Long-term Anterior and Posterior Topographic Analysis of the Cornea After Deep Lamellar Endothelial Keratoplasty

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Purpose: To analyze the 2-year topographic response of the cornea to deep lamellar endothelial keratoplasty (DLEK).

Methods: The Orbscan topographies of 24 eyes that underwent DLEK for corneal decompensation were retrospectively analyzed. Twelve eyes received a large-incision DLEK technique and 12 eyes received a small-incision DLEK. All the preoperative and postoperative corneal raw data were imported into a custom software program, which computed the average composite corneal maps and difference maps for both study groups to evaluate the corneal response to the surgery. The software delineated 2 concentric zones of the cornea to characterize the regional response after the surgery: the central and peripheral regions.

Results: At 2 years after surgery, no significant changes (<0.41 diopters; analysis of variance, \( P > 0.05 \)) in the central topography configuration were measured in comparison with the preoperative state after DLEK procedures. On the other hand, a significant increase \(( P < 0.01 \)) in the mean tangential curvature and astigmatic power of the anterior corneal periphery was measured after surgery, with higher changes after large-incision DLEK. No significant differences in the average curvature profile of the posterior corneal interface were measured after DLEK procedures \((<0.40, P > 0.05)\) in comparison with the preoperative state.

Conclusions: DLEK provides stable central corneal topography, with minimal changes in curvature and astigmatic power in the years after surgery. Moreover, the donor posterior cornea shows to maintain its vitality and integrity in the long-term postoperative period, with curvature values similar to the original posterior corneal interface.

Key Words: deep lamellar endothelial keratoplasty, DLEK, endothelial keratoplasty, EK, corneal topography

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Deep lamellar endothelial keratoplasty (DLEK) is one of the former surgical procedures designed to replace diseased corneal endothelium with healthy donor endothelium, leaving the surface of the corneal tissue untouched.¹⁻³ Accordingly, 2 different techniques of DLEK have been designed for this purpose, that is, the large-incision surgery (9-mm scleral access incision) and the subsequent small-incision (5-mm scleral access incision)⁴ surgery. The motivation for the small-incision modification was to minimize incision-induced astigmatism, speed visual rehabilitation, and provide a tectonically stronger globe in the long term. Large prospective studies by Terry and Ousley⁵ in both large- and small-incision DLEK demonstrated that these forms of selective endothelial replacement can minimize corneal topography changes and normalize the surface regularity with slight changes in manifest refraction and corneal astigmatism.⁶⁻⁷

Nowadays, the endothelial keratoplasty (EK) procedure has evolved from DLEK to Descemet stripping endothelial keratoplasty (DSEK).⁸⁻⁹ In DSEK, only Descemet membrane is removed from the recipient cornea and a donor tissue that contains endothelium and Descemet membrane comprising the posterior stroma is attached. On the other hand, DLEK represents a unique technique in which the posterior corneal stroma is selectively excised, further theoretically preserving the anterior stromal integrity. For that reason, the changes in topography configuration in the years after surgery can give us valuable scientific and clinical information on the regional biomechanical properties of the corneal tissue.

At present, no work aimed to mathematically analyze the long-term changes in the curvature profile of the host corneal surface and the posterior donor corneal interface after DLEK. The purpose of the present work is to investigate the changes occurring to corneal topography up to 2 years after DLEK surgery.

MATERIALS AND METHODS

Twenty-three patients (24 eyes), 9 males and 14 females, with a mean age of 78.1 ± 11.18 years (range: 53–92 years), were enrolled in an institutional review board–approved prospective study of EK. Inclusion criteria were patients with endothelial decompensation resulting from Fuchs dystrophy, no significant anterior corneal scarring, and no concomitant ocular pathologies. An institutional review board–approved surgical consent form was signed by all the patients who underwent DLEK.

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408
All surgeries included in the study were uneventful and performed by a single surgeon (M.A.T.) from April 2000 through 2004. All the eyes in this study were pseudophakic at the time of DLEK surgery.

Eyes included in the study underwent the original DLEK technique of using a large 9-mm scleral access incision and by 2002 a small-incision surgery (5-mm scleral access incision). Using a Terry trephine (Bausch & Lomb, St. Louis, MO) and Cindy I scissors (Bausch & Lomb), the excision of the recipient tissue was performed and closure of the scleral wound was accomplished with 5–7 sutures. Grafts of 7.5 or 8.0 mm diameter were used matching the achieved diameter of the recipient bed, with the vast majority of grafts with a diameter of 8.0 mm. The lamellar pocket cut in the host cornea was at approximately 80% depth (estimated thickness of about 150 μm) with an estimated residual stromal roof between 300 and 450 μm; the estimated lamellar donor disc thickness was between 120 and 150 μm (25% of the entire donor disc thickness). Further details on DLEK surgical procedures and techniques can be found in previous works.1,10,11

The eyes were subdivided into 2 groups for analysis: the large-incision group (or 9-mm incision group, 12 eyes) and the small-incision group (or 5-mm incision group, 12 eyes) with a mean age of 82.4 ± 8.26 years (range: 63–92 years) and 71.63 ± 12.33 years (range: 53–89 years), respectively.

All patients underwent complete ocular evaluation, including corneal topography performed with the Orbscan (Bausch & Lomb). At each examination interval, that is, preoperative, 6, 12, and 24 months after surgery, topographies were taken 3 times, by a single examiner, for all the eyes included in the study to assess reliability and reproducibility of technique; only 1 topography for each eye was then used for analysis.

The Orbscan Data Recorder tool allows exportation of 1 or more Orbscan maps to sample. Recorder output consists of a text file containing patient and acquisition information, sampling pattern specifications, and 1 or more arrays of sampled data. For the purpose of this work, we exported 90 × 90 samples in the x, y coordinates for a total area of examination of 10 mm (x, y: ±5 mm). We exported the following Orbscan maps for processing and analysis: keratometric tangential, keratometric astigmatic, posterior tangential, posterior astigmatic power, and pachymetry maps.

The preoperative and postoperative topographic data recorded were exported into a custom software written in Matlab version 7.0 (The MathWorks, Inc). The corneal reference frame was divided into 2 concentric regions: the central region with a radius of 3.00 mm from the reference axis of topography and the peripheral region with a radius of 4.50 mm from the reference axis of topography (Fig. 1). This was done to highlight the preoperative and postoperative differences between the zones themselves and to better characterize the regional responses of the cornea to DLEK.

The mathematical algorithm software computed the average maps for each study group both preoperatively and postoperatively. The average differences in the maps obtained...
at 6, 12, and 24 months postoperatively and preoperatively were also calculated. An absolute color scale, visually similar to that used by Orbscan topographer, was developed for rapid and easy interpretation.

**Statistical Analysis**

Multivariate analysis of variance for repeated measures was used to compare preoperative and postoperative corneal topography and refraction data in each study group and the changes in curvature values and refraction data from preoperative to 2 years postoperatively between large- and small-incision groups. A P value <0.05 was considered statistically significant.

**RESULTS**

The surgically induced change in spherical equivalent refraction was not statistically significant in both groups (P > 0.05), ranging from +0.48 ± 0.95 and −0.33 ± 0.77 diopters (D) preoperatively to −0.23 ± 1.16 and −0.50 ± 1.28 D, 2 years postoperatively for the large- and small-incision DLEK groups, respectively; this difference was calculated to be statistically significant between groups (P < 0.001). The preoperative average astigmatism by manifest refraction was 1.62 ± 0.96 and 1.16 ± 0.81 D for the large- and small-incision groups, respectively; at 24 months, the average manifest astigmatism was 1.81 ± 0.83 D (P > 0.05) and 1.25 ± 0.57 D (P > 0.05), respectively, with a significant difference (P < 0.001) in the induced manifest astigmatism between DLEK procedures.

The preoperative best spectacle–corrected visual acuity (BSCVA) was between count fingers and 20/40 in the 9-mm incision group and between 20/200 and 20/25 in the 5-mm incision group. At the end of follow-up, BSCVA significantly improved (Student t test, P < 0.05) in the large-incision group, ranging from 20/200 to 20/25; the same trend (P < 0.05) was measured for the small-incision group, with the BSCVA ranging from 20/70 to 20/25.

**Corneal Topography Analysis**

In general, the surface topography configuration of the central cornea was observed to slightly flatten during the first 6 months after surgery, then steepening in the long-term postoperative period. At the end of follow-up, no statistically significant changes (P > 0.05) in the curvature values of the central cornea were assessed after either large-incision (>0.40 D) or small-incision DLEK (<0.23 D). Tables 1 and 2 summarize the preoperative and postoperative corneal data for the anterior corneal topography after DLEK procedures. The mean central keratometric astigmatism was shown to be unchanged (P > 0.05) after large-incision (>0.40 D) and small-incision (>0.24 D) DLEK, with no statistically significant changes detected.
significant difference between groups ($P > 0.05$). Figures 2 and 3 represent the mean central keratometric maps for the 2 study groups.

At the end of follow-up, major changes in the anterior topography of the peripheral cornea were measured after large-incision DLEK, with a significant increase of 1.24 D ($P < 0.01$) and 2.14 D ($P < 0.01$) in the mean keratometric tangential and astigmatism maps, respectively, in comparison with the preoperative state. After small-incision DLEK, a moderate, although statistically significant, increase of 0.85 D ($P < 0.05$) in the mean anterior tangential map of the peripheral region was determined, with a mean increase in the astigmatic power of 1.86 D ($P < 0.01$). The mean-induced postoperative curvature change of the anterior peripheral cornea was shown to be significantly different between DLEK procedures ($P < 0.001$).

No statistically significant changes ($P > 0.05$) were measured in the curvature profile of the posterior central donor cornea after both DLEK procedures, with a mean increase lower than 0.40 D, as summarized in Tables 3 and 4. No significant differences ($P > 0.05$) in the response of the posterior donor central corneal interface were measured between DLEK procedures. Figures 4 and 5 depict the mean central posterior tangential maps of the 2 study groups during follow-up. No statistically significant topographic changes ($P > 0.05$) were measured in the peripheral region of the posterior donor cornea, with mean curvature changes lower than $\pm 0.40$ D at the end of follow-up in comparison with the preoperative state.

The postoperative thinning of the central and peripheral cornea was statistically significant ($P < 0.001$) after both DLEK procedures. Regional pachymetry analysis during follow-up is summarized in Table 5.

**DISCUSSION**

The introduction of EK procedures has enabled surgeons to improve significantly the postoperative corneal topography compared with standard penetrating keratoplasty procedure for patients suffering from corneal decompensation. Nowadays, DSEK has replaced DLEK for the treatment of endothelial diseases; on the other hand, long-term results of DLEK may have particular scientific interest considering that this technique subtracts only the third posterior stroma, allowing us to study the corresponding mechanical implications in the corneal tissue.
There are a few studies on the long-term results after DLEK surgery,\textsuperscript{5,8,12} all demonstrating how the procedure is topographically neutral, with a great predictability of the postoperative surface corneal topography and a mean endothelial cell loss count of 25\% at 2 years postoperatively. In this work, we aimed to analyze the changes occurring in the anterior and posterior cornea during a 24-month follow-up after DLEK. Furthermore, differences in the response between the central optical region of the cornea and the peripheral one have been investigated.

In our series, at 24 months, the spherical equivalent refraction did not significantly change in comparison with the preoperative state, with a mean myopic shift of approximately 0.7 and 0.2 D after large- and small-incision DLEK, respectively. Also, astigmatism by manifest refraction was slightly influenced by DLEK with a positive increase, although not statistically or clinically significant, of approximately 0.2 and 0.1 D after large- and small-incision techniques, respectively. Average BSCVA significantly improved after both DLEK procedures, gradually recovering up to 1 year postoperatively. All these data are in large agreement with those from previous studies.\textsuperscript{1,5,12}

Mild, no statistically significant changes in the surface central corneal topography were determined during the 24-month follow-up. Also, the postoperative response of the anterior cornea was measured to be lesser after small-incision DLEK procedure in comparison with large-incision DLEK, especially in the peripheral cornea. A higher increase in the mean curvature values of the peripheral anterior cornea was measured between 12 and 24 months postoperatively, especially after large-incision DLEK. The cause can be 2-fold, depending on the limbal incision size with the resulting different mechanical response of the severed circumferential collagen lamellae between the techniques\textsuperscript{13–15} and to the measurement accuracy by the Orbscan topographer.\textsuperscript{16} Indeed, it was demonstrated how peripheral area measures are less accurate than central ones, and standard deviation was calculated to increase from the center to the periphery continuously.\textsuperscript{17} In living human corneas, where tear inconsistencies, surface irregularities, and light scatter are potential sources of variation, the measurement precision could remain uncertain if a repeatability testing is not performed: in our study, the measurement repeatability was calculated to be $0.19$ D in the peripheral region of analysis of the keratometric tangential map. A higher repeatability was shown in corneas of normal young eyes.\textsuperscript{18} By consequence, the potential limitation of this study may be the dependence on topographer measurements; in the absence of external validation, however, repeatability and reproducibility provide support for the overall accuracy of Orbscan measurements.\textsuperscript{19} Nonetheless, during acquisition, careful attention is needed to obtain a wide corneal coverage and avoid loss of

\begin{table}
\centering
\caption{Posterior Tangential Average Curvature (D, mean $\pm$ SD) of the 2 Analyzed Corneal Zones in Each Study Group Both Preoperatively and Postoperatively}
\begin{tabular}{|c|c|c|c|c|}
\hline
Corneal Zone: Radius ($R$, mm) & Examination Interval & Large-Incision Group (n = 12) (D) & Small-Incision Group (n = 12) (D) \\
\hline
Central zone: 3.00 & Preoperative & $-5.98 \pm 0.38$ & $-5.86 \pm 0.30$ \\
& 6 months postoperative & $-6.13 \pm 0.60$ & $-6.40 \pm 1.10$ \\
& 1 year postoperative & $-5.94 \pm 0.68$ & $-6.31 \pm 0.76$ \\
& 2 years postoperative & $-6.30 \pm 0.65$ & $-6.02 \pm 0.80$ \\
Peripheral zone: 3.01 < $R$ < 4.50 & Preoperative & $-5.77 \pm 1.53$ & $-5.89 \pm 0.77$ \\
& 6 months postoperative & $-5.91 \pm 1.50$ & $-5.95 \pm 0.70$ \\
& 1 year postoperative & $-6.03 \pm 1.31$ & $-5.94 \pm 0.62$ \\
& 2 years postoperative & $-5.93 \pm 1.39^*$ & $-5.59 \pm 0.65^*$ \\
\hline
\end{tabular}
\end{table}

\begin{table}
\centering
\caption{Posterior Average Astigmatic Power (D, mean $\pm$ SD) of the 2 Analyzed Corneal Zones in Each Study Group Both Preoperatively and Postoperatively}
\begin{tabular}{|c|c|c|c|c|}
\hline
Corneal Zone: Radius ($R$, mm) & Examination Interval & Large-Incision Group (n = 12) (D) & Small-Incision Group (n = 12) (D) \\
\hline
Central zone: 3.00 & Preoperative & $-1.57 \pm 0.62$ & $-1.46 \pm 0.12$ \\
& 6 months postoperative & $-1.98 \pm 0.66$ & $-2.05 \pm 0.98$ \\
& 1 year postoperative & $-2.07 \pm 0.91$ & $-2.20 \pm 0.97$ \\
& 2 years postoperative & $-1.90 \pm 0.86$ & $-1.86 \pm 0.26$ \\
Peripheral zone: 3.01 < $R$ < 4.50 & Preoperative & $-2.58 \pm 0.98$ & $-1.94 \pm 0.95$ \\
& 6 months postoperative & $-1.91 \pm 1.35$ & $-2.49 \pm 1.21$ \\
& 1 year postoperative & $-2.15 \pm 1.29$ & $-2.47 \pm 1.26$ \\
& 2 years postoperative & $-2.52 \pm 1.18$ & $-2.05 \pm 1.28$ \\
\hline
\end{tabular}
\end{table}

\begin{footnotesize}
\begin{tabular}{l}
Analysis of variance: $^*P < 0.05$ (preoperative to 2-year postoperative changes between groups) and $P < 0.05$ (between the preoperative and 2 years postoperatively).
\end{tabular}
\end{footnotesize}
Peripheral topographic data, which may result in deceptive values. This care however cannot be sufficient for an adequate reconstruction of the posterior corneal periphery in treated eyes, as previously demonstrated after laser refractive surgery, probably as a result of optical phenomena and artifacts.

The posterior donor corneal interface was shown to maintain stable curvature profile, with changes lower than 0.4 D in the years after surgery. This minimal remodeling of the posterior corneal curvature profile should be related essentially to changes in donor tissue swelling. In this work, corneal pachymetry was demonstrated to remain stable between 6 and 24 months postoperatively; therefore, the maintenance of a constant hydration in the donor tissue helped to stabilize the profile of the posterior cornea in the years after surgery. Nevertheless, the dissection geometry in the posterior host cornea and/or the graft geometry may play a significant role in the definite configuration of the posterior corneal interface.

In the cornea, the relationship between collagen fibril orientation or packaging and tissue mechanics is of considerable interest because the mechanical performance of the stroma governs corneal shape. The corneal stroma exhibits structural and mechanical anisotropy. Studies have demonstrated how the collagen fibrils appear to be more closely packed and interwoven in the anterior part of the stroma: the portion of the corneal tissue that has been also measured to have a main importance in maintaining the corneal strength and hence corneal curvature. Moreover, it has been extensively demonstrated how the various stromal regions strain differently when exposed to the same load, with the posterior stroma straining more than the anterior. These differences have been related to a real difference in the mechanical properties of stromal compartments. In this work, we analyzed the response of corneal topography to DLEK and observed how severing less than one third of the full complement of stromal lamellae, limited to the posterior cornea, did not significantly influence the original anterior corneal topography. The stability of surface topography may be strictly dependent on the maintenance of the structural integrity and the corresponding mechanical stability of the intact anterior complement of collagen lamellae without resultant ectasia, as also inferred by theoretical studies. A larger population of eyes or experimental topographic studies on whole eye globes in which EK has been performed could enhance the power significance of our analysis and hypothesis.

This study confirmed how former EK techniques do not significantly influence the original surface corneal topography, with a lower response of the cornea to small-incision DLEK procedure. Also, the donor posterior corneal lenticule was shown to preserve its vitality and integrity in the long-term postoperative surface topography showed a smoother profile in comparison with that of the preoperative state. A, B, C, and D represent the preoperative, 6-, 12-, and 24-month maps, respectively.
postoperative period, with a curvature profile similar to that of the original posterior cornea. It is expected that corneal structural integrity and curvature would be even less affected with DSEK surgery. Further work in characterizing the

FIGURE 4. Preoperative and postoperative average composite maps of the posterior central cornea for the large-incision group (color scale bar: diopters). At the end of follow-up, a slight increase of approximately 0.30 D in the mean curvature profile of the posterior cornea was measured.

A slight increase in the astigmatic power of 0.33 D was also assessed after surgery. A, B, C, and D represent the preoperative, 6-, 12-, and 24-month maps, respectively.

FIGURE 5. A, B, Preoperative and 24-month postoperative average composite maps of the posterior central cornea for the small-incision group (color scale bar: diopters). C, Difference map between 24 months postoperatively and preoperatively (color scale bar: diopters). A moderate asymmetric increase of 0.40 D in the mean astigmatic power of the posterior central cornea, however not statistically significant, was induced by surgery.

A slight increase of approximately 0.30 D in the mean curvature profile of the posterior cornea was measured.
Long-term Corneal Topographic Analysis After DLEK

TABLE 5. Average Pachymetry (μm, mean ± SD) of the 2 Analyzed Corneal Zones in Each Study Group Both Preoperatively and Postoperatively

<table>
<thead>
<tr>
<th>Corneal Zone: Radius (R, mm)</th>
<th>Examination Interval</th>
<th>Large-Incision Group (n = 12) (μm)</th>
<th>Small-Incision Group (n = 12) (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central zone: 3.00</td>
<td>Preoperative</td>
<td>786 ± 88</td>
<td>765 ± 60</td>
</tr>
<tr>
<td></td>
<td>6 months postoperative</td>
<td>591 ± 120</td>
<td>568 ± 103</td>
</tr>
<tr>
<td></td>
<td>1 year postoperative</td>
<td>601 ± 140</td>
<td>577 ± 104</td>
</tr>
<tr>
<td></td>
<td>2 years postoperative</td>
<td>596 ± 130*</td>
<td>561 ± 107*</td>
</tr>
<tr>
<td>Peripheral zone: 3.01 &lt; R &lt; 4.50</td>
<td>Preoperative</td>
<td>777 ± 107</td>
<td>760 ± 45</td>
</tr>
<tr>
<td></td>
<td>6 months postoperative</td>
<td>716 ± 139</td>
<td>597 ± 104</td>
</tr>
<tr>
<td></td>
<td>1 year postoperative</td>
<td>684 ± 141</td>
<td>613 ± 90</td>
</tr>
<tr>
<td></td>
<td>2 years postoperative</td>
<td>687 ± 137*</td>
<td>640 ± 99*</td>
</tr>
</tbody>
</table>

Analysis of variance: *P < 0.05 (between the preoperative and 2 years postoperatively) and P < 0.05 (preoperative to 2-year postoperative changes between groups).

Topographic changes after DSEK surgery may be highly beneficial in the knowledge of the mechanical properties of the cornea.

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