ARTICLE

# Prediction of postoperative intraocular lens tilt using swept-source optical coherence tomography

*Nino Hirnschall, MD, PhD, FEBO, Tobias Buehren, PhD, Ferid Bajramovic, PhD, Michael Trost, Tanja Teuber, PhD, Oliver Findl, MD, MBA, FEBO*

**Purpose:** To compare crystalline lens tilt in eyes before and intraocular lens (IOL) tilt in eyes after cataract surgery using swept-source optical coherence tomography (SS-OCT) (IOLMaster 700).

**Setting:** Hanusch Hospital, Vienna, Austria.

**Design:** Prospective case series.

**Methods:** Patients' eyes were scanned 1 week before and 2 months after cataract surgery with IOL implantation using an SS-OCT device. This device performs B-scans along 6 meridians (0, 30, 60, 90, 120, and 150 degrees) to determine lens and IOL tilt.

**Results:** Sixty-two eyes (62 patients) were included in the analysis. The mean magnitude and direction of tilt showed mirror symmetry between both eyes along the vertical axis and a primarily nasal outward tilt for right eyes and left eyes. The mean tilt was 4.3 degrees at 15.8 degrees preoperatively and 6.2 degrees at 16.8 degrees postoperatively. The mean direction of crystalline lens tilt preoperatively and IOL tilt postoperatively showed a strong correlation ($R = 0.71$), whereas the mean magnitude of tilt showed a weaker correlation ($R = 0.37$). The direction and magnitude of tilt of the crystalline lens and IOL eyes were normally distributed around similar values before and after surgery.

**Conclusions:** The correlations between crystalline lens tilt and IOL tilt using whole-eye scanning indicate that preoperative tilt determination using SS-OCT could help predict postoperative IOL tilt, assist in IOL (toric) power calculations, and potentially improve visual outcomes.

*J Cataract Refract Surg 2017; 43:732–736* © *2017 ASCRS and ESCRS*

Tilt and decentration of intraocular lenses (IOLs) have a negative effect on optical performance, especially for aspheric, toric, and multifocal IOLs. Decentration and tilt of IOLs can cause worsening of the optical quality by inducing aberrations, such as coma.[1–3] For toric IOLs, tilt and decentration lead to less predictable astigmatism outcomes after surgery. For multifocal IOLs, decentration might result in a different light distribution between the distance focus and near focus. Although tilt is widely discussed in the literature,[4–10] to our knowledge, there is no algorithm available for the prediction of postoperative tilt. An improved ability to predict postoperative tilt would help determine the best IOL for a patient and potentially improve long-term outcomes.

The aim of this study was to observe the correlation between preoperative and postoperative tilt and to find an algorithm to predict postoperative tilt using preoperative tilt measurements derived from swept-source optical coherence tomography (SS-OCT).

## PATIENTS AND METHODS

### Patients

This prospective study included patients who were scheduled for cataract surgery and had no other significant ophthalmologic comorbidities. Only 1 eye from each patient was included.

Exclusion criteria were opacities of the cornea, conditions that prevented the patient from focusing on the fixation target during the measurement, or unsuccessful detection of the crystalline lens or IOL. All the research and measurements complied with the tenets of the Declaration of Helsinki and were approved by the local ethics committee. Written informed consent was obtained from all patients before the measurements were taken.

### Surgical Technique

Surgery was performed using topical anesthesia. A self-sealing 2.4 mm incision, injection of an ophthalmic viscosurgical device (OVD), capsulorhexis, phacoemulsification, irrigation/aspiration of cortical material, and injection of OVD into the capsular bag were performed as standard procedure.[11] In all cases, the same plate-haptic IOL (Asphina, Carl Zeiss Meditec AG) was implanted in the capsular bag, after which the OVD was aspirated

Submitted: August 25, 2016 | Final revision submitted: January 4, 2017 | Accepted: January 4, 2017

From the Vienna Institute for Research in Ocular Surgery (Hirschall, Findl), a Karl Landsteiner Institute, Hanusch Hospital, Vienna, Austria; Carl Zeiss Meditec AG (Buehren, Bajramovic, Trost), Jena, and Carl Zeiss AG (Teuber), Oberkochen, Germany; Moorfields Eye Hospital (Findl), NHS Foundation Trust, London, United Kingdom.

Corresponding author: Oliver Findl, MD, MBA, Hanusch Hospital, Heinrich-Collin-Strasse 30, 1140 Vienna, Austria. E-mail: oliver@findl.at.


Published by Elsevier Inc.

0886-3350/$ - see frontmatter
http://dx.doi.org/10.1016/j.jcrs.2017.01.026

thoroughly from the eye, taking care to also remove all OVD from behind the IOL.

### Swept-Source Optical Coherence Tomography

In all cases, optical biometry was performed using SS-OCT (IOLMaster 700, Carl Zeiss Meditec AG) 1 week preoperatively and 2 months after cataract surgery. The IOLMaster 700 is a noncontact optical biometer for the visualization and measurement of structures of the eye for IOL power calculation.[12–14] Measurements of the distances along the visual axis were performed to determine the central corneal thickness, anterior chamber depth (ACD), lens thickness, and axial length (AL) in each eye. The length measurements are based on swept-source frequency domain OCT, enabling a 44.0 mm scan depth with 22 μm resolution in tissue. The speed of the measurement system allows the acquisition of full-eye-length tomograms at 2000 A-scans per second. In addition to optical biometry devices that use A-scans, the IOLMaster 700 applies B-scan technology to determine the biometric data from each eye and to configure the central 1.0 mm vitreoretinal interface of the examined eye.

### Measurement Data

The B-scans with anterior segment focus allow visualization of the crystalline lens and the IOL. Axially, the entire lens is captured. Laterally, only the portion of the lens within the pupil is visible because of light absorption by the iris (Figure 1). To maximize lateral information, dilating drops were applied before the SS-OCT measurement.

Geometrically, B-scans are recorded along 6 meridians that are approximately centered on the vertex of the cornea. The meridians are defined at 0, 30, 60, 90, 120, and 150 degrees. This setup allows the acquisition of 3-dimensional (3-D) information of the lens from the B-scans. In total, 18 B-scans were recorded by repeating the 6-meridian pattern 3 times.

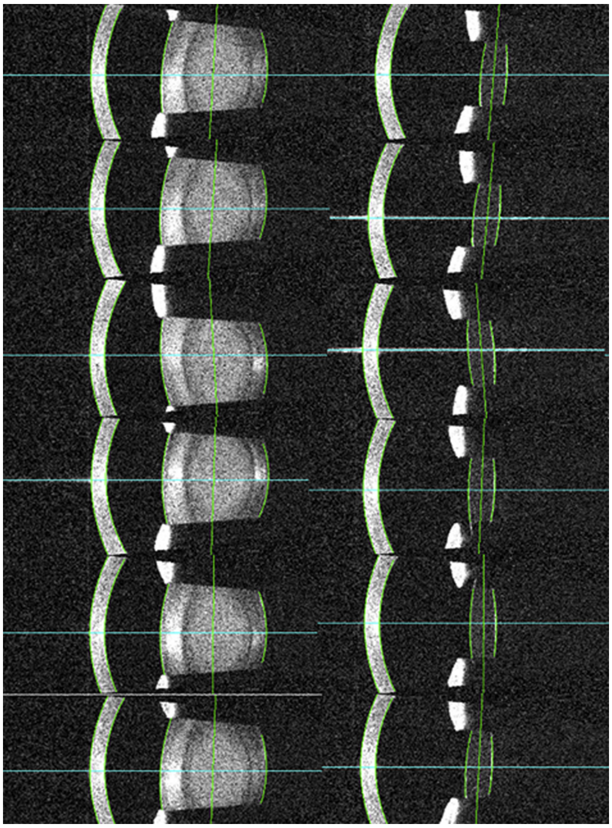

**Figure 1.** Example of OCT dewarped B-scans along 6 meridians from 1 phakic eye (*left side*) and its correlating scan of the same eye in a pseudophakic state (*right side*).

### Purpose-Designed Processing Software

With the IOLMaster 700 software, raw measurement data can be exported to an external hard disk drive, after which, purpose-designed prototype software was used to determine the tilt of the lens. This software performs the following processing steps: (1) Applies the same image-processing method used by the SS-OCT software to fit parabolas to the cornea and lens surfaces of all 18 B-scans. (2) Dewarps the fitted parabolas to compensate for geometric distortions caused by scanning geometry and refraction in the eye (also as SS-OCT software). (3) Computes the mean of the 2 dewarped lens surface parabolas as a "fuzzy" description of the axis of the lens within the respective B-scan. (4) Transfers all 18 mean parabolas from the 2-dimensional coordinate system of the respective B-scan to a common 3-D coordinate system, including lateral motion compensation based on vertex estimates from pairs of B-scans. (5) Applies robust multilinear regression (an iteratively reweighted least-squares method) to fit a plane to 3-D points sampled from all 18 transferred mean parabolas. The orientation of this plane describes the tilt of the lens. (6) Expresses the tilt by the normal vector ($n_x$, $n_y$, $n_z$) of the plane and as a pair of angles (phi [φ], which indicates tilt direct and rho [ρ], which indicates tilt magnitude) in spherical coordinates, which are defined as follows:

$$\phi = \operatorname{atan2}(n_y,\ n_x)$$

$$\rho = \operatorname{acos}(n_z)$$

(7) For manual verification, the software projects the fitted plane into each B-scan and visualizes the resulting line along with the fitted surface parabolas in the dewarped B-scan image. Figure 1 shows an example of 1 B-scan per meridian.

Midline symmetry between right eyes and left eyes can lead to superimposition, thus masking certain characteristics of interest if not taken into account.[5] Because of an observed horizontal mirror symmetry of tilt between the right eye and the left eye, for correlation purposes, left eyes were rotated along the vertical axis to mimic the tilt in right eyes.

### Statistical Analysis

For statistical analysis, Excel for Mac software (2011, Microsoft Corp.) with a Statplus:mac (version 5.8.3.8 plug-in, Analystsoft), and an Xlstat (2012 plug-in, Addinsoft) were used. For missing data, observations were excluded from analysis. All descriptive data are given as the mean ± SD and range.

## RESULTS

### Patients

The study recruited 74 patients (74 eyes) with no comorbidities who were scheduled for cataract surgery. Twelve patients did not meet the inclusion and exclusion criteria, leaving 62 eyes of 62 patients for analysis. Of the 12 excluded patients, 10 were lost to follow-up, and in 2 cases, the measurements were unsuccessful (<4 meridians of the B-scan successful). The mean age was 78.4 ± 10.9 years (range 45 to 104 years).

### Amount of Tilt

The amount of tilt of all crystalline lenses and IOLs was 4.3 ± 0.9 degrees (median 4.3 degrees; range 2.7 to 7.1 degrees) and 6.2 ± 1.3 degrees (median 6.1 degrees; range 3.6 to 9.0 degrees), respectively. These data were normally distributed ($P$ = .203, Shapiro-Wilk test).