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ORIGINAL ARTICLE

Investigation of corneal topography after deep lamellar endothelial keratoplasty

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PURPOSE. *To analyze the 6-month anterior and posterior topographic changes of the cornea after deep lamellar endothelial keratoplasty.*

METHODS. *Orbscan topographies of 22 eyes from 21 patients with corneal decompensation were retrospectively analyzed: 11 eyes received a 9-mm scleral access incision (large-incision group) and 11 eyes received a 5-mm scleral access incision (small-incision group). All the preoperative and postoperative corneal raw data were imported into custom software which computed the average composite corneal maps and difference maps for both study groups in order to evaluate the corneal response to the surgery. The software delineated 2 concentric zones of the cornea to characterize the regional response following the surgery: the central and peripheral regions.*

RESULTS. *There were no significant differences (analysis of variance, <0.35 D, $p>0.05$) between 6-month postoperative and preoperative average anterior central corneal topographies in either group. At the end of follow-up, the average posterior curvature tangential map did not significantly differ from before surgery in either group (<0.35 D, $p>0.05$). However, a significant increase (>0.60 D, $p<0.01$) in the average posterior central astigmatic power of the cornea was found in both groups.*

CONCLUSIONS. *Deep lamellar endothelial keratoplasty effectively preserves the preoperative keratometric corneal topography, minimizing changes in curvature and astigmatism of the cornea. The great predictability of corneal topography following deep lamellar endothelial keratoplasty is likely to be attributed to the minimal changes that occur in the anterior stroma, the portion of the cornea that appears to be mainly responsible for maintenance of corneal shape.*

KEY WORDS. *Corneal biomechanics, Corneal topography, Deep lamellar endothelial keratoplasty, Endothelial keratoplasty.*

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INTRODUCTION

Deep lamellar endothelial keratoplasty (DLEK) is a surgical technique for the replacement of the corneal endothelium entirely through a limbal scleral tunnel incision (1). In 1998, Melles and colleagues (2) designed the first surgical technique for posterior lamellar keratoplasty (PLK). Melles et al (3) subsequently first described the small-incision posterior lamellar keratoplasty, wherein the donor disk was folded and transplanted through a 5-mm incision. 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. Terry and Ousley (4) have subsequently modified the PLK procedure, redesigned the instrumentation, and renamed the procedure DLEK. Large prospective studies by Terry and Ousley in both large- and small-incision DLEK demonstrated that these forms of selective endothelial replacement can minimize corneal topography changes, normalize the surface regularity, and accomplish the safe transfer of healthy donor endothelium with a mean cell loss count of approximately 25% from preoperatively to 2 years postoperatively (5-7). Melles et al and Terry and Ousley have confirmed the inherent value of PLK/DLEK in that it allows faster and stronger wound healing and the avoidance of suture-related problems such as infection, ulceration, and suture-induced vascularization leading to graft rejection in comparison with standard penetrating keratoplasty (8, 9). Although DLEK has been replaced by Descemet stripping automated endothelial keratoplasty (DSAEK) for the treatment of endothelial decompensation, it may be still used in particular cases, e.g., eyes with retained anterior chamber lens or with very large sector iridectomies. On the other hand, it still represents a unique technique in which only the posterior corneal stroma is removed; it is therefore of scientific importance to determine quantitatively the changes that occur in the cornea following surgery.

The purpose of the present work was to analyze post-DLEK topographic changes of the cornea, either after the large 9-mm incision or the small 5-mm incision technique, during a 6-month follow-up, and to compare the refractive and topographic changes between techniques.

MATERIALS AND METHODS

Twenty-one patients (22 eyes), 9 men and 12 women, with a mean age of 77.5±10.86 years (range 53–92 years), were included in this retrospective study. Inclusion criteria were patients with endothelial decompensation resulting from Fuchs dystrophy, no significant anterior corneal scarring or other ocular pathologies, and no history of vitreoretinal or glaucoma surgery.

An institutional review board–approved surgical consent form was signed by all the patients who underwent DLEK. All surgeries included in the study were uneventful and performed by a single surgeon (M.A.T.). All the eyes in this study were pseudophakic at the time of DLEK surgery; phacoemulsification and intraocular lens implantation had been performed through a clear corneal incision of approximately 3.0 mm, placed superiorly at the 90° meridian, in all the eyes included in the study.

During DLEK surgery, a caliper was used to place the incisions of 9- or 5-mm lengths symmetrically around the 90° meridian. Eleven eyes (50%) underwent the original DLEK technique of using a large 9-mm scleral access incision with the stromal pocket formed using specialized Devers Dissectors (Bausch & Lomb, St. Louis, MO). Using a Terry trephine (Bausch & Lomb) and Cindy I scissors (Bausch & Lomb), the excision of the recipient tissue was performed and closure of the scleral wound was accomplished with 7 sutures.

Eleven eyes (50%) underwent the small 5-mm scleral access incision. The 5-mm scleral access incision required that the graft be folded (endothelial side inside) and inserted into the anterior chamber with specialized Charlie insertion forceps (Bausch & Lomb) through the small incision. Grafts of 7.5 mm or 8.0 mm diameter were used matching the achieved diameter of the recipient bed with the vast majority of grafts having 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 can be found in previous works (1, 4-7).

All patients underwent complete ocular evaluation, including corneal topography performed with the Orbscan (Bausch & Lomb). Preoperative and 6-month postoperative Orbscan maps were collected for all the eyes of the population study. Topographies were taken 3 times to assess reliability and reproducibility of the technique (10); 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. We exported the following Orbscan maps for processing: keratometric tangential, keratometric astigmatic, posterior tangential, posterior astigmatic power, and pachymetry maps (11). The preoperative and postoperative topographic data recorded, sampled as described above, were exported into custom software written in MATLAB version 7.0 (MATLAB, MathWorks, Inc., Natick, MA). 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, as illustrated in Figure 1. This was done in order to highlight the preoperative and postopera-

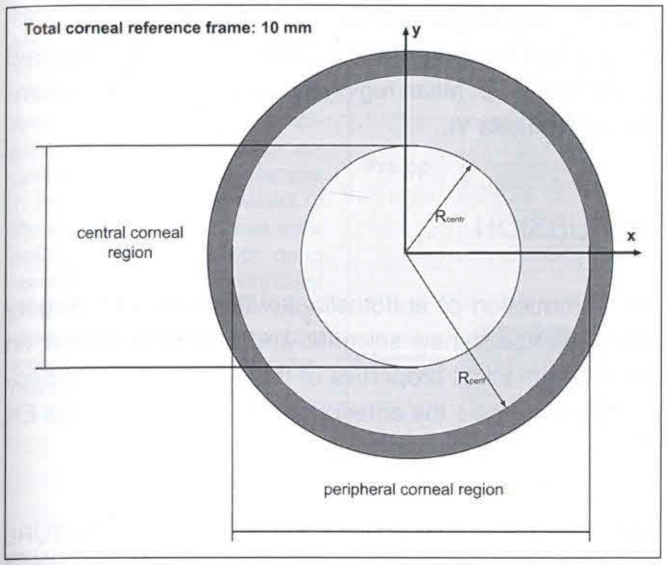

Fig. 1 - *Regional topographic data analysis dividing the cornea reference frame (5.00 mm in radius) into 2 concentric regions: the central and peripheral cornea. The central cornea is enclosed by an inner circular region with radius R_{centr} = 3.00 mm and the peripheral cornea by an outer circular region with radius R_{perif} = 4.50 mm. The central region allowed measurement of topographic changes inside the optical zone. The peripheral region highlights changes occurring in the topographic ring between 3.01 mm and 4.50 mm from the reference axis of topography.*

tive 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 preoperatively as well as postoperatively. The average differences in the maps obtained at 6 months postoperatively and preoperatively were also calculated.

Vector analysis of refractive cylinder was performed, using adjusted axes for the left eye (adjusted axis = 180° – original axis) and doubled angles, to determine the change in both direction and magnitude of refractive cylinder from the preoperative to the 6-month postoperative visit (12).

Statistical analysis

Multivariate analysis of variance for repeated measures was used to compare preoperative and postoperative spherical equivalent (SE) refraction data and corneal topographic changes between large- and small-incision groups. Statistical significance was set at $p<0.05$ for each test performed.

RESULTS

The eyes were subdivided into 2 groups for analysis: the large-incision group (or 9-mm group, 11 eyes) and the small-incision group (or 5-mm group, 11 eyes) with a mean age of 82.0±8.22 years (range 63–92 years) and 72.25±11.51 years (range 53–89 years), respectively.

Preoperative and postoperative refractive data of the population study are summarized in Table I. At 6 months after surgery, the average change in SE refraction from before surgery was not statistically significant ($p>0.05$) in either group; no statistically significant differences ($p>0.05$) in the amount of induced refractive shift between groups were measured. The preoperative mean defocus equivalent refraction (DEQ) was 1.02±0.82 and 0.94±0.81 in the large- and small-incision groups, respectively; at 6 months postoperatively, the mean DEQ was 1.08±0.85 and 0.92±0.85, respectively. No statistically significant differences ($p>0.05$) were measured between preoperative and postoperative DEQ data in the groups nor in DEQ changes between groups. The vector change in refractive cylinder has been plotted using a double-angle format, as illustrated in Figure 2: 82% and 90% of the population of difference vectors in the large- and small-incision groups, respectively, were within 2.00 D of the origin. No common induced direction in the refractive cylinder was assessed after surgery. The difference in the vector changes between groups was not statistically significant ($p>0.05$).

TABLE I - MEAN PREOPERATIVE AND POSTOPERATIVE SPHERICAL EQUIVALENT REFRACTION (DIOPTERS ± SD) IN THE 2 STUDY GROUPS

	Large-incision group (n=11)		**Small-incision group (n=11)**	
	Preop (n=11)	**6 Months postop (n=11)**	**Preop (n=11)**	**6 Months postop (n=11)**
SE refraction	+0.51±1.25	+0.10±0.68	−0.47±1.15	−0.52±1.00

Analysis of variance: $p>0.05$ between preoperatively and 6 months postoperatively as well as between groups.

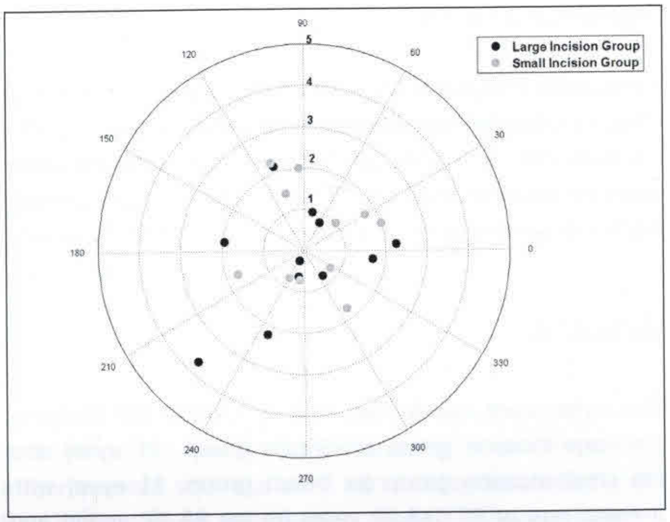

Fig. 2 - *Double-angle vector analysis showing the induced change in refractive cylinder, in both magnitude and axis, following deep lamellar endothelial keratoplasty procedures. Each point represents a single induced astigmatism uniquely characterized by a pair of values in the x- and y-coordinates. The cylinder change was mostly distributed within 2 D and the 0°–180° meridian in both study groups.*

Corneal topographic analysis

At the end of follow-up, no statistically significant changes in the surface topography of the central cornea (<0.35 D, $p>0.05$) were determined following both DLEK procedures. A significant difference in the topographic response of the anterior corneal periphery ($p=0.03$) was measured between DLEK procedures, with lesser tangential curvature changes after the small-incision DLEK than the large-incision DLEK. Tables II and III summarize mean topographic anterior curvature data; the preoperative and postoperative composite average keratometric tangential maps during follow-up are shown in Figure 3. The mean central and peripheral astigmatic power of the anterior cornea did not significantly differ from before surgery following both DLEK procedures (<0.30 D, $p>0.05$).

No clinically significant changes (<0.35 D, $p>0.05$) in the curvature radius of the posterior donor corneal interface were measured at 6 months after surgery, with no statistically significant differences between large- or small-incision procedures. On the other hand, the average posterior astigmatic power of the central cornea significantly increased (>0.60 D, $p<0.01$) following both DLEK procedures, as summarized in Tables IV and V. Figure 4 represents the average posterior tangential maps for the large- or small-incision groups.

A significant thinning of the corneal tissue was measured during follow-up. Mean regional pachymetry data are summarized in Table VI.

DISCUSSION

The introduction of endothelial keratoplasty (EK) surgery has given rise to new scientific and clinical questions on the biomechanical properties of the cornea, since it theoretically preserves the anterior stroma. Nowadays, the EK

TABLE II - ANTERIOR TANGENTIAL AVERAGE CURVATURE (D ± SD) OF THE 2 ANALYZED CORNEAL ZONES IN EACH STUDY GROUP PREOPERATIVELY AND POSTOPERATIVELY

Corneal zone: radius (R, mm) and examination interval	**Large-incision group (n=11)**	**Small-incision group (n=11)**
Central zone: 3.00 mm		
Preoperative	43.13±1.38	43.05±1.20
6 Months postoperative	42.79±1.35	42.93±1.35
Peripheral zone: 3.01<R<4.50 mm		
Preoperative	39.61±2.21	41.60±1.91
6 Months postoperative	38.48±2.38†	41.41±1.94†

Analysis of variance: $p>0.05$ between preoperatively and 6 months postoperatively; $^{\dagger}p<0.05$ (between groups).

TABLE III - AVERAGE ANTERIOR ASTIGMATIC POWER (D, ± SD) OF THE 2 ANALYZED CORNEAL ZONES IN EACH STUDY GROUP PREOPERATIVELY AND POSTOPERATIVELY

Corneal zone: radius (R, mm) and examination interval	**Large-incision group (n=11)**	**Small-incision group (n=11)**
Central zone: 3.00 mm		
Preoperative	4.60±1.80	3.61±1.31
6 Months postoperative	4.51±1.12	3.36±0.95
Peripheral zone: 3.01<R<4.50 mm		
Preoperative	7.85±2.27	8.34±1.95
6 Months postoperative	8.07±2.03	8.58±1.86

Analysis of variance: $p>0.05$ between preoperatively and 6 months postoperatively as between groups.

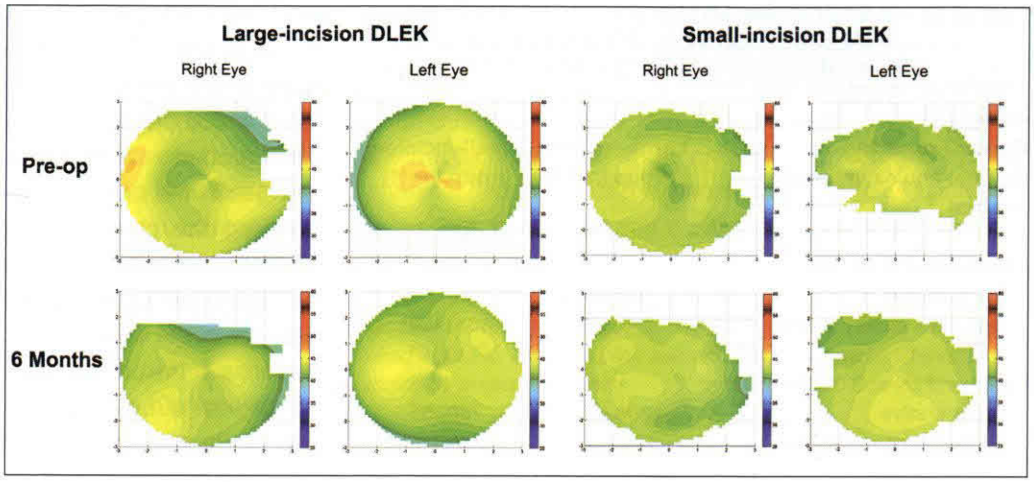

Fig. 3 - *Average preoperative and postoperative composite keratometric tangential maps obtained from the right and left eyes of the large- and small-incision groups (color scale bar: diopters). No significant changes in the mean curvature values of the anterior central cornea were assessed following both deep lamellar endothelial keratoplasty procedures. Further, the topography configuration achieved a smoother surface postoperatively than preoperatively.*

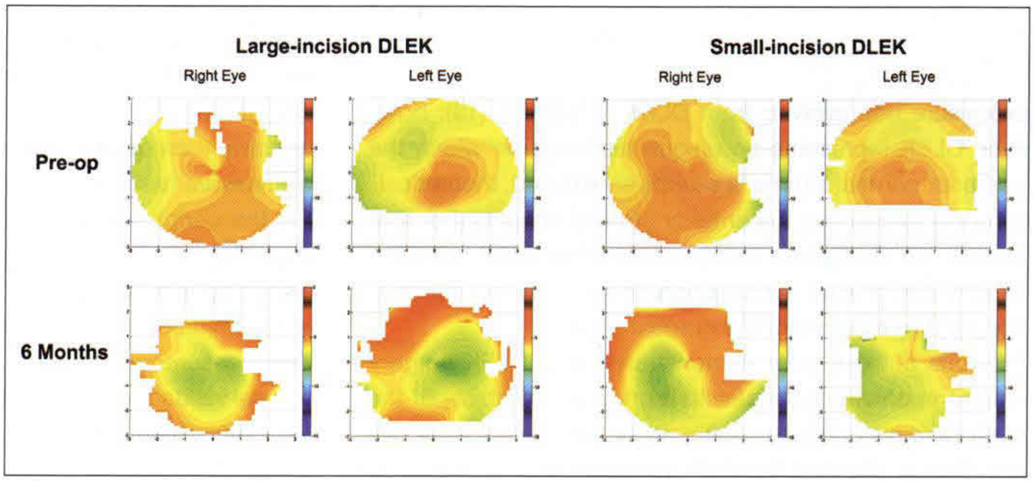

Fig. 4 - *Preoperative and 6-month postoperative average composite maps of the posterior central cornea for the 2 study groups (color scale bar: diopters; range 0 to –15 D). At the end of follow-up, a mean increase in the astigmatism power of 0.64 D and 0.68 D was measured after the large- and small-incision deep lamellar endothelial keratoplasty procedures, respectively. An asymmetric increase in the astigmatism power of the posterior cornea has been observed following both deep lamellar endothelial keratoplasty procedures.*

TABLE IV - POSTERIOR TANGENTIAL AVERAGE CURVATURE (D ± SD) OF THE 2 ANALYZED CORNEAL ZONES IN EACH STUDY GROUP PREOPERATIVELY AND POSTOPERATIVELY

Corneal zone: radius (R, mm) and examination interval	Large-incision group (n=11)	Small-incision group (n=11)
Central zone: 3.00 mm		
Preoperative	–6.08±0.58	–5.84±0.34
6 Months postoperative	–5.96±0.61	–6.17±0.59
Peripheral zone: 3.01<R<4.50 mm		
Preoperative	–5.58±1.52	–5.74±0.72
6 Months postoperative	–5.84±1.48	–5.95±1.06

Analysis of variance: p>0.05 between preoperatively and 6 months postoperatively as well as between groups.

TABLE V - AVERAGE POSTERIOR ASTIGMATIC POWER (D ± SD) OF THE 2 ANALYZED CORNEAL ZONES IN EACH STUDY GROUP PREOPERATIVELY AND POSTOPERATIVELY

Corneal zone: radius (R, mm) and examination interval	Large-incision group (n=11)	Small-incision group (n=11)
Central zone: 3.00 mm		
Preoperative	–1.74±0.66	–1.32±0.26
6 Months postoperative	–2.38±0.80*	–2.00±0.64*
Peripheral zone: 3.01<R<4.50 mm		
Preoperative	–2.63±0.89	–1.89±0.90
6 Months postoperative	–2.03±1.17*	–2.74±1.09*

Analysis of variance: *p<0.05between preoperatively and 6 months postoperatively; p>0.05 between groups.

TABLE VI - AVERAGE PACHYMETRY (M ± SD) OF THE 2 ANALYZED CORNEAL ZONES IN EACH STUDY GROUP PREOPERATIVELY AND POSTOPERATIVELY

Corneal zone: radius (R, mm) and examination interval	Large-incision group (n=11)	Small-incision group (n=11)
Central zone: 3.00 mm		
Preoperative	797±94	780±60
6 Months postoperative	576±121*	560±120*
Peripheral zone: 3.01<R<4.50 mm		
Preoperative	796±113	780±55
6 Months postoperative	702±200*	632±118*

Analysis of variance: *p<0.05 between preoperatively and 6 months postoperatively; p>0.05 between groups.

procedure has evolved from DLEK to DSAEK (13); however, DLEK represents an unique technique in which the posterior corneal stroma is selectively excised, theoretically further preserving the anterior stromal integrity. For that reason, the changes in topography configuration following surgery can give us valuable scientific and clinical information on the response of the corneal tissue.

Previous authors have demonstrated how DLEK surgery is topographically neutral with a great predictability of the postoperative corneal topography (4, 14). In this work, we provided a detailed 6-month postoperative topographic analysis of the anterior and posterior corneal interfaces following DLEK. In our series, at 6 months postoperatively, the amount of postoperative induced myopic refractive shift was not statistically significant in the groups, although it was higher following the large-incision (−0.4 D) than the small-incision (−0.05) technique. The induced astigmatism, determined by nonvector analysis using defocus equivalent refraction, was measured to not statistically significantly change after surgery. Vector analysis was further performed in order to determine the presence of a preferred directional shift in refractive cylinder from the preoperative to the 6-month postoperative visit: no common direction in the induced refractive astigmatism following either DLEK procedure has been measured, confirming how the scleral tunnel incision did not statistically significantly change the refractive astigmatism postoperatively. All these data are in large agreement with those from previous works (1, 5, 6, 13-16).

At the end of follow-up, no statistically significant changes in the tangential curvature and keratometric astigmatism maps of the central cornea (lower than 0.4 D) were measured in comparison with the preoperative state for either DLEK procedure. Also, no statistically significant curvature changes in the anterior corneal periphery were measured following the procedure; however, with statistically significantly higher changes in the large-incision DLEK group than the small-incision group. This was likely to be attributed to the larger incision and the corresponding mechanical response of the cornea in the 9-mm incision DLEK. Indeed, the corneal stroma exhibits unequal elastic modulus and strength distribution from the central to peripheral region that were exaggerated after surgery (17-19); nevertheless, differences can also be due to measurement accuracy by the Orbscan topographer (11). Using different test objects, Cairns and colleagues (20) have determined that central area measurements are more accurate than peripheral ones. In our study, peripheral data have shown a greater variability than central data, especially in the 9-mm group: 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 (21). By consequence, the potential limitation of this study is the dependence on Orbscan measurements; on the other hand, in the absence of external validation, repeatability and reproducibility provide support for the overall accuracy of Orbscan measurements (20, 22, 23).

No statistically significant changes in the curvature profile between the preoperative and postoperative posterior cornea were assessed following DLEK. On the other hand, a higher astigmatic power of the posterior donor cornea was measured following surgery, with a similar response between the 2 procedures. This phenomenon may be related to differences in the dissection geometry in the posterior host cornea and in the graft geometry as well as to changes in tissue swelling of the donor corneal lamella that may play a significant role in the definite configuration of the posterior corneal interface. A significant thinning of the whole cornea was measured between the preoperative and postoperative examinations.

Understanding the biomechanics of the cornea is of great clinical importance: mechanical properties are fundamentally related to the shape of the cornea and how the shape may influence the optical performance of the eye. In the clinical environment, precise knowledge of corneal shape may be achieved by corneal topography. On the other hand, the sole knowledge of the changes induced by surgery on the corneal tissue is, in general, not adequate to accurately predict the outcome of surgery. This is due to the fact that the corneal tissue exhibits nonlinear viscoelastic properties, in which the stress-strain relationship is time-dependent and shows hysteresis (24). The nonlinear viscoelastic properties of the corneal tissue are strongly dependent on the stromal microstructure; many authors reported regional differences in the histology and biomechanics of the corneal tissue (25-29). In the native human cornea, the anterior stroma has been measured to have higher stiffness and a main importance in maintaining the corneal strength and hence curvature than the posterior stroma (30), that exhibits a greater extensibility and less resistance to swelling compared to anterior stromal layers (31). This has been related to the notion that in the anterior stroma, collagen lamellae are more closely packed and interwoven than the posterior ones, especially in the central region of the cornea (32). Preservation of anterior corneal integrity, as occurs in DLEK, and the corresponding maintenance of an adequate stiffness in the intact tissue may explain the minimal changes occurring in corneal shape following surgery (33). This in vivo study may strengthen the hypothesis of the main contribution of the anterior stroma to the biomechanical properties of the whole intact cornea, as inferred by various theoretical and in vitro studies (28, 30, 34).

Dr. Mark A. Terry has a financial interest in the specialized instruments used in DLEK. The remaining authors have no financial interest in the materials presented herein.

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