VOLUME 12, NUMBER 11 • NOVEMBER 2008

REFRACTIVE EYECARE®

SPECTACLES, CONTACT LENSES, AND CORNEAL AND LENTICULAR REFRACTIVE SURGERY FOR PRACTICE GROWTH

Understanding Problems with Presbyopic IOLs: Look to the Cornea

Ming Wang, MD, PhD

While most patients are very happy with their presbyopic IOLs, some patients are not. This article suggests that sometimes a low level of *corneal* aberration—a level that would not be a problem with a monofocal IOL—may produce significant problems when a presbyopic IOL is implanted.

As the sum of human knowledge grows, each of us knows an ever smaller fraction of the whole. Certainly, we see this trend in medicine. Once a profession of generalists, medicine evolved into specialties like pediatrics, internal medicine, and ophthalmology. And as that trend has continued, we have focused on ever smaller parts of the human body, becoming specialists in a single piece of tissue or a single disease.

To properly take care of our patients, however, we have to see our tiny piece of tissue as part of a larger context. Sometimes, as we improve the function of one part of the eye—for instance, by improving the optics of intraocular lenses (IOLs)—another part of the eye, the cornea, can emerge as the new rate-limiting step in vision. To truly improve a patient's overall vision, one must not only be willing to specialize but also to "despecialize" and become a generalist again.

Larger Systems

When a patient experiences a visual problem following cataract surgery and IOL implantation, our first (and often our only) impulse is to ask what is wrong with the lens and/or the associated surgery. While sometimes the problem is indeed in the lens, it also may be due to sources other than the lens. To successfully analyze and address the problem, we may find it helpful to step back and view the lens as part of a larger system.

Specifically, I will argue in this article that some of the vexing problems that we encounter in multifocal IOL patients—and to a lesser degree in accommodating IOL patients—derive not from our IOLs but from non-lens parts of the anterior segment, including the cornea, anterior chamber (AC), and pupil.

New Powers, New Problems

Despite the success of today's new presbyopic IOLs, some patients are unhappy with their results. Particularly troublesome is that (1) we are largely unable to predict which patients will be unhappy and (2) in many, perhaps most, of the patients who do have problems, we can find no obvious explanation.

I believe that part of our failure to explain patients' dissatisfaction occurs because we have been so focused on the lens that we have forgotten about the rest of the visual system. Specifically, we have forgotten that as IOLs have improved in recent years, other parts of the visual pathway may have emerged as the new rate-limiting step in vision.

Why do we have to worry more about other non-lens structures *now*? When only monofocal IOLs were available, we had little interest in other structures. What has changed? The answer is that the new presbyopic IOLs have become so sophisticated in their structural refinement and spatial resolution that the IOL has become optically superior to other parts of the visual pathway.

CAUSES OF NONPERFORMANCE OF NEW PRESBYOPIC IOLS

- Is the cornea sufficiently regular?
  - Use RGP lenses to test, if needed
- How steep is the cornea?
  - With ReZoom®, a steeper cornea will result in stronger distance vision
  - With ReSTOR®, a steeper cornea will result in stronger near vision
- How deep is the AC?
  - With ReZoom, a shallower AC will give patients more near vision
  - With ReSTOR, a shallower AC will give patients more distance vision
- How large is the pupil?
  - With ReZoom, wider pupils will give patients more near vision
  - With ReSTOR, wider pupils will give patients more distance vision
- How fast do pupils change and what is the range of pupil sizes?

Monofocal IOLs Can Tolerate More Irregularity

With traditional monofocal IOLs, the lens is a uniform structure—a single spherical or aspheric curve spans the entire lens—so the optics of the lens are relatively crude, and spatial variation across the lens occurs on a very large scale (millimeters). The lens is thus fairly insensitive to minute aberrations in other parts of the visual system such as the cornea. Even if the cornea is slightly irregular and misdirects the light beam by a small amount, causing the light to strike the lens at a slightly different position, this landing at the wrong spot will matter very little, thanks to the spatially invarient structure of the lens.

The new presbyopic lenses have fundamentally changed that situation. These lenses have much spatially finer features, so exactly where light strikes these lenses does matter. Mild corneal irregularity that would not be a problem with monofocal lenses may now be a problem with multifocal IOLs, since misplacement of the beam by just a few microns can now make a significant difference in vision. Hence, presbyopic IOLs place a greater demand on *corneal* regularity in order to achieve proper function of the *lens*.

Stricter Standards for Corneal Normalcy

Our definition of what is "normal" and what is "abnormal" for one particular structure in the visual pathway can change when the quality of the optics in the rest of the visual system changes. While no cataract surgeon would consider implanting a multifocal IOL in a patient with a significantly irregular cornea, such as a patient with keratoconus, corneas that we might previously have considered normal for the purposes of implanting a monofocal IOL may now be considered abnormal for a multifocal IOL.

For a monofocal IOL, I might consider 99% of corneas to be normal and only reject the 1% with the highest levels of corneal irregularity. However, the advent of multifocal IOLs with higher spatial resolution demands a new, *higher* standard of corneal normalcy. With the new standard, we may now have to reject a higher percentage of corneas (say, 10%) because they are too irregular to work with the new IOLs.

When we look at corneal topography, we typically see bowtie patterns, which we categorize as either symmetrical or asymmetrical. A perfectly symmetrical bowtie would have two areas of identical size and curvature that are oriented at exactly 180 degrees. However, even if we look at 100 normal people, we would be hard pressed to find a bowtie that is perfectly straight. Previously, with traditional monofocal IOLs, we might have tolerated 10 degrees of bending in a bowtie pattern and still considered that bowtie to be normal. Now with the new multifocal IOLs, more than 1 degree of bending might be considered abnormal. Similarly, our tolerance for asymmetry in the size of the two halves of the bowtie also depends on the stringency with which we define the normal range (Figure 1).

Multifocal IOLs Demand Higher Corneal Normalcy

Currently, three presbyopia-correcting lenses are marketed in the US: ReZoom® (AMO), AcrySof® ReSTOR® (Alcon), and Crystalens® (Bausch & Lomb).

The first of these lenses, ReZoom, is a refractive lens with a 6-mm optic consisting of five concentric rings: a distance zone in the center surrounded by alternating rings for near and distance vision. By dividing the radius of the optic (3 mm) by the number of rings and transition zones (10), we can determine that the zones average 300 microns in width.

Compared to a 6-mm monofocal IOL in which a single optical zone occupies the entire lens, the spatial resolution of optical features on the ReZoom lens is 10 times smaller. As a result, the ReZoom lens is "pickier" than traditional monofocal lenses, in that it requires more precise corneal focusing to ensure that the light beam strikes exactly the intended position on the IOL.

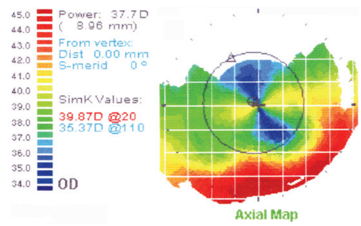

FIGURE 1 A mildly asymmetrical bowtie might be considered adequately "symmetrical" for the less demanding traditional monofocal IOLs but "asymmetrical" for more demanding new presbyopic IOLs.

The other available multifocal lens is the AcrySof ReSTOR, which has a 6-mm optic consisting of both refractive and diffractive zones. In the central 3.6 mm of the lens, the optic is diffractive, while the surrounding area is a refractive zone with a single power for distance. The central diffractive zone of the ReSTOR lens splits light into two focal points—one for near vision and one for distance—by means of multiple tiny steps (≈ 5 microns) of varying heights.

Unlike ReZoom, the center portion of the ReSTOR lens gives priority to near vision, and the lens therefore emphasizes near vision when the pupil is small. In terms of its requirement for corneal normalcy, the ReSTOR lens may be even more demanding than the ReZoom lens, since the multiple steps in the diffractive zone are more numerous than the five rings of the ReZoom design.

In summary, compared to a monofocal design (500-5,000 microns), the more spatially refined ReSTOR and ReZoom lenses (5-300 microns) demand a higher degree of *corneal* regularity in order for the *IOL* to perform.

Accommodating IOLs Are Also More Demanding

The accommodating Crystalens is more like a monofocal IOL, but it also has design features that make it more demanding of corneal regularity than a traditional monofocal lens. First, the Crystalens optic is only 5 mm, compared with the 6 mm or 6.5 mm optics of most other monofocal IOLs, so light must be targeted more precisely in order to strike the appropriate location on the optic.

Second, the Crystalens is thought to provide some accommodative ability by moving anteriorly and posteriorly. The Crystalens may also achieve some of its accommodative effect from bowing and flattening, which would also affect the Z-axis position of the lens. Because most light rays enter the eye at an angle, this Z-axis movement could actually alter the position on the lens where the light beam strikes, further enhancing the demand for accurate positioning of the light beam hitting the lens. Hence, compared with traditional monofocal lenses, the Crystalens also requires a higher degree of corneal regularity.

While all three of the currently available presbyopic IOLs have different design features, they all share one common feature: they all require a higher degree of corneal regularity than traditional monofocal IOLs. Since these new lenses need light to strike specific locations on the lens in order for it to perform, light rays must be refracted by the cornea in a more precise and predictable way, and a slightly irregular cornea can have dramatic visual consequences if paired with a presbyopic IOL.

A New "Weakest Link"—the Cornea

We know from refractive surgery that removing a layer of tissue just 10 microns thick in the Z-axis produces 1 D of refractive change. Similarly, just 500 microns of decentration in the horizontal X-Y plane can result in clinically significant visual symptoms (Figure 2). Thus the scale on which corneal imperfection is clinically important is on the order of 10 to 500 microns.

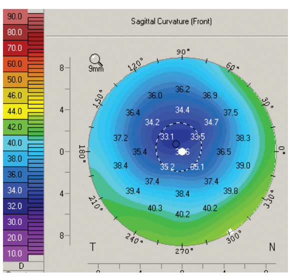

FIGURE 2 Observing the visual symptoms that result from decentered ablations shows us the spatial dimension and scale on which corneal aberrations become visually significant.

The cornea and the IOL differ in the dimension of clinical importance. For a monofocal IOL, spatial variation occurs on a scale of millimeters, but with presbyopic IOLs, it occurs over as little as a few microns. In between these two extremes lies the dimension of clinical importance for the cornea—approximately 10 microns to 500 microns.

When we were implanting traditional monofocal IOLs, the cornea (10-500 microns) was a better optic than the lens (500-5,000 microns). As a result, the coarser optics of the traditional monofocal IOL was the rate-limiting factor in vision.

However, with the advent of new presbyopic IOLs that have features on a much smaller scale (5-300 microns), these lenses now have become the better optic, and the cornea the worse one (Figure 3). Because of this new and inverted relationship, even a mild degree of corneal irregularity, which does not cause any problem with traditional monofocal IOLs, can now cause visual problems, making the cornea the new weak link in the visual system.

Anterior Segment Dimensions Are Important

While presbyopic IOLs can provide the great majority of patients with significant benefits, some patients are not happy with presbyopic IOLs, and we often do not know why. Because we cannot find a physical cause, the main strategy for patient selection is to operate only on less demanding patients.

Here, I would like to suggest some new guidelines with regard to physical dimensions of anterior segment structures that may help us better predict the success of these new lenses. As we have seen, we need to pay greater attention to even mild corneal abnormalities when selecting the appropriate patients for these new lenses. In addition, I would like to propose that corneal steepness, anterior chamber (AC) depth, and pupil size are also important.

Corneal Steepness and AC Depth Can Affect Vision

If two eyes are identical except for corneal steepness, the *steeper* cornea will bend light more, and light will strike a *smaller area* in the center of the IOL. With a monofocal lens this variation makes little difference, since the refractive power is about the same throughout a large central area of the lens. With multifocal lenses, however, corneal steepness can actually affect IOL performance. For example, with a ReZoom lens, a steeper cornea will result in preferential use of the center of the lens, and thus stronger *distance* vision, while with a ReSTOR lens, it will result in stronger *near* vision (Figure 4A).

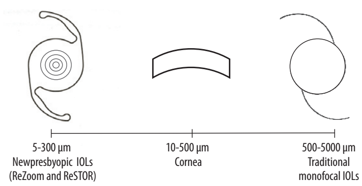

FIGURE 3 The shift from monofocal IOLs to multifocal IOLs has reversed the ranking of optical quality between the IOL and the cornea. With monofocal IOLs, the lens was the crudest part of the visual pathway, but with today's more spatially-refined IOLs, the cornea has now emerged as the new limiting factor.

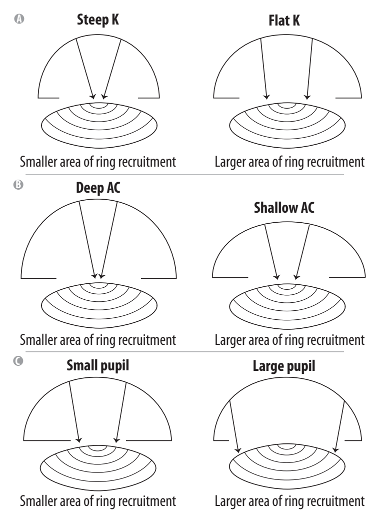

FIGURE 4 Corneal steepness, anterior chamber depth and pupil size can all affect where light hits the IOL optic. While not important considerations for traditional monofocal IOLs, these factors are important when implanting presbyopic IOLs.

Similarly, variations in AC depth can affect vision by altering where light strikes the lens. In two eyes that are identical except for AC depth, light will strike a larger area of the IOL in the eye with the shallower AC, since the lens is closer to the endothelium (Figure 4B). As a result, patients with a shallower AC will have more light passing through the peripheral zone of the lens. For patients with a ReZoom lens, this recruitment of the peripheral lens area will yield more near vision, while patients with a ReSTOR lens will experience the opposite effect, gaining more distance vision.

Pupil Size Can Now Also Affect Vision

Pupil size, dynamic range, and speed of change—while having almost no effect on monofocal lenses—can now significantly affect the visual performance of presbyopic

IOLs. The smaller the pupil, the more priority will be given to the center of the lens optic, resulting in preferential use of either near or distance vision zones, depending on the lens design. Pupil dilation will then recruit additional peripheral rings on the lens, resulting in a shift in the visual function between distance and near (Figure 4C).

For example, a smaller pupil will result in more use of the central lens area with a ReZoom lens and hence better distance vision; with a ReSTOR lens, the effect will be just the opposite, with patients gaining better near vision. Further complicating the matter, changing light conditions will change the size of the pupil, and different patients have different speeds of pupil size change and different dynamic ranges of pupil size.

As a result, these new multifocal IOLs give us a mixed bag of near and distance vision that varies with different patients and different conditions. This variation could account for some of the uncertainty and unpredictability of visual performance associated with these IOLs.

This discussion of corneal irregularity, corneal curvature, AC depth, and pupil sizes shows that, in some cases, we can indeed go beyond psychology in patient selection and look at a set of non-lens physical dimensions. These factors, although they may not affect vision with traditional monofocal lenses, can be visually significant with presbyopic IOLs.

Wavefront Data Not Useful

One flawed screening strategy is performing preoperative wavefront aberrometry and implanting premium IOLs only in patients with normal wavefronts. Because a wavefront image is a measure of the sum of aberrations of the entire visual path, it does not allow us to evaluate corneal aberration independently of other aberrations. Therefore, even if the wavefront image showed only a small amount of overall aberration, the cornea could still be significantly aberrated, since the crystalline lens naturally contains compensatory aberrations to offset the corneal aberration. In such a situation, the preoperative wavefront may appear normal, but after a cataractous lens is removed, the corneal aberrations would be unmasked and would become clinically important—and it would be impossible to "remask" these aberrations with the inserted IOL.

Therefore, we need better technologies for determining purely corneal aberration. With such equipment, we could screen patients based on more stringent criteria for corneal regularity and implant premium IOLs only in those patients whose corneas meet these higher standards.

New Options to Improve Patient Selection

I believe that lens selection should be influenced by what we know about the cornea. For example, if I am concerned that a patient's cornea may be slightly aberrated, I might consider implanting a Crystalens rather than a ReZoom or ReSTOR lens, since the more uniform and less spatially variant design of the Crystalens makes it somewhat more forgiving of corneal aberrations. I also advocate closer preoperative evaluation of non-lens anterior segment dimensions, such as corneal steepness, AC depth, and pupil size.

To bring the presbyopic IOL technology to the next level, I would like to propose a systematic study to correlate the degree of corneal irregularity with the presbyopic IOL visual performance. From such a study, we can identify the appropriate clinical threshold level of corneal irregularity above which we should not implant the presbyopic IOLs.

Postoperatively, rigid gas permeable (RGP) lenses can be used to see if the cornea is the culprit. If RGP lenses significantly improve vision, then the cornea is indeed the problem. I currently have an ongoing study in which I have identified a series of patients with presbyopic IOLs who are not happy with their vision, in whom RGP lenses reduced the problem.

If the cornea is the problem, surgeons may want to consider ways to regularize the cornea, including hydration, topographically driven keratorefractive treatments, or even implanting Intacs® segments (Addition Technology, Inc.). I would caution against performing wavefront-guided keratorefractive treatment (LASIK or surface ablation) in these patients, however, since wavefront readings taken through highly spatially variant multifocal IOLs are often inaccurate.

THE BOTTOM LINE

Presbyopic IOLs can provide superior vision for many patients, but we need to take a "big picture" approach if we are to fully understand how and why they work for some individuals but not for others. Improvement in one area of medicine (the IOL) can sometimes cause another area (the cornea) to emerge as the new rate-limiting step. Because presbyopic IOLs now have a much more refined spatial structure, they demand a higher degree of corneal regularity in order to achieve proper function of the lens. Some mild corneal irregularities that would not affect the performance of traditional monofocal IOLs may now, in fact, create significant problems with multifocal IOLs. Clinically, this means that we now need a new and stricter definition of corneal normalcy, which may reduce the number of candidate eyes suitable for the new multifocal lenses. With regard to patient selection for these new IOLs, some anterior segment dimensions may be predictive, including corneal irregularity, corneal steepness, AC depth, and pupil size.

Ming Wang, MD, PhD, is a clinical associate professor of ophthalmology at the University of Tennessee; director of Wang Vision Institute in Nashville, TN; medical director of refractive surgery at the Aier Eye Hospital Groups in China; and international president of Shanghai Aier Eye Hospital in China. **He has no financial interest in any product discussed. He expresses appreciation to Dr. Jeff Horn, MD, for discussion. *Refractive Eyecare* editors Kay Downer and David Kellner assisted in the preparation of this paper.**