eye axis increases by 0.37mm (Shih, Lin & Hung, 2007; Tsai, Cheng Nan), the diopter of the myopic eye increases by -1.00D. The human eye axis increases with age until maturity which is about at the age of 20. Fig. 1 shows the image forming of the myopic eye, and how the negative ophthalmic lens works to divert the over-converging rays to refocus on the retina to get a clear image (Pedrotti Frank L., Pedrotti Leon M. & Pedrotti Leno S., 2007; Smith Warren J., 2000a).

In general, the correction for myopia is to wear an ophthalmic lens which is made from sphere surfaces to reduce costs. From a lens design point of view, an ophthalmic lens suffers from the aberrations. In oblique sight directions, the optical axis does not coincide with the visual axis, and this creats the aberration (Jalie, M., 1994; Atchison, 1992). But it can be minimized by considering the relationship between the shape of an ophthalmic lens and the oblique error (Atchison, 1984). In

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this study, a raytracing method (Fischer Robert E., Tadic-Galeb Biljana & Yoder Paul R., 2008; Chen, 2001) is proposed to simulate optical correction of myopia. It gives a clear idea for choosing a more suitable diopter of the ophthalmic lens to correct the myopia.

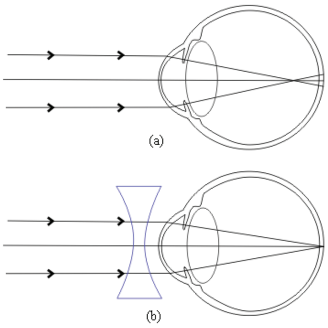

Figure 1. Uncorrected, image is focused in front of the retina (b) corrected by negative ophthalmic lens.

After measuring the degree of myopia, the optician determines the diopter of the glass. From the making formula as shown in eq.1 (Welford, 1986), the radius of the back surface can be defined assuming the radius of the front surface of the lens is known.

$$D = \frac{1}{f} = \left(n_{glass} - 1\right)\left(\frac{1}{R_{front}} - \frac{1}{R_{back}}\right) \tag{1}$$

After grinding and polishing the back surface of the lens, an eyeglass lens is completed. This kind of glass is for viewing the far distance to infinity. However, there is a lack of consideration for the three major viewing distances of the human eye: for seeing far, middle and near distance. This research uses an even aspheric surface to design an eyeglass lens, with the intention of conforming to the human eye's view angles and distances.

In general, the distance from the cornea to the ophthalmic lens is about 12 to 15 mm. This research chooses 15mm for the distance between the lens and the cornea, and uses three different scenarios of myopia by using the multi-configuration of ZEMAX lens design software to set the distances and the view angles. It can be seen that using an even aspheric surface will correct the three different viewing positions: far, middle and near distance. The standard definition of normal visual acuity (20/20 vision) is the ability to resolve a spatial pattern separated by a visual angle of 1 minute of arc as shown in Fig. 2 (Moran John). This shows that 1 minute of arc is approximately equal to 0.006mm width of line seen on the retina. It means that if we had alternating black and white lines that were clearly resolved by normal acuity, i.e., 20/20 vision, then the resolved width of a line pair is 0.012 mm, or 83lp/mm in the scale of MTF in ZEMAX.

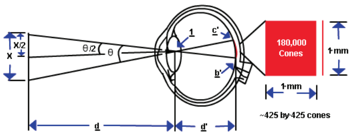

Figure 2. Resolution on the retina.

Note.(a) Normal visual acuity θ = 1 min arc = 2.9e - 004 rad
(b) Line width on the retina w = θ × mm = θ × 20.6mm(length of eye ball) = 0.006mm
(c) Width of line pair = 2w = 0.012mm, spatial frequency (f) = 1/2w = 83(lp/mm)

2. PRINCIPLE OF AN OPHTHALMIC LENS

An eyeglass is a singlet lens with negative or positive power to correct Myopia and hyperopia respectively. Myopia is due to the incoming parallel light entering the eye's refraction system in a way that the light is imaged in front of the retina, causing the image to be blurred. Adding a negative lens in front of the eye causes the parallel light to be divergent before entering the eye. The corrected light will then be focused on the retina to produce a clear image. In general, the radius of the front surface of ophthalmic singlet is generally chosen to be 100 mm and the radius of the back surface of the lens is adjusted to make the necessary corrections.

The aim of this research is to define a rigorous method to design an ophthalmic lens, i.e., finding the construction parameters for the back surface. The optical model of normal eye with ophthalmic lens can be simulated as shown in Fig. 3.

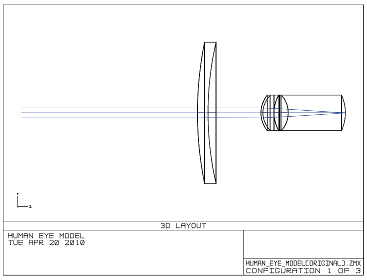

Figure 3. Optical model of normal eye with ophthalmic lens.
(no power, i.e., $R_{front} = R_{back} = 100mm$)

We use a zero power ophthalmic lens fitted to the optical eye model. The construction data is shown in Table 1.

The parameters shown in Table 1 are simulated by the ZEMAX lens design codes. Note the thickness from vitreous to retina is 16.21467mm, i.e., zero power's thickness. The rigorous lens making formula is shown as eq. 2 (Welford, 1986),

$$D = \frac{1}{f} = \left(n_{glass} - 1\right)\left(\frac{1}{R_{front}} - \frac{1}{R_{back}} + \frac{t(n_{glass} - 1)}{R_{front} R_{back} n_{glass}}\right), \tag{2}$$

where t is the thickness of the lens which is 3mm. Then, choosing the diopters of the ophthalmic lens, we get the corresponding radius for the back surface of the lens from eq. 2. We develop a Matlab code to calculate the radius of the back surface of the ophthalmic lens, as shown in Table 2.

Table 1. *Matlab code of power of ophthalmic lens*

1	% power of ophthalmic lens
2	r1 = input('r1='); % input the front radius of the lens, it is set by 0.1m
3	r2 = input('r2='); % input the back radius of the lens, it is chosen by getting the expected P (power of the lens)
4	n = input('n=');% input the index refraction of the lens; n of POLYCARB at λ = 0.5876 μm is 1.58547
5	t = input('t='); % input the thickness of the lens; t = 0.003m
6	a = (t*(n-1))/(r1*r2*n); % third term of lens making formula
7	p = (n-1)*((1/r1)-(1/r2)+a); % diopter of the lens

In practical use there are four types of diopters named low, medium (two types), and high diopter. After rigorous calculation the radius of the back surface of the ophthalmic lens is shown in Table 3.

Table 2. R_{back} *of ophthalmic lens with respected to the four types of diopters*

Diopter of lens	-1.00D low diopter	-4D medium diopter	-8D medium diopter	-10D high diopter
R_{back}	84.47mm	58.75mm	41.8mm	36.5mm

3. DESIGN EXAMPLE

This research is to design an eyeglass to correct the -1D myopic, the procedures are as follows:

3.1 Set Up the Optical Eye Model

Use ZEMAX optic design code (Tocci Mike, 2007) to construct an optical model of the human eye (Chen, 2007; Smith George & Atchison David A., 1997). The human eye responds to three main wavelengths of the electromagnetic spectrum. These are the visible light of F, d, and C lines which correspond to the three wavelengths are 0.486 μm, 0.587 μm, and 0.656 μm respectively. In this study we use a multi-configuration method to systematically design the myopic ophthalmic lens. The tree configurations are shown in Table 4. In the FAR field, the object distance is infinity and the stop direction is parallel to the optical axis, i.e. the visual sight is not rotated about the optical axis. In MID and NEAR fields the object distance is set at 1000 mm, 500 mm, respectively and the visual sight is rotated about the optical axis by -10 degree, and -20 degree in MID and NEAR fields.

Table 3. *Multi-configuration parameters*

Active: 1/3		Config 1*	Config 2*	Config 3*
1: MOFF	0	FAR	MID	NEAR
2: THIC	0	1.000000E+009	1000.000000	500.000000
3: PAR3	0	0.000000	-10.000000	-20.000000

3.2 Wearing the -1D Ophthalmic Lens by Lens Maker Calculation

A myopic eye is chosen by low diopter (for example:-1D). After setting the -1D ophthalmic lens, the construction data are shown in Table 5. We can see the thickness from vitreous to retina is changed from 16.21467 mm to 16.610009 mm. The eye axis is enlarged by Δl = 16.610009 – 16.21467=0.39533 mm, i.e., -1.07D ($\frac{\Delta l}{-0.37} = -1.07D$. This means the -1D eyeglass is heavier than expected, i.e., overcorrected.

Table 4. *Optical data of wearing -1D ophthalmic lens,* $R_{back} = 84.47mm$

Surf:	Type	Comment	Redius	Thickness	Glass	Semi-Diameter		Conic
OBJ	Standard	OBJECT	Infinity	1.000000e+009		0.000000		0.000000
1	Standard	INPUT BEAM	Infinity	50.000000		1.606689	U	0.000000
2*	Even Asphere	GLASSES-FRONT	100.000000	3.000000	POLYCARS	20.000000	U	0.000000
3*	Even Asphere	GLASSES-BACK	84.470000	28.000000		20.000000		0.000000
4	Coord Break	CENTER OF EYE		-13.000000	-	0.000000	U	
5*	Standard	CORNEA	7.770000	0.550000	1.38,50.2	5.000000	U	-0.180000
6*	Standard	AQUEOUS	6.400000	3.160000	1.34,50.2	5.000000	U	-0.600000
STO	Standard	PUPIL	Infinity	0.000000	1.34,50.2	1.250000	U	0.000000
8*	Gradient 3	LENS-FRONT	12.400000	1.590000		5.000000	U	0.000000
9*	Gradient 3	LENS-BACK	Infinity	2.430000		5.000000	U	0.000000
10*	Standard	VITREOUS	-8.100000	16.610009	1.34,50.2	5.000000	U	0.960000
IMA	Standard	RETINA	-12.000000			5.000000	U	0.000000

If the radius of the back surface of the ophthalmic lens is chosen to be flatter, i.e. a larger radius, it is selected from 84.47 mm to 85.34 mm. From the optical data shown in Table 6 it can be seen that the thickness from vitreous to retina is 16.584057 mm. We get $\Delta l = 16.584057 - 16.21467 = 0.37(mm) - 1D$ myopia (Shih, Lin & Hung, 2007; Tsai, Cheng Nan), and now the diopter of the ophthalmic lens is -0.93D, called "eyeglass 1". The layouts of 'eyeglass 1" in three viewing field are shown in Fig.4.

Table 5. *Optical data of "eyeglass 1"*, $R_{back} = 85.34mm$

Surf:	Type	Comment	Redius	Thickness	Glass	Semi-Diameter	
OBJ	Standard	OBJECT	Infinity	1.000000e+009		0.000000	
1	Standard	INPUT BEAM	Infinity	50.000000		1.606689	U
2*	Even Asphere	GLASSES-FRONT	100.000000	3.000000	POLYCARS	20.000000	U
3*	Even Asphere	GLASSES-BACK	84.470000	28.000000		20.000000	
4	Coord Break	CENTER OF EYE		-13.000000	-	0.000000	U
5*	Standard	CORNEA	7.770000	0.550000	1.38,50.2	5.000000	U
6*	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
8*	Gradient 3	LENS-FRONT	12.400000	1.590000		5.000000	U
9*	Gradient 3	LENS-BACK	Infinity	2.430000		5.000000	U
10*	Standard	VITREOUS	-8.100000	16.610009	1.34,50.2	5.000000	U
IMA	Standard	RETINA	-12.000000			5.000000	U

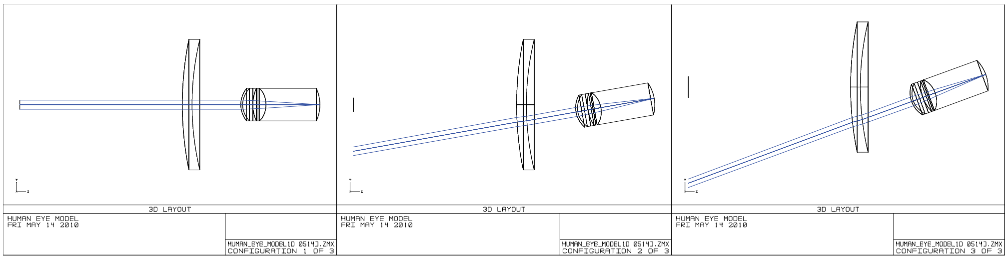

Figure 4. Layout of "eyeglass 1" system in FAR, MID, and NEAR fields.

3.3 Evaluate the Image Quality of Eyeglass 1

MTF (Modulation Transfer Function) (Smith Warren J., 2000b) is the general image assessment tool, and gives the ratio of the modulation in the image to the modulation in the object as a function of spatial frequency. By ZEMAX code, after running the MTF calculation, we get the three configuration's MTF, as shown in Fig. 5. Note the thickness from vitreous to retina is kept at 16.584057 mm, i.e., -1D myopia.

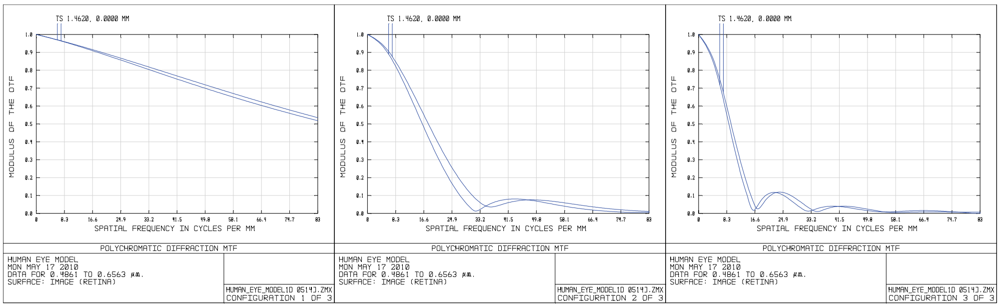

Figure 5. MTF of FAR, MID, and NEAR fields (from left to right) by wearing "eyeglass 1".

We can see the MTF of MID and NEAR cases leave the space to optimize as it degrades quickly by increasing the spatial frequency.

3.4 Optimization of Eyeglass 1

The solution to optimize the above ophthalmic lens is to change the surface type of R_{back} back surface of the ophthalmic lens, glass-back in ZEMAX data sheet from sphere to asphere, and this gives more degrees of freedom to design the ophthalmic lens. Then we can set the variation terms up to the 12th term of the aspheric surface (Chen, 2001). The optimized results are shown in Fig. 6, and the optical parameters are shown in Table 7, named "eyeglass 2".

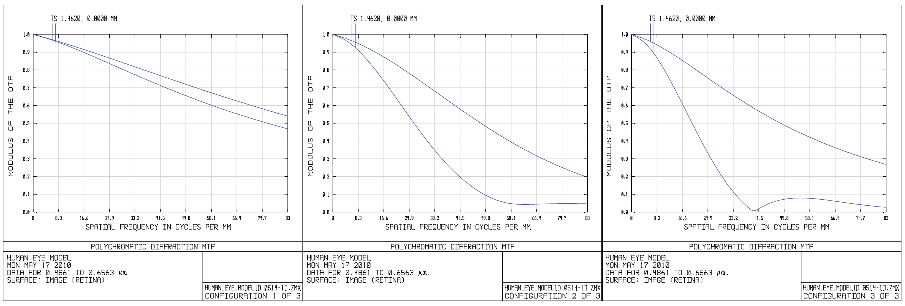

Figure 6. MTF of FAR, MID, and NEAR fields from left to right by wearing "eyeglass 2".

4. RESULTS AND ANALYSIS

Comparing Fig.6 with Fig.5, we can see the MTFs of MID and NEAR fields are optimized to high spatial frequencies by applying the aspheric surface to "eyeglass 1". Clearly the image quality of "eyeglass 2" is better than "eyeglass 1". We can see that while aspheric surface of "eyeglass2" corrects high order aberrations, it also shows that the MID and NEAR fields are not corrected well.

Table 6. *Optical data of "eyeglass 2" with aspheric surface on "glass-back"*

Surf: Type		Comment	Redius	Thickness	Glass	Semi-Diameter		Conic		Par 0 (unuses)
OBJ	Standard	Object	Infinity	1.000000E+009		0.000		0.000		
1	Standard	Input Beam	Infinity	50.000		1.409		0.000		
2*	Even Asphere	Glasses-front	100.000	3.000	Polycarb	20.000	U	0.000		
3*	Even Asphere	Glasses-back	84.470	28.000		20.000	U	0.323	V	
4	Coord Break	Center of eye		-13.000	-	0.000				
5*	Standard	Cornea	7.770	0.550	1.38,50.2	5.000	U	-0.180		
6*	Standard	Aqueous	6.400	3.160	1.38,50.2	5.000	U	-0.600		
STO	Standard	Pupil	Infinity	0.000	1.38,50.2	1.250	U	0.000		
8*	Gradient 3	Lens-front	12.400	1.590		5.000	U	0.000		
9*	Gradient 3	Lens-back	Infinity	2.430		5.000	U	0.000		
10*	Standard	Vitreous	-8.100	16.584	1.38,50.2	5.000	U	0.960		
IMA	Standard	Retina	-12.000	-		5.000	U	0.000		

Table 7. *Optical data of "eyeglass 2" with aspheric surface on "glass-back"*

Surf: Type		2nd Order Term	4th Order Term		6th Order Term		8th Order Term		10th Order Term		12th Order Term
OBJ	Standard										
1	Standard										
2*	Even Asphere	0.000	0.000		0.000		0.000		0.000		0.000
3*	Even Asphere	0.000	-3.941E-006	V	-4.398E-009	V	3.025E-012	V	2.816E-013	V	
4	Coord Break	0.000	0.000		0.000		0.000		0.000		
5*	Standard										
6*	Standard										
STO	Standard										
8*	Gradient 3	1.000	1.368		-1.978E-003		0.000		0.000		0.000
9*	Gradient 3	1.000	1.407		-1.978E-003		0.000		0.000		0.000
10*	Standard										
IMA	Standard										

If now wearing "eyeglass 1" with a spherical "glasses-back" surface, we release the thickness of vitreous to retina. We can see the MTFs in FAR, MID and NEAR fields respond with high contrast values, and he spatial frequency reaches to 83lp/mm 20/20 vision. This is shown in Fig. 7.

Fig.7 describes the phenomena of adaptation in the human eye to enforce the myopic eye obtain a clear image. It also gives the evidence of why the myopic eye may get a higher negative diopter if wearing an unsuitable eyeglass. Checking the FAR case of "eyeglass 2", we find the object distance is set in infinity. The object distance of the derivation of the cut off frequency of MTF is chosen to be 20ft, i.e. 6,096mm (the test distance of the visual acuity), but not infinity. We reset the object distance in FAR field to 20ft, and we can see the radius of R_{back} is

87.45mm when the thickness from vitreous to retina is kept at 16.584057 mm, i.e., -1D myopia. The diopter of the eyeglass is -0.77D, named “eyeglass 3”. We can see the diopter of the ophthalmic lens is changed from the -1D to -0.77D. It shows how we should make a suitable eyeglass. The MTFs of eyeglass 3 in three fields are shown in Fig. 8.

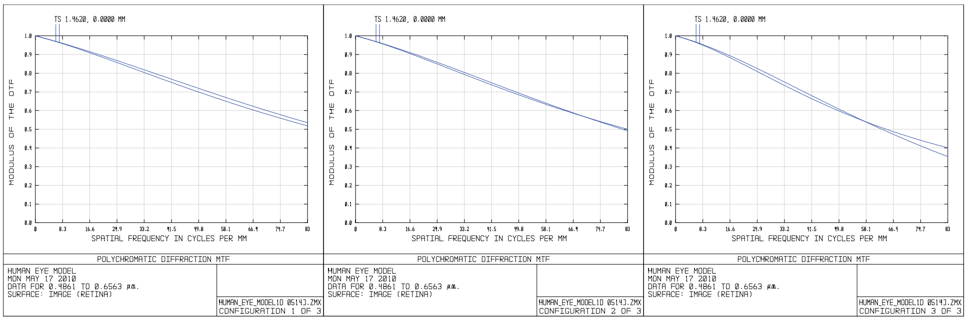

Figure 7. MTF of FAR, MID, and NEAR fields by adapting the thickness of vitreous to retina as 16.584mm, 16.941mm, and 17.265mm respectively in “eyeglass 1”.

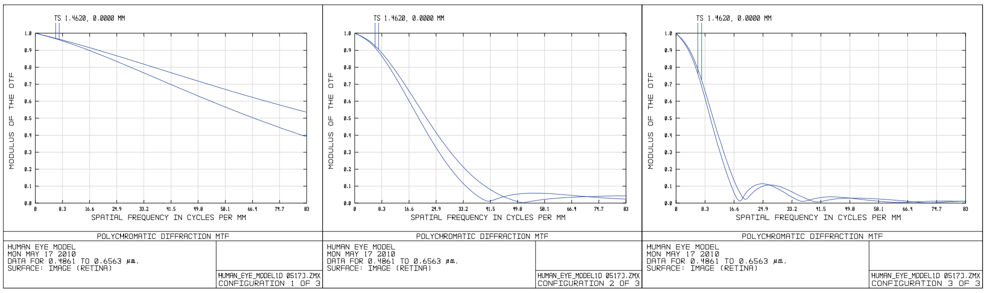

Figure 8. MTF of FAR, MID, and NEAR fields (from left to right) by wearing “eyeglass 3".

Now if we optimized the glass-back surface to the 12th term of the aspheric surface, we get the optimized eyeglass 3, named “eyeglass 4”. The optical construction data are shown in Table 8, and the MTFs of eyeglass 3 at three fields are shown in Fig. 9. We can see the optical performance of “eyeglass 4” is much better than that of “eyeglass 2”. This is mainly by considering the FAR field distance is set at 20 ft. Comparing Fig. 9 with Fig.6, it can be seen that choosing the proper object distance gives a better correction for the myopic eye.

Table 8. *Optical data of "eyeglass 4" with aspheric surface on "glass-back"*

Surf: Type		Redius	Thickness	Glass	Semi-Diameter		Conic	
OBJ	Standard	Infinity	6096.000		0.000		0.000	
1	Standard	Infinity	50.000		1.960		0.000	
2*	Even Asphere	100.000	3.000	Polycarb	20.000	U	0.000	
3*	Even Asphere	84.450	28.000		20.000	U	-0.307	V
4	Coord Break		-13.000	-	0.000			
5*	Standard	7.770	0.550	1.38,50.2	5.000	U	-0.180	
6*	Standard	6.400	3.160	1.38,50.2	5.000	U	-0.600	
STO	Standard	Infinity	0.000	1.38,50.2	1.250	U	0.000	
8*	Gradient 3	12.400	1.590		5.000	U	0.000	
9*	Gradient 3	Infinity	2.430		5.000	U	0.000	
10*	Standard	-8.100	16.584	1.38,50.2	5.000	U	0.960	
IMA	Standard	-12.000	-		5.000	U	0.000	

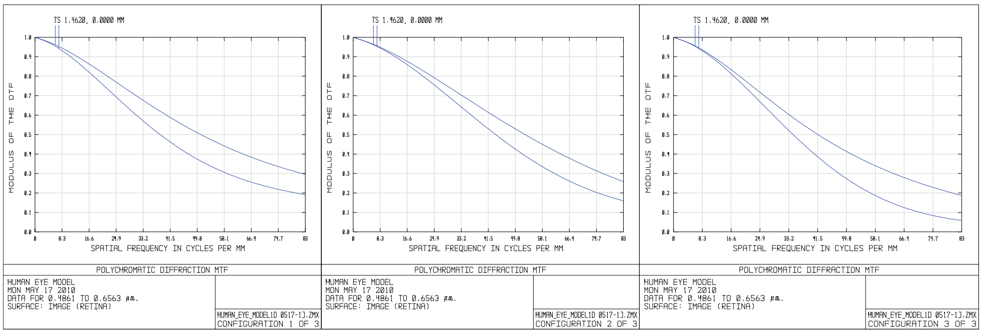

Figure 9. MTF of FAR, MID, and NEAR fields from left to right by wearing "eyeglass 4".

5. CONCLUSION

From the discussion at section 4, we can summarize the ideas of system design of myopic ophthalmic lens as follows:

(1) Test the diopter of the myopic eye.
(2) Choose a suitable diopter for the eyeglass, and it shows the diopter of the eyeglass is weaker than the expected, i.e the -1D myopic eye should wearing -0.77D eyeglass if the FAR distance is set by 20ft.
(3) Optimizing the ophthalmic lens with aspheric surface, we can get a better image quality of three configurations of lens, i.e., FAR, MID, and NEAR.

In practical cases, the optician will face two important requirements: an enormous variety of lenses and a very short delivery time (Home, 1978; Brooks, 1992). This study describes the methods to choose a suitable diopter for myopia. It also shows that the aspheric surface of the ophthalmic lens gives a better image quality of the three viewing configurations. We find the optical simulation code can be a tool to aid predetermining the choice of a suitable diopter for the eyeglass. We hope to cooperate with opticians to construct a data base to verify the validity of weaker eyeglasses for myopic eyes in a further study.

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