Until recently, the treatment of presbyopia included a variety of suboptimal modalities, such as progressive lens spectacles; bifocal contact lenses; monovision using contact lenses, IOLs, or conductive keratoplasty; and other more questionable techniques, including scleral implants and multifocal excimer laser corneal surgery. Recent improvements in phacoemulsification have afforded safe and efficacious cataract and lens extraction techniques, and partial coherence interferometry for axial length measurement provides preoperative measurements and calculations allowing excellent results that continue to improve. As a result of improved outcomes with lower energy, smaller incisions, and adjunctive astigmatic techniques, the increased accuracy and safety in cataract surgery has led to a natural evolution in refractive surgery.

Corneal refractive surgery has limitations, including high hyperopia, high myopia, cataract, and, questionably, presbyopia. It is highly likely that lens modalities will become the dominant refractive surgical procedure in the not-too-distant future. Newer techniques, specifically designed to remove soft, clear lenses, have led to minimally invasive, maximally safe refractive lens exchange (RLE).

With increasing age, spherical aberration remains stable in the cornea; however, it changes in the crystalline lens. When refractive surgery is performed on the cornea—including the most sophisticated custom-shaping techniques—spherical aberration still changes in the human lens, thereby degrading the outcome.

IOLs for Refractive Lens Exchange

Presbyopia-correcting IOLs for RLE include the ReZoom (Advanced Medical Optics, Inc., Santa Ana, California), Restor (Alcon Laboratories, Inc., Fort Worth, Texas), Eyeoneics Crystalens (Bausch & Lomb, Rochester, New York), Tecnis Multifocal IOL (Advanced Medical Optics, Inc.), Synchrony Dual-Optic accommodating IOL (Visiogen, Irvine, California), NuLens (Herzliya, Israel), and SmartIOL (Medennium, Irvine, California), as well as other new and innovative technologies.

With the continuing evolution of presbyopia-correcting IOLs, it seems highly likely that accommodating IOLs will supplant multifocal IOLs for several reasons: (1) While multifocal IOLs require no accommodative effort, they do require central nervous system adaptation; however, in an accommodating IOL, there is no need for adaptation; (2) multifocal IOLs almost always cause halos or blur circles; (3) some loss of contrast sensitivity occurs with the use of multifocal IOLs; (4) multifocal IOLs should not be used in the presence of age-related macular degeneration (AMD) or cornea guttata; (5) accommodating IOLs more closely mimic patients’ experience as prepresbyopes; (6) in an accommodating IOL, all of the light comes from the object of regard; (7) accommodating IOLs do not cause unwanted retinal images or loss of light energy or contrast sensitivity; and (8) accommodating IOLs provide continuous excellent vision at all distances.

Accommodating IOLs must provide adequate accommodation to avoid reading fatigue and, in most cases, they require adequate capsule clarity and elasticity; however, they hold great promise as ideal IOLs. There are several ways to characterize accommodating IOLs. Perhaps the best characterization method is by mechanism of action. In this article, we discuss the following IOLs: (1) those that theoretically move within the eye and change refractive power, (2) dual-optic IOLs, (3) deformable optic IOLs, and (4) innovative technology IOLs.

Lenses That Move Within the Eye

Crystalens. Although several accommodating IOLs are available in Europe, the only US Food and Drug Administration (FDA)-approved accommodating IOL is the Crystalens. This lens provides excellent distance and intermediate vision and fair near vision. Although theoretically the optic moves anteriorly and redistributes the ciliary body mass on accommodative effort, new data (iTrace; Tracey Technologies, Houston) indicate that it is...
really a deformable-optic IOL. A curvature change occurs in the IOL with accommodative effort (ie, accommodative arching or asymmetric tilting of the lens).

Figures 1 and 2 demonstrate the difference between phakic accommodation in a 19-year-old college student and accommodation in a 62-year-old patient with a Crystalens AT-45. In the Crystalens patient, change takes place in a small portion of the central pupil, suggesting a deformation rather than full movement of the lens that results in the accommodative amplitude.7

According to quality-of-life surveys, 25.8% of patients with bilateral Crystalens (n=130) never wear spectacles, and 47.7% almost never wear spectacles, leading to a relative spectacle independence of 73.5%, a number comparable with US survey data for multifocal IOLs.

In our own practice, we commonly use the Crystalens for high myopes, tall patients, and monocular cataract patients. Most of our highly myopic patients are 20/20 and J1 uncorrected postoperatively, which may be related to the thinness of the optic in high myopes compared with emmetropes or hyperopes. When the optic is thinner, it has greater facility for deformation. In theory, because the lens arches posteriorly in the lens capsule, it may stabilize the vitreous face and result in a lower incidence of retinal detachment in high myopes.

The Crystalens is an excellent choice for tall patients because their near work is done at what we normally consider to be intermediate distances. Monocular optics also allow its use in patients with early AMD or cornea guttata. Additionally, the Crystalens is our first choice for monocular cataract patients who do not want an operation in the second eye until it is necessary. We have a 10% enhancement rate in hyperopes, which may be because the effective lens position is not predictable.

Although approved by the US FDA (but not yet released in the United States), an investigational study
documents that the new HD 5.0 Crystalens provides one line greater near visual acuity than the AT-50 model.

**DUAL-OPTIC ACCOMMODATING IOLs**

**Visiogen.** We are investigators in the FDA-monitored study of the Visiogen Synchrony Dual-Optic accommodating IOL (Figure 4). In its 3-D configuration, this IOL mimics the function of the natural lens. It is available in a preloaded injector that fits through a 3.8-mm clear corneal incision. More than 500 IOLs have been implanted worldwide. Thus far, all patients have achieved a BCVA of 20/40 or better; distance-corrected near visual acuity was 20/40 or better in 96% of patients. Defocus curves resulted in 3.20 D amplitude of accommodation. Two-year follow-up was available for 23 patients (Figure 6); uncorrected distance and distance-corrected near visions were excellent.

On ultrasound biomicroscopy, accommodative effort resulted in forward movement of the anterior optic and greater separation of the optics, resulting in a higher plus-powered lens (Figure 6). There is less anterior subcapsular opacification and less posterior capsular opacification (PCO) than seen with other silicone optics, perhaps because the anterior and posterior leaves of the capsule completely separate. Mesopic contrast sensitivity, with and without glare (Figures 7 and 8) is similar to a one-piece acrylic IOL. Figure 9 demonstrates the similarity in the average reading speed of patients implanted with the Synchrony versus a multifocal IOL.
One of the most promising new technologies is the NuLens Accommodating IOL (Figure 10A), a two-piece IOL with a posterior piston that, on accommodative effort, displaces material in the center of the lens to add power (Figure 10B). This IOL sits on top of the collapsed capsular bag. The manufacturers believe that an accommodating IOL must have at least 8.00 D of amplitude of accommodation: 1.00 D for adjustment of the far plane, 3.00 D for near, and 4.00 D to avoid accommodative fatigue.

Three-month data from a clinical pilot study show that 10 patients implanted with the NuLens achieved an average of 10.00 D accommodation. It is possible that even larger amounts of accommodation will be achievable; however, this depends on the refractive index of the silicone material that is anteriorly displaced upon accommodative effort.

Power Vision. The one-piece Power Vision IOL (Power Vision, Santa Barbara, California) incorporates applied microfluidic technology. On accommodative stimulation, microfluidic pumps reversibly alter the radius of curvature of the optic, increasing overall power for near vision purposes (Figure 11).

FlexiOptic. The optic of the FlexiOptic IOL (Quest Vision Technologies, Tiburon, California; licensed by Advanced Medical Optics, Inc.) not only has a mechanism of anterior movement but also changes shape. Depending on the refractive index, its accommodative amplitude ranges from 3.30 to 4.50 D (Figure 12).

SmartIOL. An extremely promising technology is the SmartIOL, a thermodynamic, adjustable accommodating IOL. This hydrophobic acrylic polymer has a refractive index of 1.47, 90% light transmission, and a UV absorber. The lens has a soft transition temperature of 20º to 30ºC. At temperatures below this range, it is a rigid solid; above, it is a soft gel (Figure 13). Therefore, it can be implanted as a solid rod through a small incision in the capsular bag. Once the implant reaches body temperature, it completely fills the capsular bag as a stable gel. Because it fills the capsular bag, there is no decentration, edge effect, or glare.

The great advantage of the SmartIOL is that, unlike...
other proposed injectable IOLs that require a 1-mm capsulorrhexis, it uses a normal-sized capsulorrhexis. Therefore, extracting the clear lens is easier. The SmartIOL completely separates the anterior and posterior capsule leaves (Figures 14 and 15). Combined with its hydrophobic acrylic design, these characteristics will decrease the risk of PCO.

**INNOVATIVE TECHNOLOGIES**

**Light Adjustable Lens.** After implantation into the human eye, the power of the Light Adjustable Lens (LAL; Calhoun Vision, Inc., Pasadena, California) can be altered. This IOL consists of a photosensitive, adjustable silicone matrix with embedded silicone subunits called macromers. Irradiating a portion of the lens causes the macromers to polymerize, resulting in diffusion or migration of nonpolymerized macromers into the irradiated region. The macromers accumulate in the irradiated region, causing swelling and central thickening for an increase in plus-power, peripheral thickening for an increase in minus-power, or toric power alterations by irradiating along the appropriate lens meridian. Irradiation with the Digital Light Delivery System (DLD; collaboratively designed by Calhoun Vision, Inc., and Carl Zeiss Meditec AG, Jena, Germany) can also address corneal higher-order aberrations (Figure 16). Results in early clinical trials of this lens have documented its efficacy. If this technology can be advanced to sequential adjustability and combined with other technologies, it would dramatically advance the state of RLE.

**LiquiLens.** The LiquiLens (Vision Solution Technologies, Rockville, Maryland) contains a high-

---

**TAKE-HOME MESSAGE**

- Improvements in the safety of lens surgery and in the accuracy of IOL power calculation have led to increased interest in refractive lens exchange.
- Accommodating IOLs offer advantages over multifocal IOLs for a number of physiologic and optical reasons.
- Several promising technologies to provide continuous good visual acuity from distance to near are in development.
refractive–index fluid immiscible with and positioned above a lower-refractive–index fluid in a central chamber within the optic. This lens provides emmetropia at distance, and its accommodative mechanism allows more than threefold magnification for near. It is 100% gravity dependent. Looking forward, the low-refractive–index fluid fills the pupillary space (Figure 17); downward gaze causes the high-refractive–index fluid to flow into the pupillary space, creating more plus power (Figure 18).

**Pixelated optic IOL.** Pixels can be embedded into a parent IOL (Figure 19), and applying an electric charge to the pixels can change the refractive index, thereby providing up to 4.00 D of accommodative amplitude. A rechargeable battery the size and configuration of a capsular tension ring can be implanted along with the IOL. Some of the pixels recognize contrast using a mechanism similar to an autofocus on a digital camera; reading results in an increase in plus power of up to 4.00 D.

**CONCLUSIONS**

Presbyopia-correcting IOLs must (1) be biocompatible, (2) give a full field of vision, (3) be aberration free, (4) provide continuous good visual acuity from distance to near with an adequate amplitude of accommodation to avoid accommodative fatigue, (5) have an appropriate filter for any unwanted light rays, and (6) either prevent PCO or allow Nd:YAG laser posterior capsulotomy. We believe only an accommodating IOL can achieve those requirements. ■

---

**Editor’s Note:** Portions of this article were published in: Fine IH, Hoffman RS, Packer M. Current status of accommodative IOLs. In: Goes FJ, Dick HB, Fine IH, Knorz MC, Lindstrom RL, eds. Multifocal IOLs. Jaypee Brothers: New Delhi, India; 2008, 75–83. Reprinted with permission from Jaypee Brothers, New Delhi, India.

I. Howard Fine, MD, is a Clinical Professor of Ophthalmology at the Casey Eye Institute, Oregon Health & Science University, and is in private practice at Drs. Fine, Hoffman, & Packer LLC, Eugene, Oregon. Dr. Fine states that he is a paid consultant to Advanced Medical Optics, Inc., Bausch & Lomb, iScience, Carl Zeiss Meditec AG, and Omeros Corporation. He is a member of the CRST Europe Global Advisory Board. Dr. Fine may be reached at tel: +1 541 687 2110; e-mail: hfine@finemd.com.

Richard S. Hoffman, MD, is a Clinical Associate Professor of Ophthalmology at the Casey Eye Institute, Oregon Health & Science University, and is in private practice at Drs. Fine, Hoffman, & Packer, LLC, Eugene, Oregon. He states that he is a consultant to Advanced Medical Optics, Inc., Bausch & Lomb, Advanced Vision Science, Carl Zeiss Meditec AG, Carl Zeiss, Inc., Celgene Corp., Ista Pharmaceuticals, Gerson Lehman Group, iTherapeutix, Vistakon, Leerkink Swann & Company, Transcend Medical, Visiogen, Vision Care, WaveTec Vision Systems, and TrueVision. Dr. Hoffman may be reached at tel: +1 541 687 2110; e-mail: rshoffman@finemd.com.

Mark Packer, MD, FACS, is a Clinical Associate Professor at the Casey Eye Institute, Department of Ophthalmology, Oregon Health & Science University, and is in private practice at Drs. Fine, Hoffman & Packer, LLC, Eugene, Oregon. He states that he is a consultant to Advanced Medical Optics, Inc., Bausch & Lomb, Advanced Vision Science, Carl Zeiss Meditec AG, Carl Zeiss, Inc., Celgene Corp., Ista Pharmaceuticals, Gerson Lehman Group, iTherapeutix, Vistakon, Leerkink Swann & Company, Transcend Medical, Visiogen, Vision Care, WaveTec Vision Systems, and TrueVision. Dr. Packer may be reached at tel: +1 541 6872110; e-mail: mpacker@finemd.com.

---