Get to Know the Defocus Curve

An understanding of this concept is integral to assessing how well an IOL corrects presbyopia.

BY ROBERT J. CIONNI, MD

The number of IOL options for the correction of presbyopia during cataract surgery is growing. Options include diffractive multifocal lenses (AcrySof IQ Restor [Alcon Laboratories, Inc., Fort Worth, TX] and Tecnis Multifocal [Abbott Medical Optics Inc., Santa Ana, CA]), zonal refractive lenses (ReZoom; Abbott Medical Optics Inc.), and accommodating lenses (Crystalens [Bausch + Lomb, Rochester, NY] and Synchrony [Abbott Medical Optics Inc.; not available in the United States]).

The performance of these lenses depends on many factors such as biometry, degree of corneal astigmatism, the patient's disposition, and the predictability of the lens' position. Each will affect residual refractive error, visual disturbances, and satisfaction rates and may vary by lens. Comparing the different IOLs' performance in clinical practice therefore can be difficult. One strong, objective, clinical measure of how well a lens is correcting presbyopia, however, is the defocus curve. It also directly addresses the main factor that drives patients to consider a presbyopia-correcting IOL in the first place— their desire for good visual acuity at all distances.

HOW THE CURVE IS PRODUCED

The easiest way to explain a defocus curve is through an example. Figure 1 contains defocus curves that summarize the results of binocular defocus testing for the Tecnis Multifocal lens, the AcrySof IQ Restor IOL +3.0 D, and the AcrySof IQ Restor IOL +4.0 D. The information is adapted from the lenses' product inserts.[1,2]

The curve is produced as follows. The patient is corrected for best distance acuity in both eyes while viewing a distant eye chart; this is the "zero" mark and thus, by definition, is a peak for all lenses tested. Correction for best distance acuity removes variability in results that might be related to residual refractive error. This means that the lens' function is being tested, rather than biometric accuracy or surgical variability. In other words, the approach puts each lens tested on a level playing field by eliminating any unintentional bias that might come from residual refractive error.
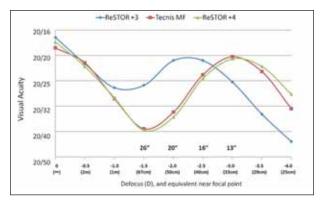

Figure 1. Relative defocus curves from product inserts. (Data adapted from product information/package inserts.[1,2])

Once the patient is best corrected at distance, an additional lens is introduced in front of each of his or her eyes simultaneously to produce some defocus, and his or her acuity with that level of defocus is tested. Typically, the examiner will use -0.50 D to start and then add more minus power in 0.50 D increments. As successive lenses are introduced, acuity is likely to change. A typical range of defocus testing might be from +1.00 D to -4.00 D; plano to -4.00 D is shown in Figure 1. The results for a single patient can be plotted, or the results for a group of patients can be averaged and plotted.

INTERPRETATION

The key to interpreting the resultant defocus curve is the relationship between lens vergence and distance focus. Viewing a distant object through a -1.00 D lens is optically equivalent to viewing an object at 1 m, and viewing a distant object through a -4.00 D lens is optically equivalent to viewing an object at 25 cm. The defocus curve, then, provides an objective measure of expected vision at different distances.

In Figure 1, all three lenses provide excellent distant visual acuity. Emmetropic postoperative patients therefore should be pleased with their distance vision. At about 39 inches (1 m), the visual acuity for the AcrySof IQ

By Guy M. Kezirian, MD

Defocus curves provide a useful method by which to compare the optical performance of technologies, as Robert Cionni, MD, describes in his article. Defocus curves are also an excellent tool to help clinicians understand the impact that postoperative refractive errors have on their patients' vision after surgery.

The creation of defocus curves commonly involves placing lenses in front of an eye while measuring the change in visual acuity that results from various amounts of refractive error. Alternatively, the visual acuity can be measured in multiple eyes with various amounts of refractive error and plotted for a population. The data from defocus curves can be plotted in several formats for different purposes, such as determining the impact of astigmatism on visual acuity for eyes with the same spheroequivalent refractions (Figure 1).

Defocus curves must be measured separately for distance, intermediate, and near in order to fully identify the impact that refractive errors will have on visual performance at any given distance. In other words, one cannot assume that the defocus curve for distance will describe visual performance at near.

When analyzing defocus curves in the context of IOLs, it is important to consider the effect of spherical aberration on the patient's ability to see in the presence of a refractive error. Patients whose eyes have significant spherical aberration usually tolerate defocus better than those whose eyes are without spherical aberration (ie, eyes with flat wavefronts), because the former can find some point in the wavefront where the image is clear and use that point to read the eye chart. This is the basis of "depth of focus" claims with IOLs that use spherical aberration to increase reading ability. The cost of spherical aberration, of course, is in image contrast, which decreases as spherical aberration increases (Figure 2).

Spherical aberration, in turn, is affected by pupillary size. For this reason, defocus curves can only be interpreted when the pupil's size is provided. With optical systems that have known spherical aberration, defocus curves can be used to characterize the impact that the spherical aber-
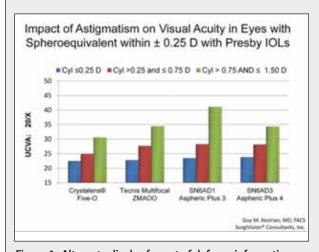

Figure 1. Alternate display format of defocus information to compare the impact of astigmatism on visual acuity for eyes with plano spheroequivalent refractions. The bars show increasing amounts of astigmatism for each IOL, and each bar averages the data from at least 20 eyes. Note that even the small amounts of astigmatism shown in this graph cause significant reductions in visual performance and that multifocal IOLs, which have more complex optics, are more affected by astigmatism than the monofocal optic of the Crystalens (Bausch + Lomb, Rochester, NY).
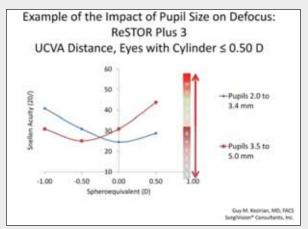

Figure 2. The pupil's size has a significant impact on people's ability to tolerate defocus in optical systems that rely on spherical aberration or multifocality for their effect. In this graph, the mean visual acuity at each 0.50 D spheroequivalent point from -1.00 D to +1.00 D is plotted for eyes at two pupillary sizes for the AcrySof IQ Restor IOL +3.0 D (Alcon Laboratories, Inc., Fort Worth, TX). The plot shows that eyes with larger pupils tolerate myopic defocus better (ie, have better visual acuities in the presence of refractive errors) than eyes with smaller pupils. Eyes with smaller pupils see better at distance when emmetropic, because the peripheral, minus focused light was excluded. Each data point is the average of at least 20 eyes.

ration has on visual performance. This is done by introducing similar refractive errors with various pupillary diameters and measuring the resulting visual acuity. If the visual acuity measurements stay the same with different pupillary sizes (and the same refractive error), then one can infer that there is little if any spherical aberration present in the optical system and vice versa. The pupil's size therefore has a major impact on visual acuity with multifocal IOLs, because these lenses have different powers across their diameter. If a small pupil blocks the light from reaching the part of the lens that would provide the correct focus at a given distance, the patient's vision will be blurred.

In any case, the results of defocus curve measurements should be averaged and described using population statistics, because significant individual variation exists from one patient to the next. It is not valid to claim that X amount of defocus results in Y drop in visual acuity, whether one is describing an IOL, a laser ablation pattern, or another technology, because some people will lose acuity more rapidly than others for the same refractive error.

Defocus curves allow surgeons to understand the impact of postoperative refractive errors on the visual performance of various presbyopia-correcting IOLs. Many ophthalmologists are surprised to see the rapid fall in vision with these lenses that results from small refractive errors, particularly residual astigmatism (Figure 1). The lesson is that these lenses rely on good refractive outcomes to deliver their full benefit.

An excellent review of historical data for defocus is available in the landmark article by Holladay et al.[1]

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1. Holladay JT, Lynn MJ, Waring GO 3rd, et al. The relationship of visual acuity, refractive error, and pupil size after radial keratotomy. *Arch Ophthalmol.* 1991;109(1):70-76.

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Restor IOL +3.0 D exceeds that for the other two lenses. The best near visual acuity for the AcrySof IQ Restor IOL +3.0 D is achieved between 16 and 20 inches versus around 13 inches (33 cm) for the other two IOLs.

Several other important observations can be drawn from Figure 1. First, intermediate acuity is significantly better for the AcrySof IQ Restor IOL +3.0 D relative to the other two lenses. To elaborate, the intermediate acuity for this lens drops to only about 20/25 at a distance of 26 to 39 inches. In contrast, the intermediate acuities for the Tecnis Multifocal and +4.00 D lenses are significantly lower at these distances and drop as low as 20/40 at 26 inches. This difference is important because patients often require intermediate acuity to work at a computer. Additionally, the approximately 20/25 or better vision for all distances found with the defocus curve for AcrySof IQ Restor IOL +3.0 D compared with the approximately 20/40 or better vision for all distances found with the defocus curves for the +4.00 D design and the Tecnis Multifocal will be clinically relevant to many patients, based on my past experience with individuals who received the AcrySof IQ Restor IOL +4.0 D.

The similarity in the defocus curves obtained for the Tecnis Multifocal lens and the AcrySof IQ Restor IOL +4.0 D is remarkable: the same near focus and the same reduction in intermediate acuity. The latter is to be expected, because both IOLs provide about a +3.00 D add at the spectacle plane, whereas the approximate add of the AcrySof IQ Restor IOL +3.0 D is about +2.50 D (based on the package inserts/product information[1,2]). The higher the add power is, the lower intermediate acuity is likely to be, because vision will degrade gradually between the near and far foci of a lens.

CONCLUSION

Each IOL manufacturer generates marketing data that depict favorable results for its implant designs based on bench laboratory testing such as modulation transfer function and air force bar targets. Why do the results look so different for each company? It is important to keep in mind that these tests can demonstrate widely varying results based on the researchers' testing design. Moreover, unlike the defocus curve, modulation transfer functions and air force bar targets do not take into account the effect of binocularity, neural processing, patients' adaptation, and varying ocular geometries. In other words, the defocus curve is a real-world measure rather than a bench test designed by a researcher.

Whatever presbyopia-correcting lens or lenses an ophthalmologist is using, the defocus curve is an important measure of the IOL's performance. Personally generating defocus curves for a few patients for each lens type can be

DISCUSSION

By Scott M. MacRae, MD

For his article, Robert Cionni, MD, measured through-focus visual acuity binocularly, which allows a better assessment than a monocular approach. It is interesting that visual acuity at 16 inches is satisfactory with all three of the multifocal lenses discussed and peaks at 18 inches with the AcrySof IQ Restor IOL +3.0 D (Alcon Laboratories, Inc., Fort Worth, TX).

Dr. Cionni's article does not address other factors such as corneal aberrations (especially astigmatism), pupillary diameter, and letter contrast. In a separate unpublished study at the University of Rochester that evaluated image quality, my colleagues and I found that the Tecnis Multifocal lens (Abbott Medical Optics Inc., Santa Ana, CA), the AcrySof IQ Restor IOL +3.0 D, and the AcrySof IQ Restor IOL +4.0 D lose their depth of focus when there is 1.00 D or more of residual astigmatism. More complex aberrations such as coma and spherical aberration combined with astigmatism can be even more visually disruptive. Clinicians need to be alert as to how residual astigmatism and corneal aberrations can undermine patients' visual quality and their depth of focus.

Dr. Cionni's report looks at visual acuity, but other issues are also important: visual quality, functional reading speed, and comfort. Perhaps assessing these issues will help ophthalmologists understand why a small number of patients who otherwise have an excellent anatomic surgical result may have persistent complaints. The binocular approach gives additional information with which to assess patients' functional capabilities.

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instructive, but it can also be time-consuming. Alternatively, surgeons can review and understand the defocus curve that is provided in the product insert. The defocus curve is also the best objective indicator of the expected range of vision for a patient using any presbyopia-correcting lens, and it can help ophthalmologists set realistic expectations for their patients. ■

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1. Figure 5. Tecnis Multifocal 1-Piece Intraocular Lens [package insert]. Santa Ana, CA: Abbott Medical Optics Inc.; 2009.
2. Figure 9. AcrySof IQ Restor Product Information—6 Months Directions for Use. Fort Worth, TX: Alcon Laboratories, Inc.; 2009.