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SPIE Proceedings Department

Resolution bench testing of monofocal lens results provides a wealth of historical data which can be used as a basis of compare to multifocal lenses. However, the physical layout of the line pairs on the USAF Target along with the monofilament light bulb used in this instrument tend to decrease the reliability of the test for multifocal lenses. Specifically, the target may not get uniform illumination and therefore the subjective reading may vary significantly because of geometric orientations and designs. This effect is seen in the RE results of the Split design (Table 1), where the low RE for both near and distance images may actually have been caused by the layout of the USAF target line pair pattern. Also, the results for diffractive lenses must be adjusted to account for the fact that these lenses function quite differently in air than they do in aqueous environment.

Design	**Near**	**Distance**
Monofocal		**86% - 96%**
Concentric 2 Zone	**68%**	**86%**
Diffractive	**68%**	**68%**
Split	**43%**	**34%**

Table 1. Resolution efficiencies of multifocal IOLs compared to that of the monofocal IOL.

The shortcomings of the RE measurement and need for further understanding of the multifocal optical system demand additional evaluation methods. Theoretical modeling by computer simulations provide two such methods. By inputting constraints based on the Gullstrand eye model[3], and multifocal IOL design parameters, ray-trace analyses can be performed. The spot diagrams shown in Figure 3 demonstrate how the light distribution, in the retinal plane, differs between multifocal design geometries (the Concentric-2-zone and the Split).

The computer ray-trace spot diagram through a Concentric-2-zone IOL shows that for a near object the lens provides a good image represented by the center dark spot. (A monofocal design has only this dark center spot.) The light that passes through the distance portion of the lens forms an out-of-focus annulus and does not interfere with the near image. However for the split design, the central dark spot represents the in-focus near image, while the scattered spots represent out of focus light.

Concentric-2-Zone
Near vision spot diagram

Split
Near Vision Spot Diagram

Figure 3. Spot diagrams of various multifocal IOL designs.

Silberman

MTF and TFR evaluations are well established standards in the optical industry and have been used in the investigation of multifocal IOLs. These evaluations have been done both by computer modeling (not presented here) and by actual bench testing. Using an eye model, MTF bench testing gives a detailed, quantitative optical evaluation of the environment that simulates the human eye. In this configuration, the IOL can be rotated, tilted, and decentered, and different pupil sizes can be introduced, in order to simulate possible clinical conditions. The set-up for MTF and TFR testing using the Gullstrand Eye Model with the MTF bench is shown in Figure 4. Representative MTF data are shown in Figure 5 and corresponding TFR data are shown in Figure 6.

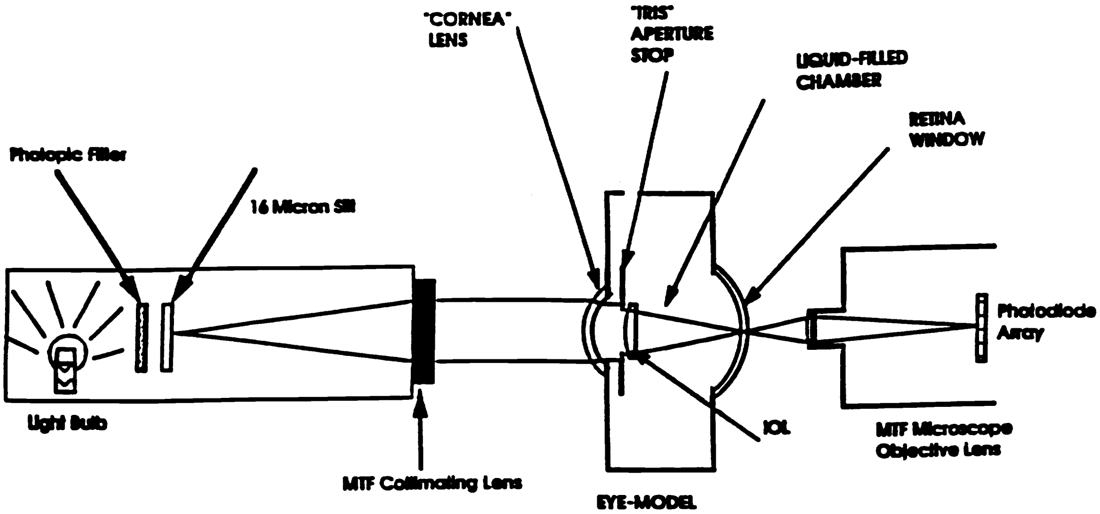

Figure 4. Schematic diagram of MTF Optical test bench.

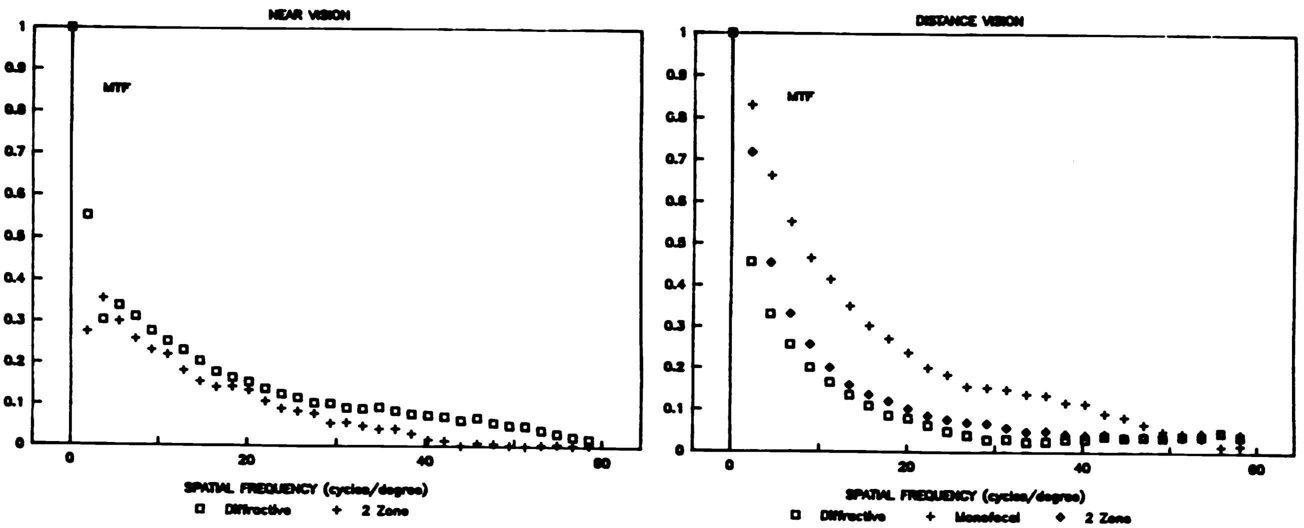

Figure 5. Near and distance vision modulation transfer function data for two (2) multifocal IOL designs and one (1) monofocal IOL.

THROUGH FOCUS RESPONSE

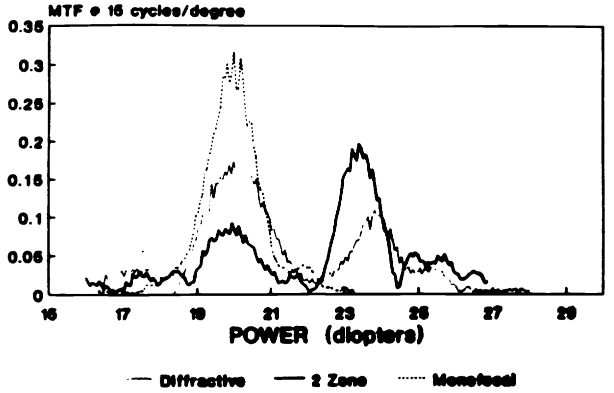

Figure 6. Through focus response data for two (2) multifocal IOL designs and one (1) monofocal IOL.

These MTF results show that for distance vision, the MTF curve for the monofocal is consistently higher than the curves for both multifocal lenses, which are nearly identical. The monofocal lens has no MTF curve at near vision, while near vision curves for the different multifocal lenses show only small differences.

The corresponding TFR results shown in Figure 6 show the monofocal lens distance vision peak is highest (0.3 MTF), followed by the diffractive lens (0.175 MTF), and the concentric 2 zone lens (0.09 MTF). The near vision peak of the 2 Zone lens (0.2 MTF) is higher than that of the diffractive lens (0.12 MTF). There is no near vision TFR data for the monofocal IOL. Note that the MTF scale in Figure 6 is expanded to show more detail than the graphs in Figure 5.

Optical performance differences between various multifocal designs are easily demonstrable to the layman by eye model photography. Eye model photography was accomplished using a standard 35 mm camera body with a simple microscope, a Snellen eye chart for the distant target and a Rosenbaum Pocket Vision Screener eye chart as the near target. The targets were oriented as shown in Figure 7, although the photographs have been turned "right side up" for presentation. Figures 8 and 9 show representative samples of the photographs taken with this arrangement.

The three (3) photographs in Figure 10 were taken through IOLs which are radially symmetric. Examination of the top photograph shows a clearly demonstrable distance acuity of 20/15. The middle photograph, taken through a multifocal, and shows a distance acuity of 20/25 and near acuity of J +1. The bottom photograph, taken through another multifocal design, shows a distance acuity of 20/25 and near acuity of J 1. The bottom photograph also clearly shows a distinct reduction in distance vision contrast for that design.

The photographs of Figure 9 were taken through the radially asymmetric Split design. The top photograph has the split axis oriented vertically, the middle photograph has the split axis oriented horizontally (distance portion of the lens on the top), and the bottom photograph has the split axis horizontal with the near portion of the lens on the top. These different