Comparison of Myopic LASIK Centered on the Coaxially Sighted Corneal Light Reflex or Line of Sight

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ABSTRACT

PURPOSE: To compare refractive outcomes of myopic LASIK with centration on the coaxially sighted corneal light reflex (CSCLR) to centration on the center of the pupil (line of sight [LOS]).

METHODS: The NIDEK CXIII excimer laser was used to treat 268 eyes with centration on the CSCLR (CSCLR group) and 288 eyes with centration on the LOS (LOS group). For the CSCLR group, the laser ablation was delivered 80% closer to the visual axis. One-month postoperative outcomes were compared.

RESULTS: Preoperative manifest refraction spherical equivalent (MRSE) was \( -4.88 \pm 1.55 \) diopters (D) (range: \(-8.50 \text{ to } -1.25\) D) in the CSCLR group and \(-5.05 \pm 1.63\) D (range: \(-9.75 \text{ to } -1.50\) D) in the LOS group. The postoperative MRSE was \( 0.17 \pm 0.39\) D (range: \(-1.38 \text{ to } +1.25\) D) in the CSCLR group and \(0.19 \pm 0.48\) D (range: \(-1.63 \text{ to } +1.88\) D) in the LOS group. Safety (1.18) and efficacy (1.047) indices were statistically significantly higher in the CSCLR group compared to the LOS group (1.138 and 0.997, respectively) (\(P<.05\)). This trend was accentuated in a subgroup analysis of patients with \(0.25\)-mm difference between the CSCLR and LOS, favoring the CSCLR group. Safety and efficacy indices were significantly lower in the LOS group compared to the CSCLR group (1.138 and 0.997, respectively) (\(P<.05\)).

CONCLUSIONS: Myopic LASIK centered on the CSCLR was significantly safer and more effective than LASIK centered on the pupil (LOS), with significantly lower induction of coma and total higher order aberrations. [J Refract Surg. 2009;25:S944-S950.] doi:10.3928/1081597X-20090915-09

CENTRATION OF MYOPIC LASIK CENTERED ON THE COAXIALLY SIGHTED CORNEAL LIGHT REFLEX OR LINE OF SIGHT

CENTRATION OF EXCIMER LASER ABLATION DURING REFRACTIVE SURGERY HAS GENERATED RENEWED INTEREST DUE TO THE Meticulous PRECISION REQUIRED FOR TOPOGRAPHY-GUIDED AND WAVEFRONT-GUIDED ABLATIONS. THIS HAS ALSO SPURRED DEBATE ON WHETHER THE ABLATION SHOULD BE CENTERED ON THE LINE OF SIGHT (LOS) OR THE COAXIALLY SIGHTED CORNEAL LIGHT REFLEX (CSCLR) (REFERRED TO AS “VISUAL AXIS” IN SOME STUDIES). The LOS is defined by the fixation point at one end and the center of the entrance pupil at the other. The visual axis is defined as the line between the fixation point and the fovea. Traditionally, centration of hyperopic ablations has been more critical due to the use of smaller optical zones and the greater prevalence of angle kappa compared to myopes. Theoretical modeling indicates decentraltion <0.10 mm can induce aberrations rather than reduce aberrations during myopic wavefront-guided treatments. Centration on the LOS does not compensate for the shift in pupil center with differing light conditions. Alternately, approximation of the visual axis by the CSCLR can vary. Additionally, the CSCLR obtained from corneal topography may not accurately determine the location of the visual axis.

Recent studies have reported safety and efficacy with hyperopic ablations centered on the visual axis using the CSCLR. However, there is a relative paucity of reports on the outcomes of centration of myopic ablations on the LOS or the visual axis. A recent study has shown differences in the location of the visual axis as estimated by the CSCLR and the LOS in a population of myopic refractive surgery candidates, indicating that centration strategies are also important for myopic ablations. Currently, only the NIDEK Advanced Vision Excimer Laser System (NAVEX; NIDEK Co Ltd, Gamagori, Japan) offers a closed loop identification of the CSCLR.

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Drs Okamoto and Kimura do not have a proprietary interest in the materials presented herein. Messers Funakura, Ikeda, and Hiramatsu are employees of NIDEK Co Ltd, and Mr Bains is a consultant to NIDEK Co Ltd.

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computation of centration landmark coordinates with regard to the LOS, shot data recalulation, and eye tracker centration to a surgeon-desired offset distance. In this study, we report our experience with myopic LASIK centered on the LOS or the CSCLR (defined as 80% of the distance of the photopic LOS and CSCLR [80% P-Dist]).

**PATIENTS AND METHODS**

Refractive outcomes and wavefront aberrations of 291 patients who underwent myopic LASIK were analyzed using chart review. One hundred forty patients (268 eyes) underwent treatment with centration on the CSCLR (CSCLR group) from January 2008 to October 2008 and 151 patients (288 eyes) underwent treatment with centration on the LOS (LOS group) from January 2007 to December 2007. The most recent patients to undergo LASIK centered on the LOS in the previous year over the same months (to negate the effects of seasonal variation of refractive outcomes, if any) were selected until a similar number of eyes to the CSCLR group were collected. Consecutive patients who underwent surgery were chosen in all cases without pre-selection criteria based on postoperative outcome, postoperative visual acuity, or postoperative higher order aberrations.

All patients in the CSCLR group underwent LASIK with the NIDEK CXIII excimer laser software version 3.41. All patients in the LOS group underwent LASIK with the NIDEK EC-5000 excimer laser software version 1.31 equipped with multipoint ablation. Both lasers were equipped with a 200-Hz eye tracker. All underwent the OPD-guided Custom Aspheric Treatment (OPDCAT) ablation with a 4.5-mm optical zone and 8.0-mm transition zone with profile #6. The Moria One Use-Plus microkeratome (Moria, Antony, France) was used for all surgeries using nomogram-adjusted rings that targeted a 9-mm flap with a single use 90-µm head. The NAVEX platform and the OPDCAT algorithm have been described previously.3,4,13

Preoperatively, all patients underwent an ophthalmic evaluation that included corneal topography, wavefront aberrometry (6-mm pupil, 6th Zernike order), autorefraction, autokeratometry, and pupillometry all performed using the OPD-Scan II (NIDEK Co Ltd); uncorrected visual acuity (UCVA) (logMAR notation); best spectacle-corrected visual acuity (BSCVA); manifest and cyclopegic refraction (pushing plus method); strabismus examination; slit-lamp microscopy of the anterior segment and cornea; tear film testing (Schirmer I and II, break up time); ultrasound corneal pachymetry; and dilated funduscopy. At 1 month postoperatively, patients underwent the same measurements as preoperatively with the exception of the cyclopegic refraction, strabismus examination, dilated funduscopy, and tear film testing unless clinically warranted.

A thorough explanation of the identification of the CSCLR and the LOS using the OPD-Scan has been reported previously.1,2 Briefly, the NIDEK OPD-Scan II identifies and digitally marks the position of the mesopic and photopic LOS relative to the CSCLR, which provides a reasonable estimate of the visual axis. This positional data can be transferred into the Final Fit software version 1.13 (NIDEK Co Ltd) during treatment simulation and preparation of the laser pulse data for ablation.3 During treatment simulation, the center of the ablation can be positioned on either the CSCLR or LOS or any point in between, which is then transferred to the excimer laser and eye tracker.3 The centering procedure is entirely automated, with data transferred to a 200-Hz infrared eye tracker, and does not rely on surgeon estimation of landmarks during surgery.1

All surgeries were performed by one surgeon (S.O.). Based on our previous experience and that reported by others,1 we elected to center the laser ablation closer to the visual axis rather than the photopic LOS using an 80% offset value for the CSCLR group. This corresponds to 80% (80% P-Dist option entered into Final Fit) of the distance towards the CSCLR. For the CSCLR group, just prior to laser ablation, the illumination on the eye is adjusted to correspond to the size of the pupil during OPD-Scan II measurement by comparing the images on the infrared monitor of the eye tracker and adjusting the slit illumination until the diameter is equal.

One-month postoperative refractive outcomes, visual acuity, safety and efficacy indices, and ocular higher order root-mean-square (RMS) values were analyzed and reported. The safety index was defined as postoperative BSCVA/preoperative BSCVA. The efficacy index was calculated as postoperative UCVA/preoperative BSCVA. Eyes were further subdivided based on the distance between the CSCLR and LOS: eyes with a ≤0.25-mm difference between landmarks (low P-Dist group) and eyes with >0.25-mm difference (high P-Dist group) between landmarks. Differences between groups in the following measures were analyzed: UCVA, BSCVA, refraction, RMS of higher order aberrations, RMS of spherical aberration, RMS of coma, and P-Dist using the Wilcoxon rank sum test. Differences in pre- and postoperative variables were analyzed using the chi-square test in males and females between groups. The Welsh two-sample t test was used to test differences in age between groups. P<.05 was considered statistically significant.
RESULTS

PREOPERATIVE VARIABLES

The preoperative parameters for both groups are shown in the Table. Preoperatively, the mean RMS value of spherical aberration was statistically significantly lower by 0.02 µm in the CSCLR group (P=.016). The higher order aberrations of the eye were statistically significantly lower by 0.036 µm in the CSCLR group. A total of 162 males and 129 females underwent surgery (P=0.05). The CSCLR group comprised 77 males and 63 females (P=0.05). The LOS group comprised 85 males and 66 females (P=0.05). No statistically significant differences were noted between groups in the number of males and females treated (P=0.05). Patients in the CSCLR group were statistically significantly older by 2.10 years compared to the LOS group (P=.028).

REFRACTIVE OUTCOMES AND WAVEFRONT ABERRATIONS

Mean postoperative manifest refraction spherical equivalent (MRSE) was 0.17±0.39 diopters (D) (range: −1.38 to +1.25 D) in the CSCLR group and 0.19±0.48 D (range: −1.63 to +1.88 D) in the LOS group. Figure 1 plots the attempted versus achieved MRSE for both groups. Postoperatively, 230/268 eyes (85.8%) in the CSCLR group and 231/288 eyes (80.2%) in the LOS group were within 0.50 D of the intended MRSE. Postoperatively, 265/268 eyes (98.9%) in the CSCLR group and 278/288 eyes (96.5%) were within 1.00 D of the intended MRSE.

Ninety-nine percent (265/268) of eyes in the CSCLR group maintained or gained lines of BSCVA (Fig 2). In the LOS group, 280/288 eyes (97%) maintained or gained lines of BSCVA (see Fig 2). Three (1%) eyes lost one line of BSCVA postoperatively and no eyes lost more than one line of BSCVA in the CSCLR group (see Fig 2). Seven (2.4%) eyes lost one line of BSCVA and 1 (0.3%) eye lost two lines of BSCVA in the LOS group.

![Figure 1. One-month postoperative attempted versus achieved manifest refraction spherical equivalent of eyes that underwent myopic LASIK centered on the coaxially sighted corneal light reflex (yellow squares) or the line of sight (pink triangles).](image)

### TABLE

Preoperative Parameters of Eyes That Underwent Myopic LASIK With Ablation Centered on the Coaxially Sighted Corneal Light Reflex or the Line of Sight

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CSCLR (n=268)</th>
<th>LOS (n=288)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCVA (logMAR)</td>
<td>1.09±0.253</td>
<td>1.10±0.241</td>
<td>.593</td>
</tr>
<tr>
<td>BSCVA (logMAR)</td>
<td>0.169±0.029</td>
<td>0.164±0.037</td>
<td>.051</td>
</tr>
<tr>
<td>MRSE (D)</td>
<td>−4.88±1.55</td>
<td>−5.05±1.63</td>
<td>.286</td>
</tr>
<tr>
<td>P-Dist (mm)</td>
<td>0.196±0.096</td>
<td>0.201±0.101</td>
<td>.610</td>
</tr>
<tr>
<td>Spherical aberration (µm)</td>
<td>0.097±0.078</td>
<td>0.117±0.090</td>
<td>.016*</td>
</tr>
<tr>
<td>Coma (µm)</td>
<td>0.170±0.105</td>
<td>0.169±0.094</td>
<td>.703</td>
</tr>
<tr>
<td>Higher order aberration (µm)</td>
<td>0.329±0.133</td>
<td>0.365±0.135</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Age (y)</td>
<td>33.9±8.0</td>
<td>31.8±8.3</td>
<td>.028†</td>
</tr>
</tbody>
</table>

CSCLR = coaxially sighted corneal light reflex, LOS = line of sight, UCVA = uncorrected visual acuity, BSCVA = best spectacle-corrected visual acuity, MRSE = manifest refraction spherical equivalent, P-Dist = distance between the line of sight and the coaxially sighted corneal light reflex measured by the OPD-Scan II under photopic (P) conditions.

Note. Root-mean-square values for all wavefront aberrations are reported for the entire eye at 6 mm diameter to the 6th Zernike order.

*Statistically significant difference using the Wilcoxon rank sum test with continuity correction, P<.05.
†Statistically significant difference using the Welch two-sample t test, P<.05.
(see Fig 2). No eyes lost more than two lines of BSCVA in the LOS group (see Fig 2). All eyes in both groups had 20/20 BSCVA postoperatively (Fig 3). More eyes in the CSCLR group had 20/10 BSCVA postoperatively (see Fig 3). Best spectacle-corrected visual acuity was statistically significantly higher in the CSCLR group ($P = .004$). The geometric mean postoperative BSCVA was $-0.21$ (range: $-0.11$ and $-0.30$) in the CSCLR group and $-0.20$ (range: $-0.11$ and $-0.21$) in the LOS group.

In the CSCLR group, 252/268 eyes (94%) had 20/20 or better UCVA and 67/268 eyes (25%) had 20/10 or better UCVA postoperatively (Fig 4). In the LOS group, 274/288 eyes (95%) had 20/20 or better UCVA and 43/288 eyes (15%) had 20/10 or better UCVA postoperatively (see Fig 4). The safety index was 1.180 in the CSCLR group and 1.138 in the LOS group. The safety index was statistically significantly higher in the CSCLR group ($P = .002$). The efficacy index of the CSCLR group (1.047) was statistically significantly higher than the LOS group (0.997) ($P = .007$).

Postoperative higher order RMS was $0.480 \pm 0.155 \mu m$ (range: 0.06 to 1.33 µm) in the CSCLR group and $0.557 \pm 0.196 \mu m$ (range: 0.10 to 1.31 µm) in the LOS group. A statistically significant greater induction of higher order aberration was noted in the LOS group compared to the CSCLR group ($P = .04$). Due to the statistical differences in both preoperative higher order aberration and spherical aberration between groups, a comparison of the induction of higher order aberration without the spherical aberration term was performed. There was a statistically significant greater induction of higher order aberrations (without the spherical aberration term) in the LOS group compared to the CSCLR group ($P = .03$). Postoperative spherical aberration was $0.244 \pm 0.140 \mu m$ (range: 0 to 0.63 µm) in the CSCLR group and $0.281 \pm 0.169 \mu m$ (range: 0 to 0.76 µm) in the LOS group. No statistically significant difference was noted in the induction of spherical aberration between groups ($P > .05$). Postoperative coma was $0.272 \pm 0.151 \mu m$.
Visual Axis vs Line of Sight/Okamoto et al

(range: 0 to 1.04 µm) in the CSCLR group and 0.318±0.181 µm (range: 0.01 to 0.93 µm) in the LOS group. A statistically significantly greater induction of coma was observed in the LOS group compared to the CSCLR group ($P<.01$).

**SUBGROUP ANALYSIS**

Histograms of the distance between the pupil center and the CSCLR as measured by the OPD-Scan II (denoted as P-Dist) for both groups are plotted in Figure 5. Twenty-eight percent (75/268) of eyes in the CSCLR group and 32% (92/288) of eyes in the LOS group had a difference of >0.25 mm between the pupil center and CSCLR.

In the high P-Dist subgroup, the safety index was statistically significantly higher in the CSCLR group (1.17) compared to the LOS group (1.10) ($P=.07$). There was no statistically significant difference in the safety indices of the low P-Dist subgroup of the CSCLR group (1.19) and the LOS group (1.16) ($P=.05$). The safety index was statistically significantly higher in the low P-Dist subgroup compared to the high P-Dist subgroup for the LOS group ($P=.006$). There was no statistically significant difference in the safety indices of the subgroups for the CSCLR group ($P>.05$). In the high P-Dist subgroup, the efficacy index was statistically significantly higher in the CSCLR group (1.05) compared to the LOS group (0.96) ($P=.003$). There was no difference in the efficacy index in the low P-Dist subgroup in the CSCLR group (1.05) compared to the LOS group (1.02) ($P>.05$). For the LOS group, the efficacy index was statistically significantly lower in the high P-Dist subgroup compared to the low P-Dist subgroup ($P=.025$).

**DISCUSSION**

These early refractive outcomes of LASIK centered on the CSCLR or the LOS show that both strategies are safe and effective. Less than 3% of all eyes treated lost BSCVA 1 month postoperatively, of which only one eye had a loss of two lines of BSCVA. The majority of eyes were within 0.50 D of the intended MRSE. Similar to Kermani et al., the outcomes presented here represent
our initial experience of centering towards the CSCLR (P-Dist 80%) in a controlled, predictable, and repeatable manner rather than subjective surgeon-sighting. This study was spurred by our personal experience, in which centering the ablation on the pupil resulted in a small percentage of decentered ablations postoperatively (data not shown) despite our subjective impression that we achieved excellent ablation centration intraoperatively. One clarification is required at the outset; although we state “visual axis” throughout the text of the paper, this is an accurate estimate based on digital landmarks from the OPD-Scan II but it is not exactly the visual axis. Additionally, we used 80% of the distance to the CSCLR rather than the entire distance. Ideally, centration would be on the corneal intercept of the visual axis; however, locating the corneal intercept is not practical. Hence, a reasonably accurate landmark will suffice. A previous investigation reported that the CSCLR is 0.02 mm closer to the corneal intercept of the visual axis. This previous study indicates that our estimation of the visual axis is reasonably accurate. However, the caveat remains that no method exists to directly locate the visual axis.

The outcomes of the current study found greater safety and efficacy centering closer to the CSCLR compared to the LOS. This was especially significant in eyes with 0.25-mm differences between the visual axis and pupil center (high P-Dist value). Approximately 30% of myopic refractive surgery candidates have a difference that is large enough to warrant centering closer to the visual axis (see Fig 5). In some eyes, a >0.50-mm difference was found (see Fig 5). This differs from previous studies on myopes that consider the difference between the pupil center and visual axis clinically negligible or recommend alignment on the LOS.

The use of wavefront-guided algorithms makes ablation centration a critical issue. For example, a tolerance <0.07 mm would be required to experience the full benefit of wavefront correction for a 7-mm pupil. Although this value is beyond clinical reality, it indicates a relatively stringent tolerance for centration. Based on differences in P-Dist found here and other documented differences, centering on the LOS for myopic ablations may risk decentered ablations in approximately one-third of patients. Decentration induces coma, which can result in symptoms such as shadowing and glare. We found a statistically significant greater induction of coma in the LOS group. This finding may indicate that better centration and better visual quality is achieved by centering closer to the visual axis. Studies incorporating contrast sensitivity testing are required to determine whether this is the case.

Location of the LOS during surgery remains ambiguous due to differing light conditions, hence there may be a greater risk of decentration by centering on the LOS. Postoperative shadowing and monocular diplopia may occur due to the change in retinal irradiance between the image and blur circle, and the reduction of the Stiles–Crawford effect due to this lack of compensation for the change in LOS. The treatments with the NIDEK NAVEX allow automated transfer and alignment, which reduces positioning errors made by the surgeon when estimating the visual axis.

The RMS of the total ocular higher order aberrations and spherical aberrations were significantly lower preoperatively in the CSCLR group. To address this issue, we performed analyses of the induction of higher order aberrations with and without spherical aberration and found statistically significantly greater induction in the LOS group.

Some limitations of this study include the fact that the groups were treated with different laser models; however, the laser algorithms between models did not differ. The pupil size was matched in the CSCLR group intraoperatively by adjusting the illumination of the laser group. Hence, the different intraoperative techniques may contribute some bias in this study. The LOS group had a higher range of preoperative MRSE, which may induce greater aberrations postoperatively.

Myopic LASIK centered on the CSCLR is safe and efficacious with lower induction of higher order aberrations. Ablation centration closer to the CSCLR may result in better centration. Long-term outcomes are required to validate our interim results with this centration technique in myopes.

**Author Contributions**

Study concept and design (S.O.); data collection (K.K., N.I.); interpretation and analysis of data (M.F., H.H., H.S.B.); drafting of the manuscript (S.O., M.F., H.H., H.S.B.); critical revision of the manuscript (K.K., N.I., H.S.B.); statistical expertise (M.F.); supervision (H.H., H.S.B.)

**References**


