Through Focus Point Spread Function and Modulus Transfer Function of Intra-Ocular Lenses

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BACKGROUND

Cataracts are the leading cause of blindness throughout the world and cataract removal surgery is one of the most commonly performed surgeries in the United States. During cataract surgery, the cloudy crystalline lens in the eye is removed and replaced with an intra-ocular lens (IOLs) (Fig. 1).

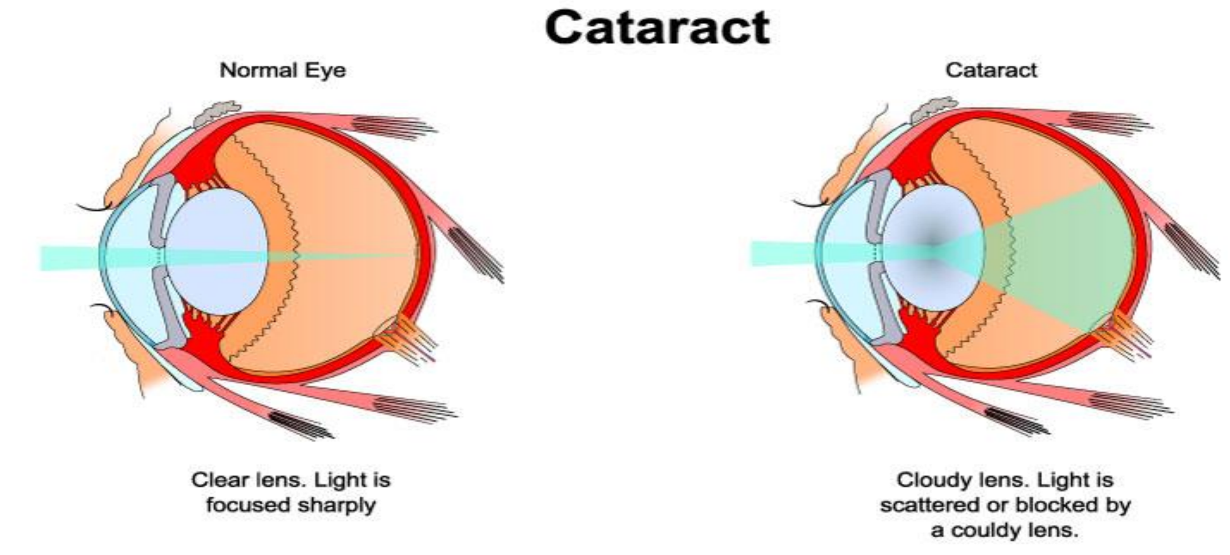


Fig. 1 Schematic diagram of eye normal eye and an eye with a cataract. [1]

Monofocal IOLs focus at one distance position and still require the use of glasses for near vision activities, such as reading. Multifocal IOLs, which can be refractive or diffractive in nature, focus at two or more positions and provide a more natural range of human vision.

It is crucial to be able to characterize the optical performance of different IOLs. Current methods involve measuring the Line Spread Function to calculating the Modulus Transfer Function (MTF) using Fourier techniques. This method has the advantage of integrating the point spread function along a single direction which amplifies information contained in the tails of the Point Spread Function (PSF), which can be faint or degraded by noise.

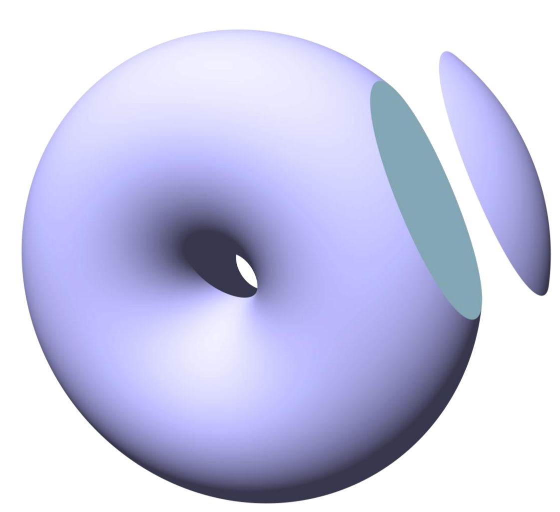


Fig. 2 Toric shape with a lens cut out. There are two distinct optical powers along the different axes of the lens. [2]

However, this method is inadequate for rotationally asymmetric IOLs. As IOL designs become increasingly complex, rotational symmetry cannot be assumed, such as in commonly used toric IOLs (Fig. 2) which employ a cylinder power to help correct ocular astigmatism. Using the PSF to determine MTF allows the MTF along any cross-section of the lens to be calculated. Additionally, the use of a 16-bit camera ensures that the fine details of the PSF tails will not be lost.

METHODS

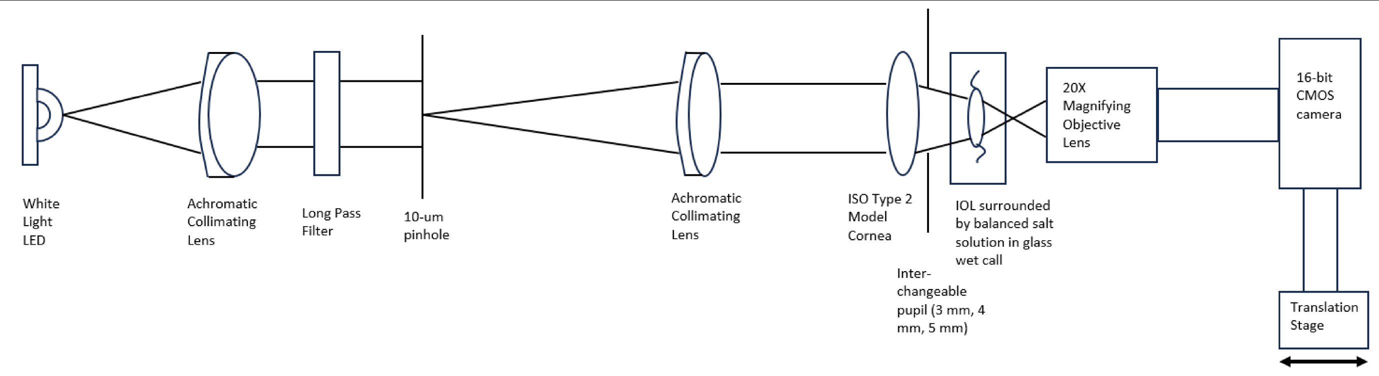
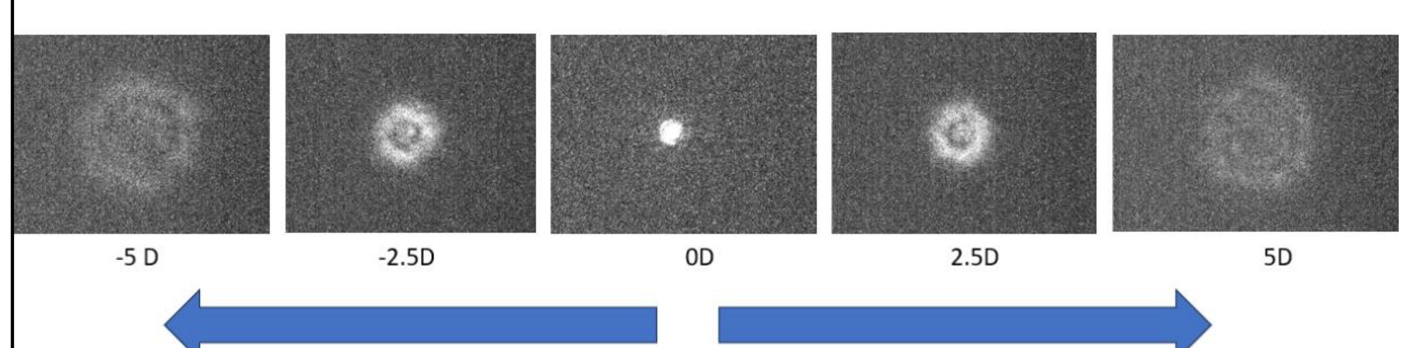


Fig. 3 Optical layout of PSF/MTF optical test bench.

A white light LED serves as the light source for this system. The light emitted by the LED is collected with an achromatic doublet and passed through a long-pass filter which helps the white light approximately simulate the spectral efficiency of the eye. The object under test is a 10-um pinhole. A second achromatic lens collimates the light from the pinhole and the focal length of that lens was selected so that the angular subtense of the pinhole is approximately the same angular subtense as a cone in the retina [3]. The collimated light then interacts with an ISO type 2 model cornea with +0.215 um of Zernike spherical aberration for 6 mm pupil [4]. The pupil in the model eye can be easily interchanged to simulate different lighting conditions. The IOL is suspended in a wet cell containing balanced salt solution, which approximates the refractive index in the eye. An objective is placed at the image plane to magnify and relay the image to a 16-bit CMOS camera, which is on a translation stage to allow through focus measurements. The optical test bench (Fig. 3) uses a cage system and custom mounts to ensure proper alignment.

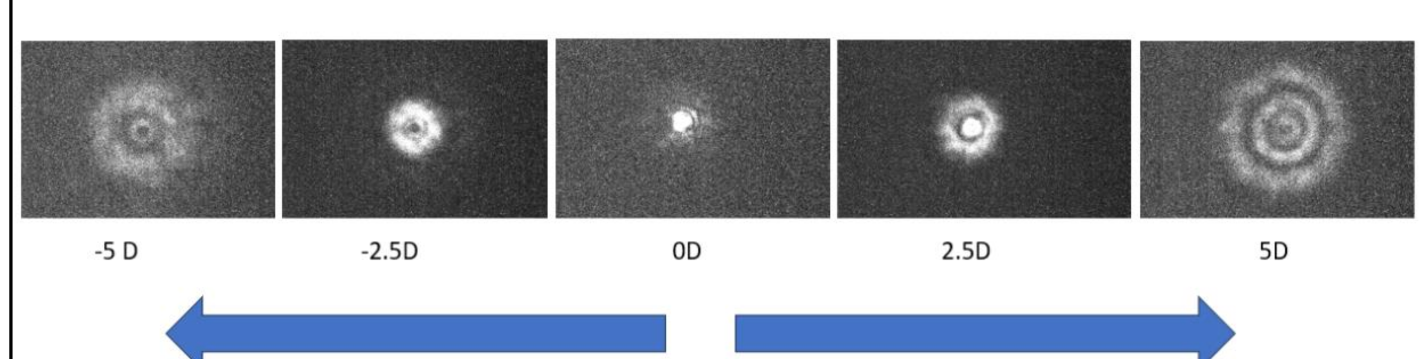
RESULTS

Monofocal IOL- Alcon SN60WF 19D



(A)

Multifocal IOL- Alcon SN6AD2 16D w/ +2.5D



(B)

Fig. 4 Through focus point spread function for (A) monofocal IOL and (B) multifocal IOL.

RESULTS

- Monofocal IOLS have a single, distinct best focus position and degrade relatively symmetrically around best focus (Fig. 4A)
- Multifocal IOLs demonstrates a secondary best focus position with a noticeable halo at the associated near-distance power (Fig. 4B)
- Toric IOLs have sagittal and tangential components that can be observed while moving through focus (Fig. 5)

Toric Multifocal IOL- Alcon SND1T3 21D +1.5D cyl w/ +3D

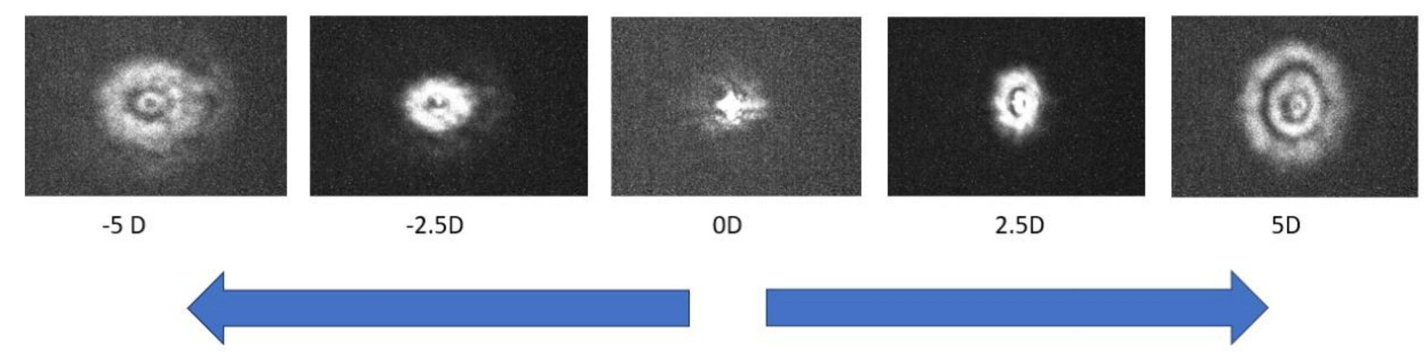


Fig. 5 Through focus point spread function for toric multifocal IOL.

CONCLUSIONS

An optical measurement system has been described and tested for finding the through focus point spread functions for IOLs. The 16-bit camera allows fine details in the tails of the PSF to be measured without saturating the peak. With the insights from the through focus PSF measurement, this information is now ready to be translated to the Fourier domain to determine the resulting 2-dimensional MTF (Fig. 6). The 2-D MTF found using this method provides a robust measurement of optical quality for different types of IOLs, including complex non-rotationally symmetric designs.

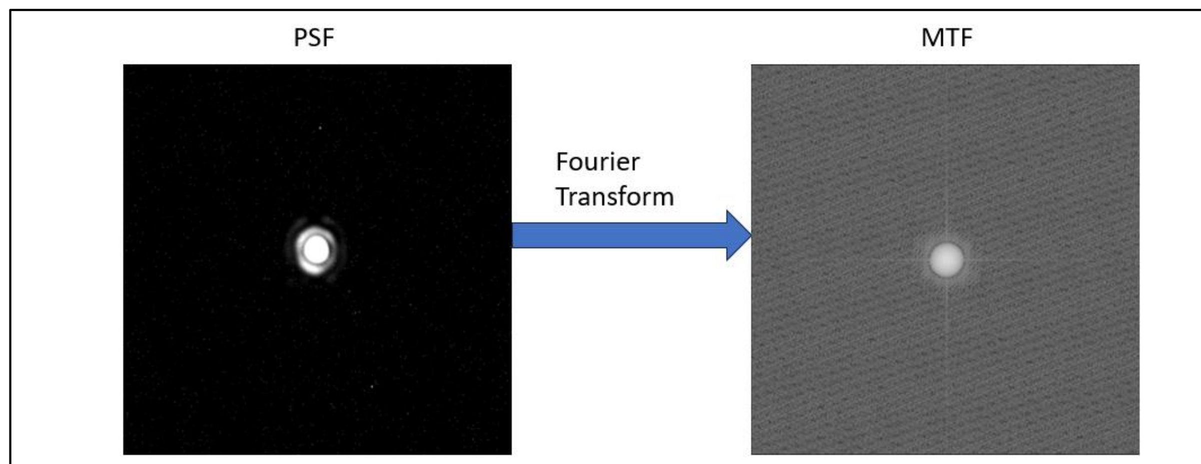


Fig. 6 Example of 2-dimensional PSF at the best focus position for a monofocal lens and it's associated 2-dimensional MTF after applying a Fourier transform.

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