Intraocular Lens Tilt and Decentration Measured By Scheimpflug Camera Following Manual or Femtosecond Laser–created Continuous Circular Capsulotomy

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ABSTRACT

PURPOSE: To compare intraocular lens (IOL) decentration and tilt following a circular capsulotomy created with a femtosecond laser (laser CCC) to a manually performed continuous curvilinear capsulorhexis (manual CCC).

METHODS: In a prospective, randomized study, a laser CCC (Alcon LenSx Inc) was performed in 20 eyes from 20 patients and a manual CCC was performed in 25 eyes from 25 patients. Intraocular lens decentration and tilt were measured using a Scheimpflug camera (Pentacam, Oculus Optikgeräte GmbH) 1 year after surgery. Uncorrected (UDVA) and corrected distance visual acuity (CDVA) and manifest refraction were also determined postoperatively. Between-group differences of IOL decentration and tilt as well as the correlation between IOL decentration and postoperative refractive changes and between IOL tilt and visual acuity were analyzed.

RESULTS: Horizontal and vertical tilt were significantly higher in the manual CCC group ($P<.001$, respectively). Lenses implanted after manual CCC showed greater horizontal and total decentration ($P<.001$, respectively). Significant differences were found in the homogeneity of dichotomized IOL vertical tilt and both horizontal and total decentration distribution ($P<.001$, respectively). Total IOL decentration showed a significant correlation with changes in manifest refraction values between 1 month and 1 year after surgery ($R=0.33$, $P=.032$). A significant correlation was noted between IOL vertical tilt and CDVA ($R^2=0.41$, 95% confidence limit: $-0.69$ to $-0.13$, $P=.005$).


Microincisional cataract surgery by phacoemulsification and implantation of an artificial intraocular lens (IOL) has become a safe and effective intervention. Due to new surgical techniques and IOL designs, surgically induced astigmatism and complications such as posterior capsular opacification are rare. Continuous curvilinear capsulorhexis (CCC) is one of the most important steps of cataract surgery. Obtaining a “perfect” CCC is important to maintain IOL centration and prevent IOL tilt. An eccentric or irregularly shaped capsulorhexis with a diameter extending beyond the optic edge loses these advantages.

With the advent of femtosecond lasers in ophthalmic surgery, a properly sized and centered CCC became possible through a laser–tissue interaction known as photodisruption. A reproducibly sized, shaped, and centered femtosecond laser CCC was shown to result in better overlap between capsulorhexis edge and IOL, which helps maintain proper positioning of the IOL.

The effect of IOL tilt and decentration depends greatly on the actual combination of these positioning parameters in an eye. Several laboratory tests have been performed to identify the maximum decentration and tilt that does not impair the visual outcome of aspheric IOLs. Holladay et al calculated the critical amount of decentration to be 0.4 mm and tilt of 5°. Piers et al calculated a greater range of decentration and tilt (0.8 mm and 10°, respectively).

Intraocular lens tilt and decentration can be measured by several methods, such as retroillumination photographs, Purkinje imaging systems, or with a Scheimpflug camera. A
Scheimpflug camera provides images of the anterior chamber of the eye. Initial Scheimpflug images suffered from geometrical distortion. However, in new systems, images are corrected using custom algorithms, which provide high reproducibility for this device in the measurement of IOL tilt and decentration.\textsuperscript{20-22}

We evaluated the use of an intraocular femtosecond laser in performing capsulotomies of the anterior lens capsule. The purpose of this study was to evaluate the effects of laser capsulotomy on centration and anteroposterior displacement of implanted IOLs and to compare results with those achieved with manually performed CCC.

PATIENTS AND METHODS

PATIENT POPULATION

In a prospective, randomized study, a laser CCC (Alcon LenSx Inc, Aliso Viejo, California) was performed in 20 eyes from 20 patients and a manual CCC was performed in 25 eyes from 25 patients undergoing cataract surgery with IOL implantation (Table 1). Each patient had undergone a complete ophthalmologic evaluation. Patients with previous ocular surgery, trauma, active ocular disease, poorly dilated pupils, or known zonular weakness were excluded from the study. Randomization was done using computer-generated tables (Microsoft Excel; Microsoft Corp, Redmond, Washington).

The study was conducted in compliance with the Declaration of Helsinki, as well as with applicable country and local requirements regarding ethics committee/institutional review boards and other statutes or regulations regarding protection of the rights and welfare of human subjects participating in biomedical research. A written informed consent was obtained prior to surgery from every patient.

SURGICAL TECHNIQUE

The surgical technique was standardized in each patient, except for the method of capsulorrhexis. All surgeries were performed by the same surgeon (Z.Z.N.). After pupillary dilation (1 drop of tropicamide 0.5% every 15 minutes \texttimes 3) and instillation of topical anesthetic (proparacaine HCl 0.5%), the laser was docked to the eye using a curved contact lens to applanate the cornea. The location of the crystalline lens surface was determined with an integrated optical coherence tomography (OCT, Alcon LenSx Inc) imaging system. A 4.5-mm diameter capsulotomy procedure was performed by scanning a cylindrical pattern starting at least 100 \textmu m below the anterior capsule and ending at least 100 \textmu m above the capsule. The capsulotomy was centered on the dilated pupil. Proprietary energy and spot separation parameters, which had been optimized in previous studies, were used for all laser procedures. A 4.5-mm capsulorrhexis, also centered on the dilated pupil, was attempted in the manual CCC group and performed with the aid of a cystotome and capsulorrhexis forceps. A marker was not used. Incisions were done with a disposable keratome (Alcon Laboratories Inc, Ft Worth, Texas) in both groups. After hydrodissection, phacoemulsification of the nucleus and aspiration of the residual cortex was performed using the Accurus phacoemulsification machine (Alcon Laboratories Inc).

All IOLs were folded and implanted in the capsular bag with the aid of an injection cartridge through the corneal wound. Intraocular lenses were all one-piece (SA60AT, Alcon Laboratories Inc) of hydrophobic acrylic material. Lens haptics were placed in the same position (at 3 and 9 o’clock). Intraocular lens power was calculated using the SRK-T formula. After IOL implantation, the viscoelastic material was removed from the anterior chamber and capsular bag by irrigation/aspiration. All incisions were left sutureless. No intra- or postoperative complications occurred. During the first 10 days, all patients received a combination of antibiotic and steroid eye drops (dexamethasone and tobramycin).

MEASUREMENTS

A Scheimpflug imaging system (Pentacam; Oculus Optikgeräte GmbH, Wetzlar, Germany) was used to evaluate IOL tilt and decentration. Lens decentration and tilt were measured according to de Castro et al\textsuperscript{21} as follows: IOL decentration is obtained from the distance between the IOL center and pupillary axis. Positive horizontal coordinates stand for nasal in the right eye and temporal in the left eye. Positive vertical coordinates stand for superior decentrations, and negative for inferior ones. By eliminating positive and negative signs, the magnitude of horizontal and vertical decentration could be determined without reference to nasal/temporal and superior/inferior orientation, respectively. Total decentration, determined by trigonometry analysis, shows the magnitude of the result vector of horizontal and vertical decentration. Regarding IOL tilt, positive tilt around the x-axis indicates that the superior edge of the IOL is moved forward, and vice versa for negative tilt. Positive tilt around the y-axis shows, in the right eye, nasal tilt and indicates that the nasal edge of the IOL is moved backward and vice versa for a negative tilt around the y-axis in right eyes. A positive tilt around the y-axis stands for temporal tilt (nasal edge of the IOL moves forward) in left eyes. By eliminating positive and negative signs, the magnitude of horizontal and vertical tilt could be determined without reference to any orientation.
Postoperative manifest refraction was determined 1 week, 1 month, and 1 year after cataract surgery, and shift in postoperative refraction was calculated.

**Statistical Analyses**

Statistical analyses were performed with SPSS 16.0 (SPSS Inc, Chicago, Illinois). Departure from normal distribution assumption was tested by the Shapiro-Wilk W test. Due to normality of data, descriptive statistics, visual acuity, and IOL positioning parameters show mean and standard deviation. Differences between the two study groups in visual acuity and IOL tilt and decentration values were tested with t test for independent samples.

The chi-square test of homogeneity was applied to compare the distribution of dichotomized tilt and decentration values of 5° and 0.4 mm, respectively, between the study groups. Due to non-normal distribution of values representing spherical equivalent changes postoperatively, correlation between IOL total decentration and spherical equivalent changes was analyzed with Spearman rank correlation. Linear regression analysis was performed to determine correlation between the absolute value of IOL vertical tilt and distance visual acuity using coefficient of determination R^2, regression coefficient β, and the corresponding P value. Significance level was set at P<.05 in all statistical analyses. Power calculation analysis was also performed, which showed 88% statistical power of our statistical analysis.

**RESULTS**

No statistically significant differences were noted in age, gender distribution, or axial length between the laser CCC and manual CCC groups (Table 1).

Table 2 shows no significant differences were noted between the two groups in regards to UDVA at any postoperative time point. However, CDVA proved to be significantly better in the laser CCC group 1 month and 1 year after surgery.

**DISCUSSION**

In our experience, femtosecond laser capsulotomies are accurate, round, and reproducible, with accurate diameters, whereas manual capsulorrhexis can be irregular in shape and difficult to control in centration.15-17 A properly sized and centered anterior capsulotomy causes a circular overlap of the IOL optic rim by the anterior capsule and can maintain the correct position of the implanted IOL.16,17 The crystalline lens
in young phakic eyes is not perfectly centered and free of tilt. However, comparing the amount and direction of lens decentration and tilt measured by Mester et al.\textsuperscript{23} and misalignments of IOLs implanted after CCC, malpositions in pseudophakic eyes are more significant.

The ultimate limitation of the potential use of a customized IOL is precision in its positioning. Intraocular lens misalignments worsen visual quality and change the planned postoperative refraction due to induced astigmatism, myopic or hyperopic shift, higher order aberrations, reflections, and halos.\textsuperscript{12,24,25}

In our study, we found significant differences in both tilt and decentration between the laser CCC and manual CCC groups 1 year after cataract surgery. The magnitude of both horizontal and vertical tilt was significantly higher in the manual CCC group. More than 5° of tilt can deteriorate visual outcomes of IOLs. Our results show a statistically significant difference in the distribution of dichotomized vertical tilt of $\geq 5°$ between the study groups (Table 4). Intraocular lenses in the manual CCC group showed higher horizontal and total decentration than in the laser CCC group. These outcomes correlate well with our previous results.\textsuperscript{16}

Deviations from the optical axis and pupil center might affect the refractive outcome of IOLs. The effect of IOL tilt and decentration on the final refractive power depends greatly on the actual combination of tilt and decentration in an individual eye. According to our results, IOL decentration influenced the stability of the postoperative manifest refraction. In our study, we found significantly better CDVA, associated with lower vertical tilt, in the laser CCC group. Correlation between these parameters shows that tilt of the IOL from the right anteroposterior position worsens visual quality, supposedly because of induced higher order aberrations that cannot be corrected with spectacles.\textsuperscript{25}

A significant difference in axial length was not found between the study groups, which means that a

### Table 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Manual CCC</th>
<th>Laser CCC</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal tilt (°)</td>
<td>2.75±1.67</td>
<td>1.53±1.08</td>
<td>.007*</td>
</tr>
<tr>
<td>Vertical tilt (°)</td>
<td>4.34±2.40</td>
<td>2.15±1.41</td>
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</tr>
<tr>
<td>Horizontal decentration (µm)</td>
<td>270.83±190.85</td>
<td>164.25±113.78</td>
<td>.034*</td>
</tr>
<tr>
<td>Vertical decentration (µm)</td>
<td>148.40±101.59</td>
<td>131.00±124.72</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Total decentration (µm)</td>
<td>334.91±169.67</td>
<td>230.27±111.54</td>
<td>.022*</td>
</tr>
</tbody>
</table>

CCC = continuous curvilinear capsulorrhexis
*P < .05 between groups using t test for independent samples.

### Table 4

<table>
<thead>
<tr>
<th></th>
<th>Manual CCC</th>
<th>Laser CCC</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal tilt (°)</td>
<td>1/25</td>
<td>0/20</td>
<td>&gt;.05</td>
</tr>
<tr>
<td>Vertical tilt (°)</td>
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<td>.008*</td>
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<tr>
<td>Horizontal decentration (mm)</td>
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<td>.036*</td>
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<tr>
<td>Vertical decentration (mm)</td>
<td>1/25</td>
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<td>&gt;.05</td>
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<tr>
<td>Total decentration (mm)</td>
<td>8/25</td>
<td>0/20</td>
<td>.017*</td>
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</table>

*P < .05 between groups using chi-square test.

Figure. Correlation between the absolute value of intraocular lens total decentration and the absolute value of changes in manifest refraction spherical equivalent between the first postoperative month and year. Spearman-rank correlation: $R = 0.33$; $P = .032$. 

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possible difference in capsular bag size is not a likely reason for the larger decenterations observed in the manual CCC group.

In this study, we were able to demonstrate that the use of a femtosecond laser to create an anterior curvilinear capsulotomy results in less IOL decenteration and tilt and better CDVA than the use of a manual CCC.

In an ongoing study, we plan to determine how different diameters of femtosecond laser capsulotomies influence postoperative visual performance of premium IOLs by maintaining the optic in the correct position. In the future, unique femtosecond laser capsulotomy diameters will be defined for IOLs with different optical diameters and principles of operation to ensure more standardized surgical procedures.

**AUTHOR CONTRIBUTIONS**

Study concept and design (K.K., K.M., Z.Z.N.); data collection (K.M., G.L.S., A.T.); analysis and interpretation of data (K.K., M.C.K.); drafting the manuscript (K.K., Z.Z.N.); critical revision of the manuscript (K.M., G.L.S., A.T., M.C.K.); statistical expertise (K.K.); administrative, technical, or material support (G.L.S., A.T.); supervision (K.M., Z.Z.N.)

**REFERENCES**


