The Appearance of Images Through a Multifocal IOL

ABSTRACT

The appearance of images through a multifocal IOL was simulated. Comparing the appearance through a monofocal IOL to the view through a multifocal lens implanted in the other eye validated the simulations.

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Introduction

Multifocal intra-ocular lenses (IOL) of various designs are now used to replace the eye's crystalline lens in cataract surgery. To replace accommodation the multifocal IOL simultaneously images near and far points on the retina. Thus, at every viewing distance an out-of-focus image is superimposed over the clear in-focus image. The optical transfer functions (OTF) of eyes with such multifocal lenses have been measured and computed (Holladay et al, 1990, Navarro et al, 1993). The appearance of images to patients with such IOLs has not been determined yet, though it is generally believed that the OTF provides all the information needed for such determination. While the OTF should be sufficient to determine the *retinal* image accurately, the OTF can not predict perception directly, because of the non-linear nature of the visual system (threshold response) (Peli, 1990). However, when comparing the image appearance between two eyes of the same person, one equipped with a monofocal IOL and one with a multifocal IOL, the between eyes' OTF ratio will properly describe the difference between the retinal image in the multifocal IOL lens and the retinal image in the monofocal IOL. Thus the image appearance based on the OTF can be tested directly in such patients and be used to verify the OTF.

We conducted such experiments for Distance and Near vision. OTF ratios were used to computationally modify images to simulate their appearance through the multifocal IOL and present them to the monofocal IOL eye. If the OTF and thus the simulations were valid, the simulated image seen through a monofocal IOL should be indistinguishable from the original (standard) image seen through the multifocal IOL.

Methods

Four subjects participated in the study (1 man and 3 women; ages 68-77 years). All 4 had a multifocal IOL in one eye (AMO®ARRAY®) and a monofocal IOL (AMO® SI26NB) in the other. Pretest examination included measurements of visual acuity at distance (20 ft), Sighting dominance, stereo acuity at distance, and suppression test using the BVAT (Mentor O&O). Subjective refraction was determined using a standard clinical procedure and was used to modify the subject's correction when needed.

"Stereo" liquid crystal (LC) shutter goggles allowed presentation of different image to each eye (dichoptic). Both images were visible and the subject indicated which side was clearer. The standard (unprocessed) image was always presented to the eye with the multifocal lens. The standard image was displayed on either the right or left half of the screen and yet was seen only with the multifocal IOL eye. The monofocal IOL eye was presented with a computationally-modified version of the image on the other side. There were seven such images for each scene that ranged from worse (more blurred) to better (sharper) than the image presented to the multifocal IOL eye. Each simulation of each scene was presented to the subject 10 times (70 trials per image). Order of scene and simulations was randomized.

Image Processing

The OTFs were recorded using a model eye composed of a wet cell containing the intraocular lens, an achromat used as the cornea, a 3mm aperture, a photopic light spectra, and configured to give the same retinal image height as the human eye (Portney 1992). OTFs were measured using the EROS system from Ealing Electro Optics. Defocus monofocal and multifocal OTFs were created by changing the back focal position by the amount calculated to be equivalent to the spectacle defocus specified. Images were processed using software written in Microsoft Visual Basic. The ratios of the various (one-dimensional) OTFs were use to create the two-dimensional filters as a rotationally symmetric filters in the spatial frequency domain. Since the final images were displayed on a Gamma corrected system, the filtering was applied to each of the RGB component separately (Peli, 1992). Following Fourier domain filtration, the simulated image (originally 256 levels for each color) was compressed to 254 colors to permit display in a PCX image format on the VisionWorks system. Visual inspection demonstrated that compressed images were indistinguishable from the originals.

At a viewing distance of 135cm, the 20cm square 512×512 pixels image reproduced a maximum spatial frequency of 30 cycles/deg. A 0.75D correction was used as appropriate to compensate for the viewing distance. Two distance images included a Roman temple and sailboats on a lake. The near images included a holly plant and a letter chart (0.1log steps).

Simulation of Multifocal Near Images

The subjects viewed the original unfiltered image through their multifocal IOL using the Add power provided by the multifocal IOL (2.75D nominal Add) and a trial lens correcting for the actual viewing distance. The simulated near images were viewed through the monofocal IOL with trial lens correction for the actual viewing distance. The ratio of the multifocal near OTF divided by the monofocal distance OTF was used to create the simulated images (Figure 1). To obtain the more blurred images, the multifocal near OTF was measured at three levels of spectacle defocus and the corresponding OTF ratios are labeled as +0.25D, +0.5D and +0.75D. To obtain the sharper set of images, the monofocal distance OTF was measured at three levels of spectacle defocus and the corresponding OTF ratios are labeled as –0.125D, -0.25D and –0.5D.

Simulation of Multifocal Distance Images

In the second experiment simulated images were set at optical infinity using trial lenses. Again, the ratio of the multifocal distance OTF divided by the monofocal distance OTF was used to compute the simulated appearance of distance multifocal images (Figure 2). To obtain the more blurred images, the multifocal distance OTF was measured at three levels of spectacle defocus and the corresponding OTF ratios are labeled as +0.5D, +0.75D and +1.5D. To obtain the sharper set of images, the monofocal distance OTF was measured at three levels of spectacle defocus and the corresponding OTF ratios are labeled as –0.125D, -0.25D and –0.5D.

Data Analysis

The proportion of trials for which the original image (seen through the multifocal lens) was selected as better was plotted as a function of the simulated refractive error and fit with a psychometric function of the form: P = *norm* ((d-D)/s),

where *norm*(•) is the normal distribution cumulative probability function, d is the simulated dioptric error, and D and s are the parameters of the fit representing the 50% transition point and the slope of the function, respectively. The computed value of D was used to indicate a simulated image that is indistinguishable from the standard image under the experimental viewing conditions. This value was recorded for each subject viewing each scene and at each distance.

Results

None of the subjects reported any difficulty seeing both images simultaneously or had any difficulty following the instructions. The subjects could make appropriate and orderly selections of the sharper images, which were monotonically consistent with the simulated blur, (Figure 3). One subject (S2, Table 1) indicated that the simulated near image was always blurrier. It was not possible to fit the psychometric function and the data point was eliminated from the analysis.

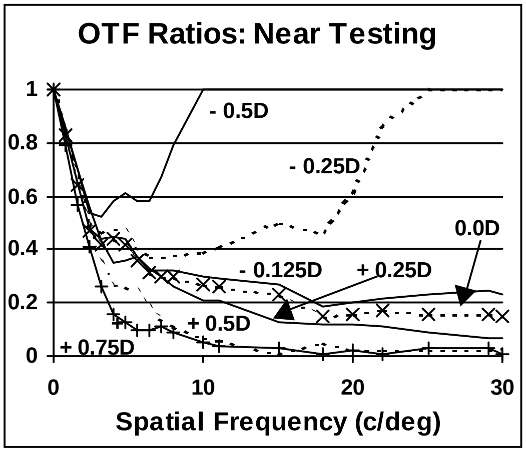


Figure 1. The OTFs' ratios used to simulate the appearance of images from a near viewing distance. The predicted ratio (marked 0.0D) was computed by dividing the OTF of the multifocal lens measured in a schematic eye from the near distance by the OTF of a best-corrected monofocal IOL. Blurrier images were obtained by measuring the OTF of the multifocal lens at different levels of blur (+0.25, +0.50, +0.75) while sharper images obtained by blurring the monofocal IOL by the amounts noted with negative signs.

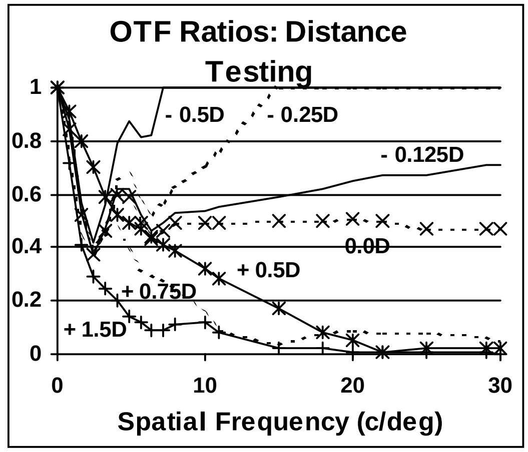
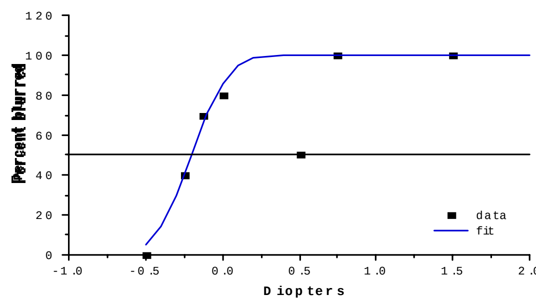


Figure 2. The OTFs' ratios used to simulate the appearance of images from a distance. The predicted ratio (marked 0.0D) was computed by dividing the OTF of the multifocal IOL, measured in a schematic eye from a distance, by the OTF of a monofocal IOL in the same eye from the same distance. Blurrier images were obtained by measuring the OTF of the multifocal lens at different levels of blur (+0.50, +0.75, +1.50D) while sharper images obtained by blurring the monofocal IOL by the amounts noted with negative signs. Note the improved performance of multifocal at distance

Figure 3: Example of the data obtained for one subject at distance for the Boat image.

Data points give percent of the presentations in which the simulation were perceived blurrier than the image seen through the multifocal lens.

The fit represents a transition at 50% of -0.20D as compared with a 0.0D prediction. The image matching the original image seen through the multifocal lens appeared slightly sharper than the 0.0D prediction. The magnitude of the difference is very small; less than what would be caused by a 0.25D error in the refraction.



In Fig. 3 note, the data point at 0.5 D that is farthest from the fit. The same deviation was found in 3 of 4 subjects' results. Further evaluation revealed an error in the filter applied to the corresponding images. The detection of this error is another indication of the sensitivity and validity of the testing method.

The 50% transition point for each subject and average results are shown in Table 1 below. The average transition points found were similar for both images in each of the two experiments.

The subjects generally selected a slightly sharper simulated image than the nominal as matching the original image seen through the multifocal IOL. But the mean deviations (as well as individual subject's) from the predication are equivalent to the small blur caused by less than 0.25D error in refraction.

For the near testing, the average deviation from the prediction is slightly larger (about +0.5D). In this case the subjects selected a more blurred image than the nominal as matching the original image seen through the near Add of the multifocal lens.

Table 1

The 50% transition point for each subject and image as derived from the curve fitting to the data. A transition with a negative sign indicates that image matching the original image seen through the multifocal IOL is sharper than the nominal or predicted (0.0D) image.

Image	Distance vision simulation (prediction 0.0)				Mean	SD
	Subj. 1	subj. 2	subj. 3	subj. 4		
temple	-0.13	-0.21	0.17	-0.25	-0.11	0.19
boat	-0.26	-0.36	0.25	-0.20	-0.14	0.27
	Near vision simulation (prediction 0.0)					
	Subj. 1	subj. 2	subj. 3	subj. 4		
chart	NA*	Eliminated	0.44	0.65	0.55	0.15
plant	NA	0.75	0.52	0.06	0.44	0.35

*Subject 1 did not complete the near testing.

Conclusion

The data from the Distance testing indicate that the simulations corresponded well to the appearance of the images seen through the multifocal lens. The consistency of the results with such a small number of very elderly and inexperienced observers demonstrates that the methods of simulation and testing were valid. The differences found between images were not large and may be explained by subjects' use of specific details. The power analysis based on the current data from the Distance testing indicates that approximately 20 subjects would be required to formally test the validity of the simulated images. Given that this is not a recommended prescription mode, we are unlikely to recruit enough subjects with a monocular multifocal IOL and monofocal IOL in the other eye in otherwise normal disease free eyes.

The slightly larger deviation in the results from the prediction for the Near testing is presumed to be a result of the edge blur that occur in the image seen through the multifocal IOL eye due to the high power trial lens used. This effect needs to be further evaluated.

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