Crystalens AO: Functionality and Real-World Performance

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Quality of Visual Outcomes With Presbyopia-Correcting IOLs

Our first responsibility is to do no harm.

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As a counterpart to Dr. Kezirian's article on visual quantity, this article discusses the quality of vision outcomes with presbyopia-correcting IOLs. As surgeons, it is important to be mindful of the dictum, "First, do no harm," when considering options for lifestyle-enhancing lens implants. Are we doing the best we can to assess our patients' present ocular conditions, and can we foretell their future vision as we select IOLs for them?

When considering the optimum premium presbyopia-correcting IOL for each patient, certain things are within our control, and certain things are not. Those factors outside of our control include our patients' pupil size, shape, diameter and dynamics; their risk for developing future comorbidities; and their potential for adapting to photic phenomena and glare. In terms of what we can control, can we guarantee that every patient will achieve a plano result? Can we predict the optical effect and the performance of the IOL if we do not achieve a plano result? Will we be able to align the lens along the visual axis that we cannot see during surgery? We must consider all of these factors when selecting presbyopia-correcting IOLs.

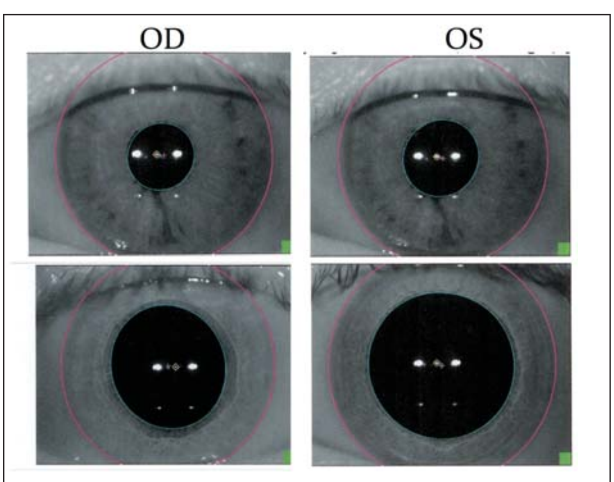


Figure 1. A patient's pupillary shape and anisocoria under different lighting conditions.

PUPILLARY SIZE AND LIGHT ALLOCATION

Most cataract surgeons do not measure the pupil preoperatively, yet the pupil's size largely dictates how IOLs function, particularly multifocal implants. Some pupils have a limited dynamic range; they may enlarge only 1 mm between photopic and mesopic conditions (and this range tends to narrow as individuals age[1]). Some patients have pupils of different sizes and shapes. Figure 1 shows a patient with a left pupil that is oval shaped and a right pupil that is round. The shapes of these pupils change even more significantly in the dark, which will impact the relative performance of a multifocal lens between each eye of this patient. We must take these considerations into account when selecting presbyopia-correcting lenses for our patients.

Figure 2 shows the distribution of light for various presbyopia-correcting IOLs. The AcrySof IQ ReSTOR IOLs +3.0 and +4.0 D (Alcon Laboratories, Inc., Fort Worth, TX) give 40% of the light to near and 40% to distance viewing with a 2-mm pupil. The drawback of these IOLs is that both near and far are cast simultaneously on the patient's retina, and he or she loses 20% of the available light. Although the Tecnis Multifocal IOL (Abbott Medical Optics Inc., Santa Ana, CA) is less pupil-dependent than the AcrySof ReSTOR, splitting the light 41% between near and distance, it loses 18% of the light energy to useless higher diffractive orders. We can imagine what reducing the energy at each primary focal point does to effect patients' contrast sensitivity. In

	Pupil	ReZoom	ReSTOR	Tecnis MF	Crystalens
Near	2 mm	0%	40%	41%	100%
	5 mm	32%	84%	41%	100%
Distance	2 mm	83%	40%	41%	100%
	5 mm	58%	10%	41%	100%
Intermediate	2 mm	17%	0%	0%	100%
	5 mm	10%	0%	0%	100%
Lost	2 mm	0%	20%	18%	0%
	5 mm	0%	6%	18%	0%

Figure 2. Distribution of light rays between various presbyopia-correcting IOLs.

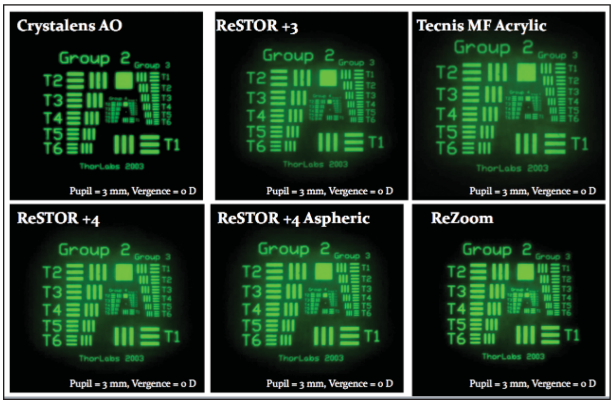


Figure 3. Sample images from the United States Air Force.[3]

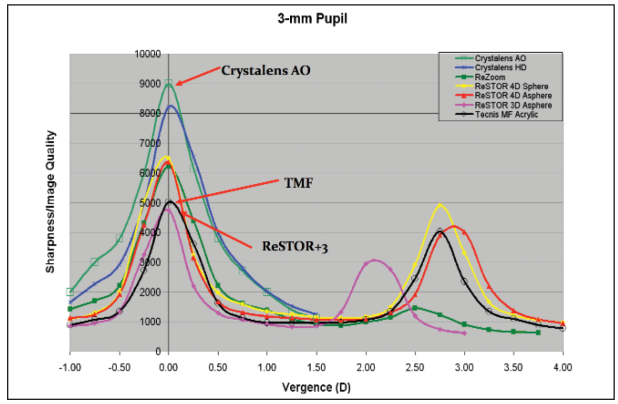
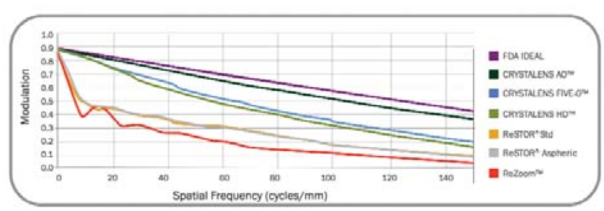


Figure 4. Note the peaks around plano (0.00). The image quality for the AO is far superior to the Tecnis Multifocal IOL and the AcrySof ReSTOR IOL +3.0 D at 3 mm (and at 4 and 5 mm). The peaks around plano predict the quality of vision at distance. The bench test cannot simulate accommodation, which is the reason the peak drops off for the Crystalens.[3]



MTF= Ratio of Image Contrast to Object Contrast as a Function of Spatial Frequency

Figure 5. Quality of vision with the Crystalens AO. Modulation transfer function, +22.00 D lenses at a 3-mm aperture.

addition, larger pupil size can negatively impact the performance of the Tecnis Multifocal at intermediate vision.[2] All models of the Crystalens Accommodating IOL deliver 100% of the light at every distance. These lenses do not lose light to higher diffractive orders, which is one reason why they offer high visual quality.

We have constructed an eye model into which we can artificially implant these IOLs. A CCD camera simulates the retina, so we can see the quality of the image the patient would see with each of these lenses at distance, intermediate, and near vision. My colleagues and I conducted an optical bench study in which we "implanted" six presbyopia-correcting IOLs into the model eye and tested them at four pupil diameters. We imaged a US Air Force target through each IOL in the model eye and captured the image digitally. Figure 3 shows the difference in visual quality between the lenses tested. Notice that there is an appreciable difference between the quality of the image through the Crystalens AO versus the other IOLs.

Then, we analyzed these images using a two-dimensional autofocus algorithm similar to that which is built into digital cameras. Figure 4 shows that in a 3-mm pupil, the Crystalens AO provides far greater sharpness than the Tecnis Multifocal and AcrySof ReSTOR lenses at distance. It is the same result for the 4-mm pupil. As the pupil gets larger, the image through all the lenses degrades, but the Crystalens AO's image remains the sharpest.

CONTRAST SENSITIVITY

Even before people begin to develop clinically significant cataracts, they begin lose contrast sensitivity as a result of age-related changes that affect the central nervous system. We need good contrast sensitivity across specific special frequencies to perform particular functions, such as recognizing faces or reading road signs at night. (It is important to note that diminished contrast sensitivity is not the same as blurry vision due to ametropia.) Multifocal IOLs reduce contrast sensitivity because they split light and produce optical scatter, and we must be sensitive to this problem in older patients who already have reduced contrast due to forward scatter of light produced by cataract and possibly other reasons. For example, we do not know who is going to develop comorbidities that may reduce contrast sensitivity in the future. Age-related macular degeneration (AMD) is the cause of more than half of all visual impairment among Caucasians,[4] and one in three people over the age of 70 has early stages of AMD. The Beaver Dam Eye Study showed that nearly 25% of patients aged 75 years or older had drusen.[5] Furthermore, in a 12-year study of high myopes, 40% developed maculopathy, which decreases contrast sensitivity.[6] In another a study of epiretinal membranes, 15% of 45 cataract patients showed this pathology on OCT scans. Most of these were not visible by ophthalmoscopy alone. These data mean we cannot assume that a patient will not lose contrast sensitivity in the future. Implanting a multifo-

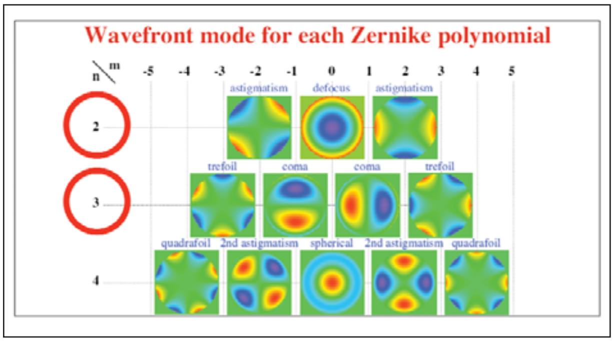


Figure 6. Decentration of an IOL with positive or negative spherical aberration induces third- and second-order aberrations.

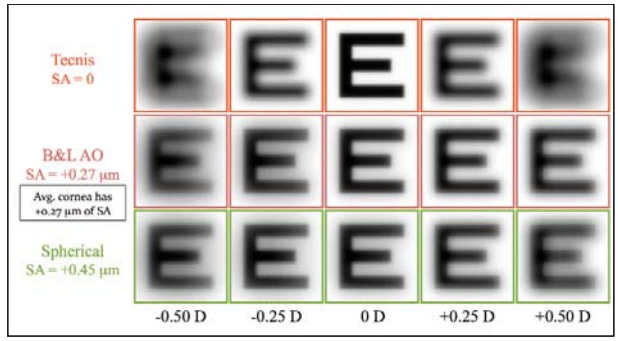


Figure 7. The effect of spherical aberration on depth of field with three IOLs.

cal IOL in the eyes of such patients may cause them problems down the road. Here again, the Crystalens AO achieves the closest to the ideal in terms of the modulation transfer function across every spatial frequency (Figure 5). Notice that adding asphericity to AcrySof IQ ReSTOR IOL did not significantly improve the relative image to object contrast.

LENS CENTRATION

Lens centration occurs on the visual axis, which is not aligned with the center of the IOL; nor is the capsular bag aligned with the center of the pupil. On average, an IOL is decentered about 0.5 mm from the visual axis.[7] With IOLs that have zero spherical aberration, like the Crystalens AO, decentration or tilt has very little effect. Decentration of a negative spherical aberration lens, however, such as the AcrySof IQ ReSTOR IOL or the Tecnis Multifocal IOL, causes second- and third-order aberrations (eg, coma and astigmatism) (Figure 6). Furthermore, the Crystalens AO has a broad tolerance for defocus. Again, missing plano with an IOL that has negative spherical aberration will cause significant image degradation with residual defocus (Figure 7).

SPHERICAL ABERRATION

There is an advantage to IOL's having a small amount of spherical aberration. First, spherical aberration offsets chromatic aberration. Studies conducted by Steven Schallhorn, MD, of Naval pilots who fly F-15s show that those eyes are not completely aberration-free. In monochromatic light, wave aberrations increase depth of focus. In polychromatic light, they counteract the retinal image blur from chromatic aberrations. Therefore, aberrations in the eye represent a biological tradeoff between excellent performance at a single distance or wavelength versus a slightly degraded but more positive performance at all distances across the visual spectrum. The Crystalens AO is more similar to the natural lens because it allows some natural aberrations to persist in the eye.

LIGHT SCATTER

A device that measures optical scatter shows the effect of the diffractive rings in a Tecnis Multifocal IOL versus the smooth optic of the Crystalens AO. In terms of nighttime glare, the FDA required a warning on the package of the ReSTOR and Tecnis multifocal IOL that recipients may experience reduced contrast sensitivity as compared to a monofocal IOL. Multifocal IOL patients are warned that they should exercise caution when driving at night and in conditions of poor visibility.

SUMMARY

Each presbyopia-correcting IOL design has inherent trade-offs with regard to contrast sensitivity, the distribution of light energy, depth of focus, night glare and photic phenomena, and near, intermediate, and distance image quality at any given pupil diameter. It is important to remember that image quantity is not the same as image quality. So, when considering which presbyopia-correcting IOL to implant in our patients, I would suggest that we follow Hippocrates' dictum and first do no harm. ■

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