Pseudophakic Wavefront Correction

A glimpse of the future.

BY DANIEL M. SCHWARTZ, MD

Despite advances in both IOL design and biometry, it remains challenging to achieve predictable refractive outcomes.[1-5] In particular, ideal centration and correction of defocus are critical to maximizing the visual function of patients who receive aspheric IOLs. The Light Adjustable Lens (LAL; Calhoun Vision, Inc., Pasadena, CA; not available in the US) is a silicone, three-piece, foldable IOL, the refractive power of which can be precisely adjusted with UV light postoperatively.[6-8] Preclinical and clinical studies of the LAL indicate that it can be adjusted to correct spherical and astigmatic errors as well as spherical aberration.

BACKGROUND

In addition to the silicone polymer and UV blocker contained in conventional silicone IOLs, the LAL has short-chain silicone macromers and a photoinitiator embedded in the lens matrix. Ordinarily, 1 to 4 weeks after cataract surgery, one adjusts the LAL using a Digital Light Delivery (DLD) device manufactured by Carl Zeiss Meditec AG (Jena, Germany). Irradiating the LAL with spatially differentiated UV light causes the selective polymerization of the embedded macromers and the subsequent diffusion of the unexposed macromers into the irradiated zone. For example, if the center of the LAL is irradiated preferentially, then the macromers polymerize centrally, and residual macromers from the unexposed periphery of the LAL diffuse centrally to increase the lens' power (ie, correct hyperopia). Then, 1 to 4 days after the LAL's adjustment, one irradiates the entire lens to polymerize the remaining macromers and lock in the power.

Figure 1. The DLD device.

Arturo Chayet, MD, of Tijuana, Mexico, and, more recently, José Güell, MD, of Barcelona, Spain, have precisely and reproducibly corrected spherical and astigmatic error in approximately 50 patients based on the spatial-

intensity pattern, duration, and intensity of the UV irradiation (unpublished data to be presented by Dr. Chayet at the 2007 AAO Annual Meeting).

The DLD (Figure 1) creates customized spatial-intensity patterns of UV light using a digital mirrored device. Found in the LCD projectors used for Powerpoint presentations (Microsoft Corp., Redmond, WA), the device has approximately 750,000 micromirrors that move extremely rapidly into the "on" or "off" position. The more a single micromirror is on, the brighter the pixel of light it creates; the more it is off, the dimmer the pixel is. Thus, the DLD enables one to define precisely a specific spatial-intensity profile, program it into the digital mirrored device, and then irradiate the LAL. One aligns the DLD's optics with the patient's visual axis by means of a fixation target paracentral to the delivery beam.

The DLD may be capable of writing an aspheric pattern onto the LAL in situ that can be centered on the visual axis. Although an aspheric IOL such as the Tecnis Z9000 (Advanced Medical Optics, Inc., Santa Ana, CA) has a modified prolate anterior surface to increase the patient's visual function by enhancing his contrast sensitivity, this IOL's optical advantage decreases if it is as little as 0.4mm off center.[9] Furthermore, the negative spherical aberration of the Tecnis lens is derived from the mean positive corneal spherical aberration of a study of 71 patients.[10]

Rather than an approach of one size fits all, it would be preferable to correct each individual's spherical aberration following cataract surgery. It may be possible to perform wavefront-driven irradiation of the LAL using the DLD. Moreover, by writing an aspheric correction on an LAL that they adjust to emmetropia and center on the patient's visual axis, surgeons could minimize the untoward optical effects of defocus and decentration on these aspheric IOLs.

To test whether a customized aspheric optic could be written onto a monofocal LAL, scientists at Calhoun Vision, Inc., and Dr. Chayet conducted preliminary in vitro and in vivo studies.

IN VITRO STUDIES

We simultaneously adjusted 32 LALs to correct 1.50D of hyperopia and remove positive spherical aberration in the lens. We measured the wavefront in the exit pupil of the LAL using a phase-shifting Fizeau Interferometer (Wyko Model 400; Vecco Instruments, Inc., Woodbury, NY) before and after irradiation.

Our analysis of the irradiated LALs showed a mean hyperopic correction of 1.45D with a standard deviation of less than 0.10D. In addition, approximately 0.30D of positive spherical aberration had been removed from the treated lenses. This laboratory study confirmed the possibility of simultaneously correcting refractive error and spherical aberration in the LAL with a specified spatial-intensity pattern programmed into the DLD.

IN VIVO STUDIES

We implanted two New Zealand white rabbits with 20.00D LALs and then adjusted the lenses for the simultaneous correction of hyperopia and spherical aberration. We irradiated the LALs 1 day after their implantation and then explanted them 1 day after the adjustment. Analysis was interferometrical.

The starting spherical aberration of the LAL was +0.35D. Our analysis of the irradiated and explanted lenses showed that we had removed approximately 0.50D of spherical aberration to confer negative spherical aberration on the LALs. As a result, the lenses would neutralize the inherently positive spherical aberration of the human cornea.

Recently, we adjusted, locked in, and then exchanged an LAL from a patient with advanced macular degeneration and visually significant cataract. Optical analysis of the explanted lens showed an approximately 0.30D reduction in spherical aberration after irradiation. The explanted LAL had excellent resolution and a modulation transfer function of 0.5 at 100 line pairs per millimeter. Chemical analysis of the explanted lens demonstrated consumption of the macromer and a successful lock-in. This result indicates the feasibility of correcting both ametropia and spherical aberration in eyes implanted with an LAL.

Although we are able to establish proof of concept for aspheric corrections, treating more complex wavefront aberrations would require tracking technology on the DLD, not a feature of the current machine. ■

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