Comparison of femtosecond laser small-incision lenticule extraction and laser-assisted subepithelial keratectomy to correct myopic astigmatism

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PURPOSE: To compare the efficacy of correcting myopic astigmatism with femtosecond laser small-incision lenticule extraction (SMILE, Carl Zeiss Meditec AG) versus laser-assisted subepithelial keratectomy (LASEK).

SETTING: The study was conducted at the Ophthalmology Department, Eye and ENT Hospital, Shanghai, China.

DESIGN: A retrospective, cross-sectional study.

METHODS: This study included patients who underwent small-incision lenticule extraction or LASEK for the correction of myopia and myopic astigmatism. Preoperative and 6-month postoperative astigmatism values were analyzed. The efficacies of the 2 surgeries to correct astigmatism were compared.

RESULTS: A total of 180 right eyes of 180 patients (small-incision lenticule extraction: \( n = 113 \), LASEK: \( n = 67 \)) were included. No significant difference was found between the 2 groups in the preoperative astigmatism (small-incision lenticule extraction: \( 1.16 \pm 0.85 \text{D} \), LASEK: \( 1.16 \pm 0.83 \text{D} \), \( P > .05 \)) or the postoperative astigmatism (small-incision lenticule extraction: \( 0.35 \pm 0.37 \text{D} \); LASEK: \( 0.31 \pm 0.42 \text{D} \), \( P > .05 \)), determined by manifest refraction. No significant difference was found between the 2 groups in surgically induced astigmatism vector (small-incision lenticule extraction: \( 1.13 \pm 0.83 \text{D} \), LASEK: \( 1.01 \pm 0.65 \text{D} \), \( P > .05 \)). The correction index was higher for the small-incision lenticule extraction group (\( 1.05 \pm 0.53 \)) than for the LASEK group (\( 0.95 \pm 0.21 \), \( P = .045 \)). The postoperative astigmatism was significantly higher for the small-incision lenticule extraction group when the preoperative astigmatism was 1.0 D or less (small-incision lenticule extraction: \( 0.26 \pm 0.30 \text{D} \), LASEK: \( 0.12 \pm 0.20 \text{D} \), \( P = .007 \)) and lower for the small-incision lenticule extraction group when the preoperative astigmatism was more than 2.0 D (small-incision lenticule extraction: \( 0.48 \pm 0.37 \text{D} \), LASEK: \( 0.89 \pm 0.46 \text{D} \), \( P = .002 \)).

CONCLUSIONS: An adjustment of nomograms for correcting low astigmatism (\( \leq 1.0 \text{D} \)) by small-incision lenticule extraction is suggested due to the tendency toward overcorrection, whereas a nomogram adjustment for tissue-saving ablation profile is needed for the correction of high astigmatism (\( > 2.0 \text{D} \)) by LASEK due to the tendency toward undercorrection.

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side incision. This procedure allows great stability, since the Bowman layer remains intact. In LASEK, an epithelium flap is created before excimer laser ablation is applied. The Bowman layer is ablated and does not regenerate. It is not clear whether one procedure is more advantageous over another. To our knowledge, there is currently no clinical investigation comparing the efficacies of treating myopic astigmatism between small-incision lenticule extraction and LASEK.

In this study, surgically induced changes in astigmatism in eyes undergoing either small-incision lenticule extraction or LASEK surgeries were retrospectively analyzed to compare the efficacies of small-incision lenticule extraction and LASEK in correcting myopic astigmatism.

PATIENTS AND METHODS

Study Group and Protocol

The research described in this article followed the tenets of the Declaration of Helsinki and was approved by the ethics committee of the EENT Hospital of Fudan University. Informed written consent was obtained from all patients.

This study included all patients who underwent small-incision lenticule extraction or LASEK for the correction of myopia and myopic astigmatism from May 2012 to March 2013 with a minimum follow-up time of 6 months. The research was conducted at the Ophthalmology Department of the Eye and ENT Hospital in Shanghai, China.

Inclusion criteria were spherical refraction from −3 to −10 D for small-incision lenticule extraction and 0 to −14 D for LASEK, astigmatism from −0.25 to −5 D for small-incision lenticule extraction and −0.25 to −6 D for LASEK, the sum of sphere and cylinder from −3 to −10 D for small-incision lenticule extraction, best corrected distance visual acuity (CDVA) of 20/25 or better, stable refraction for 2 years prior to surgery, and an absence of other pathologic ocular conditions or relevant systemic diseases.

Surgical Technique

All small-incision lenticule extraction or LASEK procedures were performed by the same surgeon. Small-incision lenticule extraction surgeries were performed using a Visumax femtosecond laser system (Carl Zeiss Meditec AG), with a repetition rate of 500 kHz and pulse energy of 130 nJ, following the surgical procedure described by Sekundo et al. The intended thickness of the upper tissue arcade (the cap) was 110 μm, with an intended diameter of 7.5 mm, whereas the diameter of the refractive lenticule was 6.5 mm. A single side cut of 90 degrees with a circumferential length of 2 to 4.5 mm was made in the superior position. Following the cutting procedure, the refractive lenticule was dissected and separated through the side cut and manually removed.

LASEK treatments began with 20% alcohol-assisted epithelial removal, followed by standard excimer laser ablation with a Mel-80 excimer laser (software version: 3.6, Carl Zeiss Meditec AG; Tissue Saving Ablation profiles [TSA]; standard nomogram). The epithelium was repositioned after laser ablation, and a bandage soft contact lens was applied. The target postoperative refraction was emmetropia in all eyes.

Measurements and Analysis for Astigmatism

Patients were examined preoperatively, as well as 1 week, 1 month, 3 months and 6 months postoperatively. A total of 59 patients (24.7%) were excluded due to loss of follow up. Only results from the preoperative and 6-month postoperative visits were used for analysis. Objective and subjective refraction tests were performed, and uncorrected distance visual acuity (UDVA) and corrected distance visual acuity (CDVA) were recorded during all follow-up visits. Pentacam (Oculus GmbH) imaging was performed by the same experienced examiner for all patients in all visits. Manifest refraction was measured by an experienced examiner starting with values obtained by objective refraction. Astigmatism was expressed in positive cylinder form. Manifest astigmatism was converted to the corneal plane using a vertex of 12 mm. Topographic parameters included flat central power ($P_s$), steep central power ($P_o$), and meridian of the steep central power from the simulated keratometry (simK), all of which were derived from the axial curvature map. Corneal astigmatism in positive cylinder form is ($P_o - P_s$), with the same axis as $P_s$.

The small-incision lenticule extraction and LASEK groups were compared using the following indices: pre- and postoperative astigmatism determined by manifest refraction or corneal topography, surgically induced change in the astigmatism vector determined by manifest refraction (surgically induced astigmatism [SIA]) or by corneal topography (SICA), flattening effect of the SIA, correction index (correction index), and flattening index (FI). SIA (or SICA) is the amount and axis of astigmatic change caused by surgery. It was calculated as the vector difference between the pre- and postoperative astigmatism determined by manifest refraction or corneal topography. Target induced astigmatism (TIA) vector is the astigmatic change the surgery was intended to induce, with its magnitude equal to that of the preoperative astigmatism and its axis perpendicular to that of the preoperative astigmatism, since the target postoperative refraction was emmetropia in all eyes. The flattening effect is the amount of astigmatism reduction achieved by the effective proportion of at the intended meridian (flattening effect = SIA vector × cos2 × [angle of SIA vector – angle of TIA vector]), where correction index is the ratio of the SIA vector to the TIA vector and flattening index is the ratio of the flattening effect to the TIA vector.
Two polar values representing the net curvital power (AKP) and net torsional power (AKP<sub>C45</sub>) over the surgical meridian (ie, preoperatively steeper meridian) were also calculated. The errors in treatment, AKP<sub>error</sub> and AKP<sub>C45, error</sub>, were calculated by subtraction of the achieved change from the intended value. Since the intended value was zero, the errors in treatment amounted to postoperative astigmatism. AKP<sub>error</sub> and AKP<sub>C45, error</sub> were calculated as follows: AKP<sub>error</sub> = [M] × cos[2(α - φ)]; AKP<sub>C45, error</sub> = [M] × sin[2(α - φ)], where M is the magnitude of postoperative astigmatism, α is the axis of postoperative astigmatism, and φ is the axis of preoperative astigmatism. A positive AKP<sub>error</sub> means undercorrection and a negative AKP<sub>error</sub> means overcorrection. A positive AKP<sub>C45, error</sub> means an unintended anticlockwise torque, and a negative AKP<sub>C45, error</sub> means an unintended clockwise torque.

**Statistical Analysis**

Statistical analyses were performed using SPSS software (version 13.0; SPSS Inc.). A Student t test was performed to determine the difference between small-incision lenticule extraction and LASEK groups. P values of less than 0.05 were considered statistically significant.

**RESULTS**

The right eyes of 73 males (40.6%) and 107 females (59.4%) were included in this study (small-incision lenticule extraction: n = 113, LASEK: n = 67). All surgeries were successfully completed. No intraoperative or postoperative complications were observed. Three eyes (4.5%) in the LASEK group had minimal corneal haze at 6 months postoperatively. The distributions of pre- and postoperative astigmatism at the spectacle plane for both groups are shown in Table 1. Figures 1 to 6 show the scatter plots of preoperative manifest astigmatism, postoperative manifest astigmatism, and SIA vector for both groups. Preoperatively, the mean spherical error was larger in the small-incision lenticule extraction group (−6.70 ± 1.53 D) than in the LASEK group (−5.61 ± 1.75 D; P < .001). No significant difference was found between the 2 groups in the following: preoperative manifest astigmatism, preoperative corneal astigmatism, and preoperative CDVA (P > .05) (Table 2).

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| Table 1. Distribution of pre- and postoperative astigmatism (spectacle plane) in small-incision lenticule extraction and LASEK groups. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | ≤0.25           | 0.25 to 0.5     | 0.5 to 1.0      | 1.0 to 2.0      | 2.0 to 3.0      | ≥3.0            |
| Preoperative small-incision lenticule extraction | 13 (11.5)       | 21 (18.6)       | 26 (23.0)       | 28 (24.8)       | 20 (17.7)       | 5 (4.4)         |
| LASEK           | 8 (11.9)        | 9 (13.4)        | 19 (28.4)       | 17 (25.4)       | 9 (13.4)        | 5 (7.5)         |
| Postoperative small-incision lenticule extraction | 64 (56.6)       | 28 (24.8)       | 17 (15.0)       | 4 (3.5)         | 0 (0)           | 0 (0)           |
| LASEK           | 44 (65.7)       | 11 (16.4)       | 6 (9.0)         | 6 (9.0)         | 0 (0)           | 0 (0)           |

LASEK = laser-assisted subepithelial keratectomy
Data in parentheses are percentages

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Figure 1. Preoperative manifest astigmatism for SMILE (SMILE = small-incision lenticule extraction).
Postoperatively, no significant difference was found between the 2 groups in following: manifest spherical error, manifest astigmatism, corneal astigmatism, UDVA, CDVA, lines difference between postoperative UDVA and preoperative CDVA (UDVA_post – CDVA_pre), SIA vector, SICA, flattening effect, flattening index, AKP_error and AKP_45_error (P > .05) (Table 2). The correction index was higher in the small-incision lenticule extraction group (1.05 ± 0.53) than in the LASEK group. No significant correlation between the preoperative spherical error and postoperative manifest astigmatism was found (P > .05). Figure 7 shows scatter plots of the surgically induced astigmatism vector plotted against the target-induced astigmatism (TIA) vector in both groups. Figure 8 shows the correction index plotted against the TIA vector in both groups. Figure 9 shows flattening effect plotted against the TIA vector in both groups.

Eyes in each group were divided into 3 categories based on preoperative manifest astigmatism: 0.25 to 1.0 D, 1.25 to 2.0 D, and 2.25 D and more. No significant difference was found between small-incision lenticule extraction and LASEK in preoperative
manifest astigmatism for all the 3 categories ($P > .05$) (Table 3). The preoperative spherical errors were higher in the small-incision lenticule extraction group than in the LASEK group for all 3 categories, but the differences were significant only in the first 2 categories (Table 3). The postoperative spherical error was greater in the LASEK group than in the small-incision lenticule extraction group when the preoperative astigmatism was more than 2.0 D.

When the preoperative astigmatism was 1.0 D or less, the postoperative manifest astigmatism was higher for the small-incision lenticule extraction group than for the LASEK group. The correction index for this low astigmatism category was higher for small-incision lenticule extraction than for LASEK, and the difference approached significance ($P = .076$). In the low astigmatism group, no significant difference was found between the small-incision lenticule extraction and LASEK in the postoperative UDVA, CDVA, SIA vector, flattening effect, flattening index, AKPerror, and AKP+$45$ error (Table 3).

When the preoperative astigmatism was between 1.25 and 2.0 D, no significant difference was found between small-incision lenticule extraction and LASEK for the following indices: postoperative astigmatism, postoperative CDVA, SIA vector, flattening effect,
correction index, flattening index, AKP_{error} and \( \text{AKP}_{+45} \) error. In this moderate astigmatism group, the postoperative UDVA was better for LASEK than for small-incision lenticule extraction (Table 3).

When preoperative astigmatism was more than 2.0D, the postoperative manifest astigmatism was significantly smaller for the small-incision lenticule extraction group than for the LASEK group. In this

![Figure 6. SIA vector for LASEK (SIA = surgically induced astigmatism; LASEK = laser-assisted subepithelial keratectomy).](image)

### Table 2. Comparison of small-incision lenticule extraction and LASEK groups.

<table>
<thead>
<tr>
<th></th>
<th>Small-incision Lenticule Extraction (n = 113)</th>
<th>LASEK (n = 67)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preoperative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>26.04 ± 6.65 (17, 52)</td>
<td>24.87 ± 4.66 (18, 41)</td>
<td>.165</td>
</tr>
<tr>
<td>Spherical error by MR (D)</td>
<td>−6.70 ± 1.53 (−9.33, −3.36)</td>
<td>−5.61 ± 1.75 (−12.35, −1.95)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Cylinder error by MR (D)</td>
<td>1.16 ± 0.85 (0.21, 3.57)</td>
<td>1.16 ± 0.83 (0.11, 3.54)</td>
<td>.967</td>
</tr>
<tr>
<td>Corneal astigmatism (D)</td>
<td>1.61 ± 0.88 (0.3, 4.1)</td>
<td>1.65 ± 0.82 (0.3, 3.6)</td>
<td>.754</td>
</tr>
<tr>
<td>CDVA (LOGMAR)</td>
<td>−0.02 ± 0.06 (−0.18, 0.10)</td>
<td>−0.02 ± 0.05 (−0.18, 0.10)</td>
<td>.828</td>
</tr>
<tr>
<td><strong>Postoperative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UDVA (LOGMAR)</td>
<td>−0.01 ± 0.09 (−0.18, 0.10)</td>
<td>−0.03 ± 0.07 (−0.18, 0.10)</td>
<td>.517</td>
</tr>
<tr>
<td>CDVA (LOGMAR)</td>
<td>−0.05 ± 0.06 (−0.18, 0.0)</td>
<td>−0.04 ± 0.07 (−0.18, 0.0)</td>
<td>.575</td>
</tr>
<tr>
<td>UDVA_{post} − CDVA_{pre}</td>
<td>0.03 ± 1.01 (−2.0, 3.0)</td>
<td>0.3 ± 1.18 (−4.0, 2.0)</td>
<td>.104</td>
</tr>
<tr>
<td>Spherical error by MR (D)</td>
<td>−0.29 ± 0.65 (−2.13, 1.01)</td>
<td>−0.34 ± 0.89 (−1.90, 1.79)</td>
<td>.672</td>
</tr>
<tr>
<td>Cylinder error by MR (D)</td>
<td>0.35 ± 0.37 (0, 1.70)</td>
<td>0.31 ± 0.42 (0.1, 1.46)</td>
<td>.580</td>
</tr>
<tr>
<td>Corneal astigmatism (D)</td>
<td>0.85 ± 0.52 (0, 3.2)</td>
<td>0.98 ± 0.56 (0.1, 3.1)</td>
<td>.137</td>
</tr>
<tr>
<td>SIA (D)</td>
<td>1.13 ± 0.83 (0.09, 3.57)</td>
<td>1.01 ± 0.65 (0.11, 2.98)</td>
<td>.307</td>
</tr>
<tr>
<td>SICA (D)</td>
<td>1.23 ± 0.98 (0.06, 4.56)</td>
<td>1.03 ± 0.62 (0.22, 3.00)</td>
<td>.107</td>
</tr>
<tr>
<td>Flattening effect (D)</td>
<td>1.05 ± 0.86 (−0.42, 3.57)</td>
<td>0.96 ± 0.67 (−0.28, 2.97)</td>
<td>.452</td>
</tr>
<tr>
<td>Correction index</td>
<td>1.05 ± 0.53 (0.20, 4.35)</td>
<td>0.95 ± 0.21 (0.46, 1.52)</td>
<td>.045</td>
</tr>
<tr>
<td>Flattening index</td>
<td>0.88 ± 0.63 (−1.29, 4.19)</td>
<td>0.87 ± 0.28 (−0.32, 1.49)</td>
<td>.944</td>
</tr>
<tr>
<td>AKP_{error} (D)</td>
<td>0.11 ± 0.36 (−1.24, 1.67)</td>
<td>0.19 ± 0.40 (−0.47, 1.40)</td>
<td>.717</td>
</tr>
<tr>
<td>( \text{AKP}_{+45} ) error (D)</td>
<td>0.05 ± 0.34 (−0.98, 1.61)</td>
<td>0.001 ± 0.28 (−0.69, 0.92)</td>
<td>.370</td>
</tr>
</tbody>
</table>

\( \text{AKP}_{error}, \text{AKP}_{+45 \text{error}} = \) polar analysis of postoperative astigmatism; Correction index = correction index (SIA/TIA); CDVA = corrected distance visual acuity; Flattening index (= flattening effect/TIA); LASEK = laser-assisted subepithelial keratectomy; MR = manifest refraction; SIA = surgically induced change in manifest astigmatism; SICA = surgically induced change in corneal astigmatism; TIA = targeted induced astigmatism; UDVA = uncorrected distance visual acuity; UDVA_{post} − CDVA_{pre} = lines difference between postoperative UDVA and preoperative CDVA.

All values are reported as mean ± standard deviation. Data in parentheses are ranges. All refractive errors were converted to the corneal plane using a vertex of 12 mm.
high-astigmatism group, the small-incision lenticule extraction group had a higher flattening effect, correction index, and flattening index than the LASEK group. The AKPerror was significantly higher for the LASEK group than the small-incision lenticule extraction group. The AKP+45 error were small for both small-incision lenticule extraction and LASEK groups for all 3 categories, which indicated little rotation of the axis for both procedures (Table 3).

**Figure 7.** SIA vector plotted against TIA vector in small-incision lenticule extraction and LASEK groups (LASEK = laser-assisted subepithelial keratectomy; SIA = surgically induced astigmatism; TIA = target-induced astigmatism).

**Figure 8.** CI plotted against TIA vector in small-incision lenticule extraction and LASEK groups (CI = correction indices; LASEK = laser-assisted subepithelial keratectomy; TIA = target-induced astigmatism).

**Figure 9.** Scatter plots of FE plotted against TIA vector in small-incision lenticule extraction and LASEK groups (FE = flattening effect; LASEK = laser-assisted subepithelial keratectomy; TIA = target-induced astigmatism).

**DISCUSSION**

In the current study, small-incision lenticule extraction was compared to LASEK in correcting myopic astigmatism ranging from 0.25 D to 4.25 D. We found that for low astigmatism (preoperative astigmatism ≤1.0D), the mean astigmatism remaining (ie, postoperative astigmatism) was significantly lower for LASEK than for small-incision lenticule extraction. Furthermore, the correction index was closer to 1.0
for LASEK. Therefore, LASEK performed better than small-incision lenticule extraction in correcting low myopic astigmatism. For moderate astigmatism (1.0 to 2.0 D), no significant differences were found between small-incision lenticule extraction and LASEK. Therefore, both small-incision lenticule extraction and LASEK were equitable strategies in correcting moderate myopic astigmatism. For high astigmatism (>2.0 D), the astigmatism remaining was much higher for LASEK than for small-incision lenticule extraction. In addition, both correction index and flattening index were much lower for LASEK than for small-incision lenticule extraction, which indicated larger undercorrections by LASEK for eyes with high astigmatism. Consequently, small-incision lenticule extraction performed better than LASEK in correcting high astigmatism.

Although laser in situ keratomileusis (LASIK) is predominantly used in refractive surgery due to little pain and rapid visual rehabilitation, surface ablation including LASEK is preferred by many surgeons because of its ability to keep more corneal tissue postoperatively. Comparable or more successful results for low to moderate myopia have been found in LASEK when compared to LASIK. LASEK is the second most frequently performed laser refractive surgery in our center, second only to small-incision lenticule extraction. As an alternative to eximer laser for the correction of myopia, small-incision lenticule extraction technology has exhibited excellent efficacy, safety, stability, and predictability in the correction of myopia and myopic astigmatism. Small-incision lenticule extraction surgery is created by the femtosecond laser without eye tracking, instead of photoablation performed by eximer laser, and the accuracy of the axis correction may be influenced by the alignment of the center of the ablated zone. To our knowledge, no study has been conducted that directly compared the efficacy of astigmatism correction between LASEK and small-incision lenticule extraction. Ganesh et al. compared the visual and refractive outcomes of femtosecond laser-assisted laser in situ keratomileusis (FS-LASIK) with small-incision lenticule extraction in the correction of myopia and myopic astigmatism. The refractive accuracy, dry eye, contrast, and induced aberrations were better following small-incision lenticule extraction compared to FS-LASIK. The authors attributed these results to the different state of hydration between FS-LASIK and small-incision lenticule extraction. Lin et al. also found that small-incision lenticule extraction has a lower induction rate of higher-order aberrations and spherical aberrations than FS-LASIK. However, postoperative astigmatism were not provided and compared in these 2 studies. Fraunfelder et al. and Stojanovic et al. compared the effectiveness of astigmatism correction in eyes treated with LASIK and photorefractive keratectomy (PRK) and found no significant differences between the 2 groups 6 months after the surgery. Huang et al. compared the efficacy of LASIK and LASEK in correcting myopic astigmatism and found that LASEK had better effects in correcting corneal astigmatism up to 2.5 D.

When comparing the efficacy of small-incision lenticule extraction across patients with varying magnitudes of preoperative astigmatism, we found that small-incision lenticule extraction was more effective in correcting moderate myopic astigmatism (1.0 to 2.0 D) than in correcting low (<1.0 D) or high (>2.0 D) myopic astigmatism, as reflected by the postoperative astigmatisms and correction indices (or flattening indices) across these patient groups. This result is similar to previous studies that found lower efficacy of small-incision lenticule extraction in correcting low or high astigmatism compared to moderate astigmatism. Moreover, we found that LASEK was less effective in treating high myopic astigmatism (>2.0 D) than in treating low or moderate astigmatism (≤2.0 D). This was also found in other studies for LASEK or PRK.

When the preoperative astigmatism was 1.0 D or less, the correction index was 1.16 for small-incision lenticule extraction, which suggested an overcorrection by small-incision lenticule extraction for low astigmatism. This was also found in a report by Kunert et al. on small-incision lenticule extraction, in which a correction index of 1.28 was found for eyes with a preoperative astigmatism ≤0.50 D. For LASEK, although the mean correction index was very close to 1.0 (1.01), the scatter plot of correction indices (Figure 8) also showed small amounts of overcorrection for low astigmatism. The overcorrection for low astigmatism was also reported in previous studies on LASIK and PRK treatments with different excimer laser platforms. Eyes with a preoperative cylinder of ≤0.50 D were found to have a higher tendency toward overcorrection and larger axis deviations upon vector analysis. The variability in low astigmatic corrections could be due to the larger axis deviations for lower astigmatism corrections because of the greater difficulty in determining the axis preoperatively, asymmetric ablations (or asymmetric lenticules) in different regions of the cornea during surgery or meridional differences in corneal wound healing postoperatively.

When the preoperative astigmatism was more than 1.0 D, both small-incision lenticule extraction and LASEK showed an undercorrection, and the undercorrection increased with the magnitude of the attempted treatment (TIA). The results of this
investigation on small-incision lenticule extraction was comparable to findings by Kunert et al., in which the correction index was 0.87 for the TIA of 2.0 to 3.0 D, 0.84 for the TIA of 2.0 to 3.0 D, 0.86 for the TIA of 3.0 to 4.0 D, and 0.93 for the TIA of 4.0 to 5.0 D. Similar results were also reported by Zhang et al. In a study by Ivarsen and Hjortdal, small-incision lenticule extraction was found to undercorrect eyes with astigmatism higher than 0.75 D, and the undercorrection increased with the attempted treatment.1

The authors also evaluated the outcome of FS-LASEK procedure with mitomycin for myopic eyes using the MEL-80 excimer laser, and found undercorrections as high as 21% of the attempted cylinder correction. Frings et al.3 used the same eximer laser system to perform LASEK with mitomycin for myopic astigmatism of 2.0 D or more. Their results were much better than those achieved with LASIK, with the mean preoperative and 6-month postoperative astigmatism measured by manifest refraction being 2.50 D and 0.27 D, respectively. This may be explained by the use of mitomycin and larger optical zone in this research.

It is believed that the refractive accuracy depends on the accurate removal of stromal tissue intraoperatively. A variation in hydration of the corneal stroma is the most likely cause for underablation or overablation of stromal tissue in excimer laser surgery. In small-incision lenticule extraction, the cutting is performed in a normal-hydrated cornea. Exposure of the stroma to hydration during the LASEK procedure could lead to greater undercorrections than small-incision lenticule extraction, especially for higher myopia or astigmatism. Moreover, the alignment of axis during surgery is of great importance to the correction of astigmatism, especially in small-incision lenticule extraction, due to the lack of eye movement. The misalignment of axis during surgery may have an effect on the accuracy in astigmatic correction.

In the current research, only visual acuity and manifest refraction were assessed, and other visual parameters such as halos, wavefront aberration, and contrast sensitivity, which are possibly correlated with postoperative astigmatism, were not evaluated. In addition, although no significant difference was found between the 2 groups in preoperative astigmatism, the...
toward undercorrection. A nomogram adjustment for TSA ablation profile is needed for the correction of high astigmatism. Furthermore, small-incision lenticule extraction surgery suggests a tendency toward overcorrection when correcting low astigmatism. The correction index was higher for the LASEK group. The tendency toward overcorrection was higher in the small-incision lenticule extraction group than for the LASEK group. Since no significant correlation was found between the preoperative spherical error and postoperative astigmatism, correcting coexisting spherical error may not have had an influence on the cylindrical error correction. Finally, the sample sizes in the moderate and high astigmatism groups were relatively small compared to those in the low astigmatism group. Future prospective studies would help to solve this problem.

CONCLUSIONS

Both small-incision lenticule extraction and LASEK were observed to be safe, effective, and predictable for the correction of myopia and myopic astigmatism. The correction index was higher for the small-incision lenticule extraction group than for the LASEK group. The tendency toward overcorrection when correcting low astigmatism (≤1.0 D) with small-incision lenticule extraction surgery suggests a need for an adjustment of nomograms. Furthermore, a nomogram adjustment for TSA ablation profile is needed for the correction of high astigmatism (>2.0 D) with LASEK surgery due to the tendency toward undercorrection.

**WHAT WAS KNOWN**
- Small-incision lenticule extraction and LASEK are both effective procedures for the correction of myopia and myopic astigmatism.

**WHAT THIS PAPER ADDS**
- An adjustment of nomograms for correcting low astigmatism (≤1.0 D) by small-incision lenticule extraction is suggested due to the tendency toward overcorrection, whereas a nomogram adjustment for TSA ablation profile is needed for the correction of high astigmatism (>2.0 D) by LASEK due to the tendency toward undercorrection.

**REFERENCES**


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