Intraocular lens power adjustment by a femtosecond laser

In vitro evaluation of power change, modulation transfer function, light transmission, and light scattering in a blue light–filtering lens

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**Purpose:** To evaluate intraocular lens (IOL) power, modulation transfer function (MTF), light transmission, and light scattering of a blue light–filtering IOL before and after power adjustment by a femtosecond laser obtained through increased hydrophilicity of targeted areas within the optic, creating the ability to build a refractive-index-shaping lens within an existing IOL.

**Setting:** John A. Moran Eye Center, University of Utah, Salt Lake City, Utah, USA.

**Design:** Experimental study.

**Methods:** Ten CT Lucia 601PY single-piece yellow hydrophobic acrylic IOLs were used in this study. The IOL power and MTF were measured with a power and modulation transfer function device. Light transmission was measured using a Lambda 35 UV-VIS spectrophotometer. Backlight scattering was assessed with a Scheimpflug camera within the IOL substance. All measurements were done with hydrated IOLs. The IOLs were also evaluated under light microscopy (LM) before and after laser adjustment.

**Results:** After laser adjustment, a mean power change of $2.037$ diopters was associated with a MTF change of $0.064$ and a light transmittance change of $1.4\%$. Backlight scattering increased within the IOL optic in the zone corresponding to the laser treatment at levels that are not expected to be clinically significant. Treated areas within the optic could be well appreciated under LM without damage to the IOLs.

**Conclusion:** Power adjustment of a commercially available hydrophobic acrylic blue light–filtering IOL by a femtosecond laser produced an accurate change in dioptric power while not significantly affecting the quality of the IOL.

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Incorrect intraocular lens (IOL) power calculation resulting from incorrect measurements of the eye is the most likely cause of refractive errors after cataract surgery with IOL implantation. Furthermore, current standards regarding IOL power labeling allow a certain tolerance, and therefore the power on the label might not be the precise power of the IOL. All of these facts warrant the development of postoperative IOL adjustment technologies.

Perfect Lens LLC has developed a femtosecond laser system (Perfector) for IOL power adjustment based on the concept of refractive-index shaping. It uses green light (520 nm) and operates with energy levels that are below the threshold for ablation or cuts. The IOL power changes are obtained through laser-induced chemical reactions in the targeted area of the optic substance, with an increase in hydrophilicity and a decrease in the refractive index, while the laser builds a refractive-index-shaping lens within the treated area. Potential advantages over existing IOL power adjustable technologies are that the laser system can be applied to any commercially available...
hydrophobic or hydrophilic acrylic IOL because special IOL material is not necessary. The power adjustment is noninvasive and fast and can be performed under topical anesthesia. The IOL power can be increased or decreased to compensate for surgical errors, IOL tilt and decentration, or a change in the physical characteristics of the eye. Multiple adjustments can be performed because they change a very thin layer within the IOL optic substance. Premium functions (eg, multifocality) can be added to the IOL and removed if necessary.7

The precision of the power change obtained with this technology and its biocompatibility have been evaluated in previous in vitro studies using a relatively limited number of IOLs and in an in vivo study using the rabbit model.3–5,A–D The objective of the current study was to assess the impact of the power adjustment obtained by the femtosecond laser on the optical quality of a commercially available hydrophobic acrylic yellow (blue light-filtering) IOLs. Parameters such as light transmittance and light scattering were evaluated for the first time.

MATERIALS AND METHODS

Ten CT Lucia 601PY (commercially available single-piece yellow hydrophobic acrylic IOLs, Carl Zeiss Meditec AG) were used in this study. Light microscopy was performed on all IOLs. They were then placed in vials containing distilled water and allowed to hydrate at room temperature for at least 1 day before the measurements were obtained. All measurements described below were performed under hydration conditions before and after laser power adjustment with a target of −2.0 diopters (D). The IOLs were placed inside a purpose-designed IOL holder to keep the IOL stabilized in distilled water at all times during the laser treatment. Laser parameters and shaping had been automatically set by the system to match the desired diopter. The laser shaping time was 23 seconds per IOL. Light microscopy was again performed after laser adjustment/shaping.

Power and Modulation Transfer Function Measurements

All measurements were taken using a power and modulation transfer function device (Lambda-X S.A.), a power and modulation transfer function (MTF) measurement device designed for refractive and diffractive IOLs. It is International Organization for Standardization (ISO) 11979-2 compliant, has an ISO 11979-2 model eye,2 and uses a measurement wavelength of 546 nm.

Light Transmittance and Backlight Scattering

Light-transmittance measurements were performed with a Lambda 35 UV-VIS spectrophotometer (PerkinElmer, Inc.) operated in a single-beam configuration with an RSA PE-20 integrating sphere (LabSphere, Inc.).2–7 Each IOL was fitted to a plastic custom insert with a 5.0 mm diameter aperture for the optic; the insert was designed to hold a 6.0 mm diameter optic. The insert containing the IOL was then mounted on a standard rectangular quartz cuvette filled with distilled water. Care was taken to prevent the presence of air bubbles inside the cuvette. The assembly was then placed directly in front of the opening of the integrating sphere so that the anterior surface of the IOL was facing the light source. Before the measurements, a background correction was performed with the empty inserter immersed in distilled water inside the quartz cuvette. Background transmittance spectra were checked to ensure that 100% ± 0.5% (SD) transmittance was achieved. The IOL spectra were then collected at room temperature with the following settings: wavelength range 850 to 300 nm, slit width 2 nm, scan speed 120 nm/min, and data interval 1 nm. Background transmittance was checked every other sample to ensure that it did not shift during measurements. Results were expressed as the percentage of light transmittance in the visible light spectrum (400 to 700 nm).11

Backlight scattering was also measured as described in previous studies.2–7 A custom 3-piece dark eye model with a poly(methyl methacrylate) cornea was used to hold the IOLs under immersion in distilled water. Care was taken to prevent the presence of air bubbles inside the eye model during loading and assembly. The distilled water–filled model containing the IOL was then placed in front of a Nidek EAS-1000 Scheimpflug camera (cornea facing the device), and the room lights were turned off. A cross-sectional image of the IOL inside the model was then obtained (settings: flash level 200 W, slit length 10.0 mm, meridian angle 0), and analyzed using the densitometry peak function. Backlight scattering was measured at the center of the IOL optic substance within the laser treated area (after treatment), along the axis of a line that crossed perpendicularly through the center of the IOL optic. Results were expressed in computer-compatible tape (CCT) units. This is a measure of brightness or intensity of reflected (scattered) light on a scale of 0 (black) to 255 (white).2–7

RESULTS

Figure 1 shows light photomicrographs of 1 of the IOLs included in this study before and after laser treatment. Surface contaminants, such as small fibers and dust-like deposits, were observed on the surface of some IOLs. Their presence was the result of the study being performed in a laboratory setting under nonsterile conditions. Light microscopy of the IOLs after laser treatment showed the phase-wrapped structure created by the laser in all treated IOLs within their optic substance. The phase-wrapped structure was centered in all cases. In the treated area, the yellow color of the IOL optic was slightly darker. None of the IOLs showed damage, deformation, pitting, or marks.

Table 1 shows power and MTF results from the 10 IOLs used in the study, measured before and after laser treatment. The mean change in power after laser treatment was −2.037 ± 0.047 D, which was associated with a mean change in the MTF of −0.064 ± 0.053.

Table 2 shows the light-transmittance and backlight-scattering results from the 10 IOLs used in the study, measured before and after laser treatment. The mean change in light transmittance was −1.46% ± 0.98%, and the mean change in backlight scattering was +56.8 ± 14.7 CCT units.

Figure 2 shows the light-transmittance curves of a representative IOL before and after laser treatment. The change in light transmittance after laser treatment was −1.16% in this IOL. The graphs show that the majority of the light-transmittance change occurred between the 420 nm and 560 nm range, with an increase between 420 nm and 460 nm (violet–blue range; light transmittance from 55.00% ± 5.33% to 57.88% ± 5.23%) and a decrease between 470 nm and 560 nm (blue–cyan–green range; light transmittance from 90.35% ± 7.17% to 85.73% ± 7.8% 7). Figure 3 shows Scheimpflug photographs of a representative IOL before and after laser treatment. The increase in backlight scattering within the optic substance of the IOL after laser treatment appeared to correspond to the area...
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