Preliminary Results of Femtosecond Laser–Assisted Descemet Stripping Endothelial Keratoplasty

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Objective: To evaluate the preliminary visual results of femtosecond laser–assisted Descemet stripping endothelial keratoplasty (FS-DSEK).

Methods: We prospectively analyzed results of 20 consecutive patients with Fuchs endothelial dystrophy or aphakic/pseudophakic bullous keratopathy who underwent FS-DSEK. Best spectacle-corrected visual acuity (BSCVA), refraction, corneal topography, and endothelial cell density were measured preoperatively and 3 and 6 months after FS-DSEK. Corneal thickness was measured using an optical coherence tomography technique.

Results: The average BSCVA of 11 eyes with normal visual potential significantly improved from 20/110±4 lines to 20/57±1 line at 6 months (P<.007). At 6 months, the mean (SD) hyperopic shift was 2.24 (2.3) diopters (D). Preoperative and 6 months postoperative refractive astigmatism were −0.75 (0.9) D and −1.58 (1.1) D (P=.01), but the topographic astigmatism did not change postoperatively (P=.95). Mean (SD) endothelial cell density at 6 months was 1368 (425) cells/mm². There was a persistent deswelling of the graft up to 3 months postoperatively. Complications included graft dislocations requiring repositioning (20%), pupillary block glaucoma (5%), epithelial ingrowth (5%), and primary graft failure (5%).

Conclusions: Femtosecond laser–assisted Descemet stripping endothelial keratoplasty was effective in treating endothelial failure with minimal induced refractive astigmatism, limited improvement of BSCVA, and induction of a hyperopic shift. Endothelial cell count and dislocation rate were significant, which may be related to the surgical technique.

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Several Endothelial Keratoplasty (EK) procedures, such as posterior lamellar keratoplasty,^1^ posterior lamellar keratoplasty using the femtosecond laser,^2^ deep lamellar endothelial keratoplasty,^3^ Descemet stripping endothelial keratoplasty,^4^ Descemet stripping automated endothelial keratoplasty (DSAEK),^5^ femtosecond laser–assisted Descemet stripping endothelial keratoplasty (FS-DSEK),^6^ and Descemet membrane endothelial keratoplasty,^7^ allow for selective replacement of the diseased endothelial layer, retaining the healthy recipient anterior corneal stroma. Endothelial keratoplasty techniques result in a rapid visual rehabilitation and minimal change in corneal astigmatism. The purpose of this study was to evaluate the clinical outcomes of the first 20 patients after FS-DSEK, where the FS laser is used to prepare the posterior lamellar disc (PLD).

METHODS

Twenty eyes of 20 consecutive patients with Fuchs endothelial dystrophy (n=11) or aphakic/pseudophakic bullous keratopathy (n=9) were included in a prospective study. Institutional review board approval and informed consent was obtained.

Preoperatively, the medical history was recorded and all patients underwent an ophthalmologic examination. Manifest refraction was obtained using Snellen acuity charts, and corneal topography (EyeMap EH-290; Alcon, Fort Worth, Texas) was performed. Best spectacle-corrected visual acuity (BSCVA) was determined using the Early Treatment of Diabetic Retinopathy Study letter charts and converted to Snellen equivalents. Endothelial cell density (ECD) of the donor tissue was obtained from the Cornea Bank Amsterdam. Best spectacle-corrected visual acuity, manifest refraction, corneal topography, and ECD (Noncon Robo SP 8000; Konan, Hyogo, Japan) were performed at 3 and 6 months postoperatively.

At 1 week and 1, 3, and 6 months postoperatively, the thickness of the PLD and the thickness of the recipient corneas were measured using an optical coherence tomography technique (Visante; Carl-Zeiss Meditec, Dublin, California). One high-resolution corneal quad scan was taken. Four cross-sectional images were taken at 0° to 180°, 45° to 225°, 90° to 270°, and 135° to 315°. Measurements of each image were
taken at the vertex of the cornea (0.0 mm) and at 3.5 mm on each side of the vertex (−3.5 mm and +3.5 mm). The 4 central measurements and 8 peripheral measurements were averaged to a single value to determine the thickness of the recipient cornea and the PLD.

DONOR TISSUE

The PLD was prepared with the 30-kHz femtosecond laser (AMO, Uppsala, Sweden and Intralase Corp, Irvine, California). The intended depth of the horizontal lamellar cut was 400 µm, and the diameter was 9.5 mm using a raster spot pattern with an energy level of 1.4 µJ.6

SURGICAL TECHNIQUE

General anesthesia was used in all patients. A 5.0-mm corneoscleral incision and 2 limbal paracenteses were made. The Descemet membrane was scored with a Price-Sinskey hook (Moria, Anthony, France), and a circle of 7.5 mm of Descemet membrane and endothelium was stripped from the posterior stroma. A 15° blade was used to make 3 or 4 transcorneal incisions in the midperipheral recipient cornea to drain fluid between the recipient cornea and PLD.4

A 8.0-mm donor corneal disc was trephined from the corneoscleral button, and the PLD was removed from the anterior cornea. The endothelial surface was coated with a small layer of viscoelastic material (Healon; AMO). The PLD was gently folded into a taco configuration, and the folded PLD was grasped and inserted using a Goosey forceps (Moria). The corneoscleral incision was closed with two 10-0 nylon sutures. An air bubble was injected to unfold the PLD and press the PLD against the recipient cornea. After 20 minutes, the bubble was partly removed and 2 drops of 0.5% tropicamide minims were instilled to avoid a pupillary block. After pupillary block occurred in 2 patients, a peripheral iridectomy was routinely performed. The patients were instructed to lie supine for the next 24 hours to maximize the pressure of the remaining air bubble against the PLD. The postoperative treatment consisted of 0.3% prednisolone acetate 6 times daily and 0.4% chloramphenicol 3 times daily in a tapering dose.

DATA ANALYSIS

Comparisons of preoperative measurements and postoperative measurements were performed using a paired t test for normally distributed data and Wilcoxon signed-rank test for non-normally distributed data. Values are reported as mean (SD). A P value of <.05 was considered statistically significant. Statistical analysis was performed with SPSS (version 12.0; SPSS Inc, Chicago, Illinois). RESULTS

Twenty eyes of 20 patients underwent FS-DSEK (Figure 1). The mean (SD) age at surgery was 70.4 (8.4) years with a mean (SD) follow-up of 27.0 (4.4) weeks. Eight patients required FS-DSEK for pseudophakic bullous keratopathy, and 1 patient required FS-DSEK for aphakic bullous keratopathy. The remaining 11 patients had Fuchs endothelial dystrophy and cataract. Two patients underwent a combined phacoemulsification and FS-DSEK procedure. The intraocular lens power was chosen for a postoperative spherical equivalent of −0.50 diopter (D).

The preoperative and postoperative details of all patients are shown in Table 1. One patient (patient 1) died prior to his 6-month examination. Before surgery and at 6 months, the average BSCVA of the 20 eyes was 20/150±4 lines and 20/94±3 lines (P = .03), respectively. After excluding the eyes with preexisting retinal problems, amblyopia, and primary graft failure, the average BSCVA of 11 eyes with normal visual potential improved from 20/110±4 lines preoperatively to 20/37±1.0 line (range, 20/38–20/100) at 6 months, and 50% had an improved BSCVA of more than 2 lines at 6 months (Figure 2). The preoperative BSCVA of the patient with a graft failure was 20/87, and at 3 and 6 months, the BSCVA was finger counting.

The mean (SD) preoperative spherical equivalent and refractive astigmatism were −0.89 (2.7) D and −0.75 (0.9) D,
compared with 1.30 (1.9) D (P = .002) (Table 2) and −1.58 (1.1) D (P = .01) 6 months postoperatively. The mean (SD) hyperopic shift was 2.24 (2.3) D at 6 months postoperatively. The mean (SD) topographic cylinder was 2.28 (1.7) D preoperatively and 1.85 (1.1) D 6 months postoperatively (P = .95).

Two patients had a surgical peripheral iridectomy during FS-DSEK because of a perioperative pupillary block. Postoperatively, 4 of the 20 patients experienced dislocation of the PLD. These patients underwent repositioning of the PLD with an air bubble between 1 day and 1 week postoperatively. One of the 4 patients underwent a second repositioning of the PLD, and in 2 additional patients, interface fluid was drained. One patient experienced pupillary block glaucoma on the first postoperative day, which was relieved by removing a small amount of air from the anterior chamber. At 1 month postoperatively, epithelial ingrowth was seen in 1 patient (patient 16) (Figure 3), with no progression up to 6 months’ follow-up. One patient had an iatrogenic graft failure, and after re–FS-DSEK, BSCVA was 20/70. All grafts remained adherent and were clear during the last follow-up visit.

At 6 months postoperatively, the mean (SD) ECD with and without dislocation of the PLD were 740 (372) cells/mm² (71% cell loss) and 1368 (425) cells/mm² (48% cell loss), respectively (Table 3).

At 3 months postoperatively, the recipient corneal thickness in the center and periphery had decreased a mean (SD) of 16.3% (8.5%) (P = .03) and 20.3% (9.0%)...
The thickness of the PLD in the center and periphery decreased a mean (SD) of 16.0% (8.5%) (P = .03) and 29.6% (10.9%) (P = .03), respectively. The PLD thinned significantly faster at the periphery than at the center (P = .03).

**COMMENT**

In a previous in vitro study, we showed that an FS laser is feasible to prepare a PLD for EK,12 and in December 2005, we performed the first FS-DSEK.6 In the present study, we report the first 20 patients with a follow-up of 6 months after FS-DSEK.

In this first series of FS-DSEK, the average BSCVA improved from 20/110 to 20/57 at 6 months’ follow-up, and 50% of our series with normal vision potential showed an improvement of 2 lines or more. After small-incision DSEK, 55% of the patients had an average BSCVA of 20/40.13,14 In a large retrospective series of DSAEK patients with 6 months’ follow-up, 69% of the patients had a BSCVA of 20/40 or better.14 In other DSAEK series, an average BSCVA between 20/45 and 20/34 was reported at 3 and 6 months, respectively.5,9,15,16 The average BSCVA in our series appears to be lower as compared with recent DSAEK series. A possible explanation for this finding is the quality of the interface at the stromal side of the PLD as prepared by the FS laser. It has been shown that the smoothness of the stromal bed of a PLD prepared with a 15-kHz FS laser is comparable with a manually prepared PLD.17 However, Jones et al18 found that a 30-kHz FS laser, using energy levels up

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### Table 2. Preoperative, 3-Month, and 6-Month Refractive Outcomes

<table>
<thead>
<tr>
<th></th>
<th>No. of Eyes</th>
<th>Preoperative Outcome, Mean (SD)</th>
<th>Range</th>
<th>No. of Eyes</th>
<th>3-mo Outcome, Mean (SD)</th>
<th>Range</th>
<th>No. of Eyes</th>
<th>6-mo Outcome, Mean (SD)</th>
<th>Range</th>
<th>P Value (^a)</th>
<th>P Value (^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSCVA, LogMAR [Snellen]</td>
<td>20</td>
<td>0.86 (0.4) [20/150]</td>
<td>0.30 to 1.70</td>
<td>20</td>
<td>0.69 (0.3) [20/98]</td>
<td>0.30 to 1.70</td>
<td>19</td>
<td>0.67 (0.3) [20/94]</td>
<td>0.28 to 1.70</td>
<td>.02</td>
<td>.03</td>
</tr>
<tr>
<td>BSCVA, LogMAR [Snellen]</td>
<td>11</td>
<td>0.74 (0.4) [20/110]</td>
<td>0.30 to 1.70</td>
<td>11</td>
<td>0.51 (0.1) [20/64]</td>
<td>0.30 to 0.70</td>
<td>11</td>
<td>0.46 (0.1) [20/57]</td>
<td>0.28 to 0.70</td>
<td>.01</td>
<td>.007</td>
</tr>
<tr>
<td>Spherical equivalent, D</td>
<td>20</td>
<td>−0.89 (2.7) [−6.25 to 3.50]</td>
<td>20</td>
<td>−1.11 (1.8) [−4.50 to −3.50]</td>
<td>20</td>
<td>−1.56 (1.3) [−5.0 to 0]</td>
<td>19</td>
<td>−1.58 (1.1) [−4.63 to 0]</td>
<td>19</td>
<td>−4.9 to 0</td>
<td>.01</td>
</tr>
<tr>
<td>Refractive cylinder, D</td>
<td>20</td>
<td>−0.75 (0.9) [−2.50 to 0]</td>
<td>20</td>
<td>−2.50 to 0</td>
<td>17</td>
<td>2.03 (1.2) [0.50 to 4.30]</td>
<td>17</td>
<td>1.85 (1.1) [0.37 to 4.14]</td>
<td>17</td>
<td>4.9 to 0</td>
<td>.01</td>
</tr>
</tbody>
</table>

**Abbreviations:** BSCVA, best spectacle-corrected visual acuity; D, diopters; LogMAR, logarithm of the minimum angle of resolution.

\(^a\) P value for preoperative vs 3-mo outcome.

\(^b\) P value for preoperative vs 6-mo outcome.

\(^c\) Excluding all visually limiting pathology.

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### Table 3. Preoperative, 3-Month, and 6-Month ECD

<table>
<thead>
<tr>
<th></th>
<th>No. of Eyes</th>
<th>ECD, cells/mm(^2), Mean (SD) [Range]</th>
<th>% Cell Loss, Mean (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes without dislocation</td>
<td>16</td>
<td>2645 (121) [2400-2800]</td>
<td>NA</td>
</tr>
<tr>
<td>3 mo</td>
<td>15</td>
<td>1325 (379) [807-1683]</td>
<td>49 (35-70)</td>
</tr>
<tr>
<td>6 mo</td>
<td>15</td>
<td>1368 (425) [761-2108]</td>
<td>48 (25-72)</td>
</tr>
<tr>
<td>Eyes with dislocation and repositioning</td>
<td>4</td>
<td>2611 (176) [2300-2900]</td>
<td>NA</td>
</tr>
<tr>
<td>3 mo</td>
<td>4</td>
<td>753 (280) [546-1183]</td>
<td>71 (53-80)</td>
</tr>
<tr>
<td>6 mo</td>
<td>3</td>
<td>740 (372) [468-1489]</td>
<td>71 (43-82)</td>
</tr>
</tbody>
</table>

**Abbreviations:** ECD, endothelial cell density; NA, not applicable.

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Figure 3. Slitlamp photograph after femtosecond laser–assisted Descemet stripping endothelial keratoplasty. Epithelium in the interface through the transcorneal incision is visible (A and B).

(\(P = .03\)), respectively (Figures 4, 5, and 6). The thickness of the PLD in the center and periphery decreased a mean (SD) of 16.0% (8.5%) (\(P = .03\)) and 29.6% (10.9%) (\(P = .03\)), respectively. The PLD thinned significantly faster at the periphery than at the center (\(P = .03\)).
to 7.4 µJ, produced a rougher stromal surface than a manual microkeratome. Some authors suggest that the FS laser may cause concentric ridges at the interface disc because of the flat applanation when making the lamellar cut. Another explanation for the lower than expected BSCVA could be an increase in interface haze after FS-DSEK because of activation of keratocytes, which results in more scatter. Our study showed a mean (SD) hyperopic shift of 2.24 (2.3) D at 6 months postoperatively, which was higher in comparison with other studies.15,16 Previous studies of small-incision DSEK or DSAEK have reported a mild hyperopic shift, but other studies did not find a change in spherical equivalent.9,13,14,16,22 The shape of the PLD may account for the mild hyperopic shift after small-incision DSEK or DSAEK. The PLDs prepared with the microkeratome or the FS laser are thinner in the center and thicker at the edges, as has been shown by our optical coherence tomography results, where the periphery was 53.9% thicker than the center at 6 months. The intraocular lens selection in our series was targeted to account for emmetropia. The hyperopic shift induced by the PLD should be neutralized by targeting for −1.00 D to −1.25 D of myopia when combining cataract procedures with DSEK.23

Descemet stripping endothelial keratoplasty or DSAEK results in more predictable postoperative corneal curvature than penetrating keratoplasty.2,5,10 In our study, the change of the topographic astigmatism was not significant, which was comparable with other studies.9,10 In contrast to previous DSEK or DSAEK studies, which have generally shown no increase in mean refractive astigmatism, our study showed a mild increase in refractive astigmatism, which may be explained by the changes of the posterior corneal curvature. The optical coherence tomography images showed that the thickness of the recipient cornea and the PLD decreased in the first 3 months and remained stable at 6 months. Further, the thickness of the PLD decreased faster in the periphery than in the center, which may influence the posterior corneal curvature and the refraction. Consequently, centering the PLD on the visual axis may be important to avoid inducing astigmatism.

In the past few years, the surgical techniques for EK have evolved impressively.24,25 The major goal of EK is to replace endothelial cells (ECs), as the ECD is an important factor for long-term graft survival. Small-incision deep lamellar endothelial keratoplasty showed an EC loss between 15.4% and 34.0% after 6 months, and the EC loss after small-incision DSEK was between

Figure 4. Optical coherence tomography image after femtosecond laser–assisted Descemet stripping endothelial keratoplasty. The corneal thickness at the vertex and 3.5 mm on each side of the vertex in the 45° to 225° meridian.

Figure 5. The corneal thickness of the recipient and the posterior lamellar disc at the vertex. At 3 months postoperatively, the thickness of the recipient cornea and posterior lamellar disc had decreased 16.3% and 16.0%, respectively (P=.03), and remained stable at 6 months.

Figure 6. The corneal thickness of the recipient and the posterior lamellar disc at the periphery (3.5 mm of the vertex). At 3 months postoperatively, the thickness of the recipient cornea and posterior lamellar disc had decreased 20.3% and 29.6%, respectively (P=.03), and remained stable at 6 months.
was between 34% and 50% with various follow-up.\textsuperscript{5,15,29}

In our series, the EC loss of eyes without dislocation was 48% at 6 months, which was comparable with the results of small-incision DSEK and DSAEK. Several steps (folding of the PLD, compression of ECs by forceps during insertion, unfolding, long-standing contact with air bubble) during the EK may induce EC loss.\textsuperscript{30,31}

In the present multicenter study, FS-DSEK was a new surgical technique for the participating surgeons and the learning curve may have influenced the EC loss. The most frequently reported complication of small-incision DSEK and DSAEK was PLD dislocation. The dislocation rate after small-incision DSEK was between 0.7% and 50.0%, and after DSAEK, it was between 4.0% and 34.6%, which was comparable with our study.\textsuperscript{4,5,9,14,16,32}

Pupillary block has been reported in between 3.8% and 9.5% after DSAEK and occurred peroperatively in 2 of our patients.\textsuperscript{9,15} We suggest that a surgical iridectomy is preferable at the time of DSEK to prevent this complication. One patient in our series had epithelial ingrowth presumably through the transcorneal incision. Epithelium in the interface 9 months after DSEK has been described by Culbertson,\textsuperscript{33} but it was not reported where the epithelium originated from. In previous studies, the primary graft failure ranged from 1.0% to 11.3%, and in our series, 1 graft (5%) failed because of extensive donor manipulation.\textsuperscript{4,5,9,13,16,32}

In summary, FS-DSEK was effective in treating endothelial failure, with minimal change in refractive astigmatism and a mild hyperopic shift in refraction. Although BSCVA improved significantly, we believe that interface issues may result in a lower than expected visual acuity. The EC loss after EK is a concern for long-term graft survival, but this may be related to the steep learning curve of the surgeons. A randomized multicenter study is in progress to compare the visual outcomes and ECD of FS-DSEK with the results of penetrating keratoplasty.

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