Five-year Outcomes of Converted Mushroom Keratoplasty from Intended Deep Anterior Lamellar Keratoplasty (DALK) Mandate 9-mm Diameter DALK as the Optimal Approach to Keratoconus

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• PURPOSE: To compare the 5-year outcomes of 9-mm-deep anterior lamellar keratoplasty (DALK) for keratoconus with those of conversions to mushroom keratoplasty (MK).

• DESIGN: Retrospective cohort study.

• METHODS: The setting was the Ospedali Privati Villa Igea, Department of Ophthalmology, Forlì, Italy. The study population consisted of the medical records of all attempted DALK procedures (416 eyes) for the indication of keratoconus performed between January 2012 and January 2018; 68 eyes (16.4%) were converted to MK and analyzed as a separate cohort. The mean follow-up time was 33.8 ± 15.1 months. Procedure(s) consisted of 9-mm DALK and MK (9-mm anterior lamella with 6-mm posterior lamella). Outcome measurements were best-corrected visual acuity (BCVA), refractive astigmatism, and endothelial cell loss (ECL) at 5 years.

• RESULTS: Average BCVA at 5 years was 0.06 ± 0.07 in the DALK group and 0.09 ± 0.15 in the MK group ($P = .88$). Refractive astigmatism following suture removal (all visits later than 12 months) was slightly less in the DALK cohort (5-year DALK = 2.16 ± 1.40 diopter [D]; MK = 3.02 ± 0.89 D; $P = .04$; mean difference = 0.86 D [95% confidence interval [CI]: 0.71-1.01]). ECL was significantly higher in the MK group than in the DALK group at all follow-up intervals (5-year DALK = 19.36 ± 21.47%; MK = 56.61 ± 15.82%; $P < .001$). The total all-cause graft failure rate at 5 years was 0.58% for DALK (2 of 348) cases and 5.88% for MK (4 of 68) cases.

• CONCLUSIONS: Excellent 5-year visual and clinical outcomes associated with a 2-piece MK in cases converted from intended DALK mandate large-diameter DALK (9 mm) as the optimal surgical approach to keratoconus. (Am J Ophthalmol 2020;220:9–18. © 2020 Elsevier Inc. All rights reserved.)

IN THE MANAGEMENT OF KERATOCONUS, DEEP ANTERIOR lamellar keratoplasty (DALK) allows for selective removal of diseased stroma while preserving healthy host endothelium, thereby eliminating the risk of endothelial rejection.[1–3] Because the largest contributing component to overall corneal optical power is the anterior corneal curvature, it is desirable from a refractive point of view to maximize the diameter of the graft used during DALK.[4,5] However, because the risk of intraoperative conversion from intended DALK to penetrating keratoplasty (PK) is reported to occur in up to one-fourth of cases[6] and because the risk of endothelial rejection increases for full-thickness grafts larger than 8 mm, wide-diameter DALK is not widely performed as the technique of choice.[4]

In order to be able to confidently attempt wide-diameter DALK, it is therefore essential in cases where conversion to PK is necessary to have a technique that still maximizes the refractive benefit of the initially performed wide-diameter trephination while minimizing the risk of endothelial failure or rejection conventionally associated with wide-diameter grafts.[7] As previously described, a 2-piece microkeratome-assisted mushroom keratoplasty (MK) with an anterior lamella of 9 mm and a posterior lamella of 6 mm combines the increased survival rate of minimal endothelial replacement with the visual outcomes of a large-diameter anterior lamella graft.[8] Accordingly, it is the authors' technique of choice in cases in which intended DALK requires intraoperative conversion to PK.

The outcomes of conventional PK compared with those of DALK as primary procedures have been well reported.[8,9]

See Accompanying Editorial/Article on page xxx.

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However, there is generally a lack of evidence about the outcomes in eyes that were intended to undergo DALK yet required conversion to PK; those are worse than those that had successfully completed DALK.[6,9] Particularly, studies have not compared long-term clinical and refractive outcomes for wide-diameter grafts. To routinely attempt wide-diameter DALK, confidence that the respective outcomes of such patients are comparable to planned DALK is imperative.

Therefore, the purpose of this study was to evaluate and compare the 5-year survival rates and visual outcomes of keratoconic eyes that had successfully completed DALK as intended with those in which conversion from DALK to MK was mandated.

METHODS

• **STUDY DESIGN:** This was an institutional retrospective cohort study performed at Ospedali Privati Forlì Villa Igea (Forlì, Italy). The medical records of all attempted DALKs for the indication of keratoconus, regardless of severity of the cone and presence of the scar, performed between January 2012 and January 2018 were evaluated. Keratoconic eyes with clinically significant endothelial disease such as concomitant Fuchs endothelial dystrophy were offered MK to simultaneously address both of these pathologies and were thus excluded from the analysis. All data had been initially collected prospectively and entered the institutional database. The study followed the tenets of the 2013 Declaration of Helsinki and was approved by the local ethics committee of Ospedali Privati Forlì (Forlì, Italy).

All operations were performed by either a senior surgeon or by a fellow supervised by a senior surgeon.

• **SURGICAL TECHNIQUE:** DALK was performed according to previously described technique.[10] Briefly, a deep trephination of 9-mm-diameter was carried out by using a vacuum trephine (Moria, Antony, France) calibrated within 100 μm from the thinnest pachymetry value at the 9-mm zone measured by anterior segment optical coherence tomography (Casia, Tomey, Tokyo, Japan). In cases with highly irregular peripheral corneal thickness (>100 μm difference in corneal thickness at the 9-mm zone), peripheral intrastromal hydration using 1 ml of normal saline for every clock hour of corneal thinning was performed to increase stromal volume and allow deep trephination.[11] A blunt probe was advanced 1 mm centripetally from the base of the trephination. The probe was replaced by a cannula which was advanced 1 mm further along the same track created by the probe, before performing pneumatic dissection. Then, en bloc anterior keratectomy was performed starting from the base of deep trephination (i.e., within 100 μm from the thinnest paghymetric value at 9.0 mm, thus resulting in a residual bed 9 mm in diameter and approximately 100-150 μm in thickness). At this point, the central 6 mm of the bubble roof was removed by baring the optical zone at the level of the pre-Descemet's layer or Descemet's membrane (DM), depending on the plane of dissection achieved. A 9-mm anterior lamellar graft was prepared by means of a 400-μm microkeratome head and sutured into place.

When a perforation occurred during trephination, the site was initially sutured before attempting pneumatic dissection. The sutured wound allowed completion of the procedure because bubble formation typically does not extend as far as the 9-mm site of trephination. When microperforation occurred during lamellar dissection, the procedure was completed after the anterior chamber was filled with air, and DALK was completed according to the authors' institutional technique.

• **INTRAOPERATIVE CONVERSION TO MUSHROOM-SHAPED PENETRATING KERATOPLASTY:** In cases in which there was either unsatisfactory clearance of the optical zone of a full-thickness opacity or a macroperforation of the DM, the procedure was converted to a 2-piece microkeratome-assisted mushroom-shaped penetrating keratoplasty, according to the authors' previously described technique.[8] After a 9-mm-diameter anterior keratectomy was performed, the central 6-mm optical zone was excised, leaving a 1.5-mm posterior corneal crown of approximately 100- to 150-μm thickness. Using the automated lamellar keratoplasty system (Moria SA, Antony, France), the donor cornea was split into anterior and posterior lamellae by using a 350-μm microkeratome head. Both anterior and posterior lamellae were punched to the corresponding diameters of the recipient beds of 9 and 6 mm, respectively. The donor stem of the mushroom (endothelium and deep stroma) was placed into the central hole of the recipient bed without sutures and the anterior lamella was placed on top before being sutured into position with double running sutures. To complete the intervention, the anterior chamber was filled with balanced saline solution. All cases of postoperative double-anterior chamber formation (in DALK) or posterior lamella detachment (in MK) underwent rebubbling of the anterior chamber with a complete filling of air, which was partially released after 2 hours.[12]

• **STATISTICAL ANALYSIS:** All data collected from the study were entered into an electronic database using Excel 2007 software (Microsoft, Redmond, Washington), and statistical analyses were performed using SPSS version 16 software (IBM, Armonk, New York). Chi-squared test was used to determine the significance of difference between nominal variables. Continuous variables were reported as mean ± SD, and the Wilcoxon signed-rank test was used for comparison. Correlations were examined using

TABLE 1. Best Spectacle-Corrected Visual Acuity and Refractive Astigmatism

	Follow-up Duration (y)							
	Preoperative	0.5	1	1.5	2	3	4	5
BCVA (logMAR)								
DALK	0.66 ± 0.30	0.23 ± 0.15	0.16 ± 0.17	0.12 ± 0.15	0.08 ± 0.13	0.09 ± 0.16	0.09 ± 0.13	0.06 ± 0.07
MK	0.71 ± 0.28	0.28 ± 0.19	0.17 ± 0.16	0.08 ± 0.09	0.10 ± 0.10	0.10 ± 0.11	0.09 ± 0.11	0.09 ± 0.15
P value	0.23	0.26	0.89	0.46	0.28	0.54	0.81	0.88
RA (D)								
DALK	4.76 ± 2.13	3.64 ± 1.80	3.60 ± 1.78	3.03 ± 1.27	2.74 ± 1.30	2.53 ± 1.25	2.39 ± 1.57	2.16 ± 1.40
MK	4.86 ± 2.45	3.81 ± 0.82	3.51 ± 1.58	3.49 ± 1.36	3.27 ± 1.50	3.31 ± 1.61	3.09 ± 1.66	3.02 ± 0.89
P value	0.77	0.72	0.58	**.041**	**.033**	**.028**	**.039**	**.042**

P values in bold = DALK vs MK.

BCVA = best spectacle-corrected visual acuity; DALK = deep anterior lamellar keratoplasty; D = diopter; logMAR = logarithm of minimum angle of resolution; MK = mushroom keratoplasty; RA = refractive astigmatism.

the Spearman rank-correlation test. *P* values less than .05 were considered statistically significant.

RESULTS

DURING THE STUDY PERIOD THERE WERE 416 9-MM DALKS attempted, 68 of which (16.4%) were converted to MK. The indications for conversion to MK included failure to clear the optical zone of full thickness opacity and/or macroperforation. The mean follow-up time was 33.8 ± 15.1 months. The mean age was 38 ± 15 years with no significant differences between the DALK and MK groups ($P = .74$).

The visual outcomes of the 2 groups are listed in Table 1. Eyes that developed graft failure (7 eyes total across both groups) were excluded from the analysis of visual outcome but were included for the rest of the analysis. Briefly, there were no significant differences in best-corrected visual acuity (BCVA) between DALK and MK at any time point recorded. Average BCVA at 5 years was 0.06 ± 0.07 in the DALK group and 0.09 ± 0.15 in the MK group ($P = .88$) (Table 1). At 18 months (all after complete suture removal), 93.82% of DALK patients saw 20/40 or better compared with 95.85% of MK (Figure 1); no statistically significant differences were found between DALK and MK groups ($P = .67$; chi-squared test). Only 0.77% and 2.07% of cases, respectively, had BCVA worse than 20/80.

Refractive astigmatism at all time points following suture removal (all visits later than 12 months) was slightly lower in the DALK group than in the MK group. Mean differences ranged from 0.46 D to 0.86 D across all time points after suture removal; all were statistically significant (Table 1). At 18 months (all after complete suture removal), 89.94% of DALK patients had 4 D or less of refractive astigmatism compared with 92.65% of MK (Figure 2). Only 1.72% and 1.47% of cases, respectively, had refractive astigmatism greater than 8 D. High levels of astigmatism (greater than 4.5 D) were observed in 35 of 313 eyes (11%) in the DALK group and 5 of 63 eyes (8%) of the MK group; this difference was not statistically significant ($P = .49$).

Endothelial cell loss (ECL) was significantly higher in the MK group than in the DALK group at all follow-up intervals (Table 2). The mean annual ECL in MK was 11.4 % and 4.7% in the DALK group. Endothelial cell density (ECD) was relatively stable in the DALK group after the first year (Figure 3), with mean ECL at the fifth year of follow-up only 2.44% of year 1 ECD (in comparison to 29.73% in the MK group). There were no cases of endothelial failure in the MK group other than 2, resulting from episodes of endothelial rejection.

Postoperative complications are listed in Table 3. Eyes that underwent MK were more prone to develop cataract, endothelial rejection, and graft failure than DALK eyes, which had a higher incidence of rebubbling for DM detachment. Only 1 case developed posterior lamella detachment after MK. The Kaplan-Meier survival curve (Figure 4, Table 4) shows significantly higher survival after DALK than MK ($P < .001$); however, after 2 years, the probability of survival remained stable in both DALK and MK. Table 4 details causes for graft failure in the 6 of 416 cases where failure occurred.

DISCUSSION

THIS PAPER DESCRIBES THE 5-YEAR FOLLOW-UP RESULTS OF 416 keratoplasties for keratoconus, all intended as 9-mm DALK, with 68 (16.4%) requiring conversion to a 2-piece mushroom-shaped full-thickness keratoplasty (previously described in detail) for reasons of DM macroperforation or full-thickness opacity within the optical zone.[8] Those converted to MK showed no differences in BCVA at any time point but had significantly greater refractive astigmatism at time points after sutures were removed,

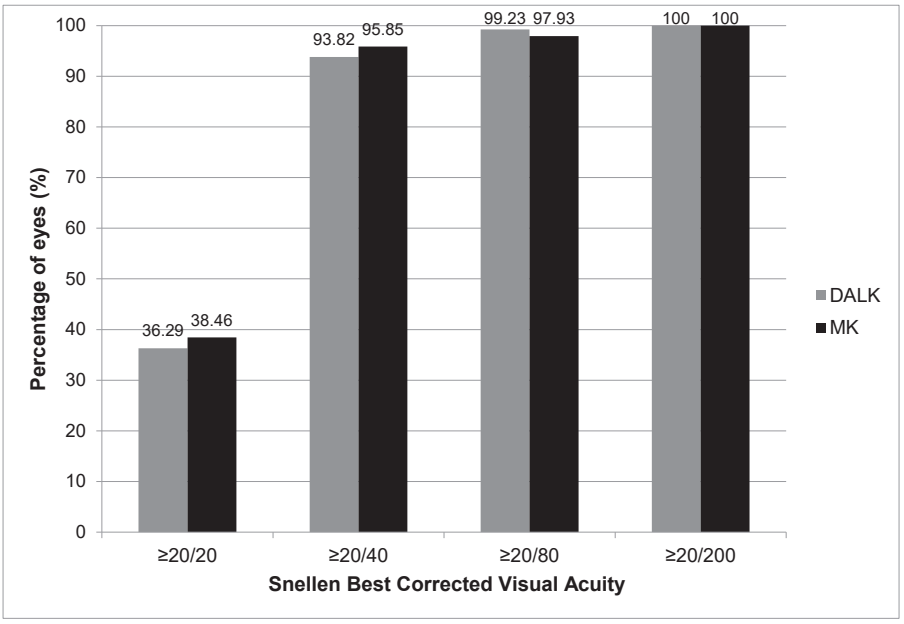

FIGURE 1. BCVA after complete suture removal (1.5-year follow-up). BCVA = best corrected visual acuity; DALK = deep anterior lamellar keratoplasty; MK = mushroom keratoplasty.

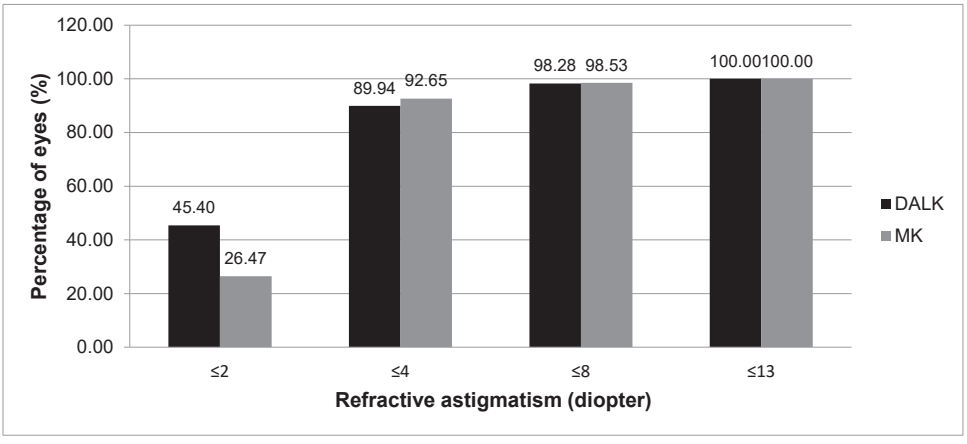

FIGURE 2. Refractive astigmatism after complete suture removal (1.5-year follow-up). DALK = deep anterior lamellar keratoplasty; MK = mushroom keratoplasty.

from 18 months to 5 years (5-year DALK = 2.16 D ± 1.40; MK = 3.02 D ± 0.89; $P = .04$; mean difference of 0.86 D; 95% CI: 0.71-1.01). This difference has limited clinical significance among postkeratoplasty eyes considering that, in approximately 90% of cases in this series, refractive astigmatism could be corrected with spectacles, with no significant differences in rates of high astigmatism (>4.5 D) between the 2 groups. Total rates of failure from all causes by 5 years were 2 of 348 DALK (0.58%) and 4 of 68 MK (5.88%) procedures.

Large-diameter DALK (8.50-9.00 mm) has been shown to have superior refractive outcomes compared to smaller diameter grafts while avoiding an increased risk of stromal rejection, which in any case is manageable medically in most cases.[10,13,14] Such diameters are larger than those conventionally performed for PK due to concerns of the increased risk of endothelial rejection.[7] In the first instance, macroperforation of DM during DALK can still result in successful DALK.[15,16] Nevertheless, DALK still has a relatively high rate of conversion to full-thickness keratoplasty, 16.4% in this series and between 14.9% and 35.3% in others.[6,9,15] In such cases, conversion to a 9-mm PK is significantly larger than the conventionally considered optimal compromise of an 8- to 8.25-mm-

TABLE 2. Endothelial Cell Density and Endothelial Cell Loss

	DALK			MK			
	Number of Eyes	ECD (cells/mm^2)	ECL (%)	Number of eyes	ECD (cells/mm^2)	ECL (%)	*P* value
Preoperative	348	2,431 ± 334	-	68	2,370 ± 238	-	.63
6 mo	348	2,113 ± 430	13.07	68	1,575 ± 434	31.57	**<.001**
1 y	348	2,005 ± 401	14.04	68	1,463 ± 294	33.53	**<.001**
18 mo	313	2,000 ± 395	17.50	59	1,347 ± 381	43.15	**<.001**
2 y	278	2,001 ± 356	17.70	53	1,274 ± 304	46.24	**<.001**
3 y	192	1,967 ± 413	17.65	29	1,158 ± 279	51.13	**<.001**
4 y	110	1,960 ± 375	19.08	16	1,072 ± 260	54.74	**<.001**
5 y	53	1,956 ± 522	19.36	5	1,028 ± 375	56.61	**<.001**

P values in bold = DALK vs MK. DALK = deep anterior lamellar keratoplasty; ECD = endothelial cell density; ECL = endothelial cell loss; MK = mushroom keratoplasty

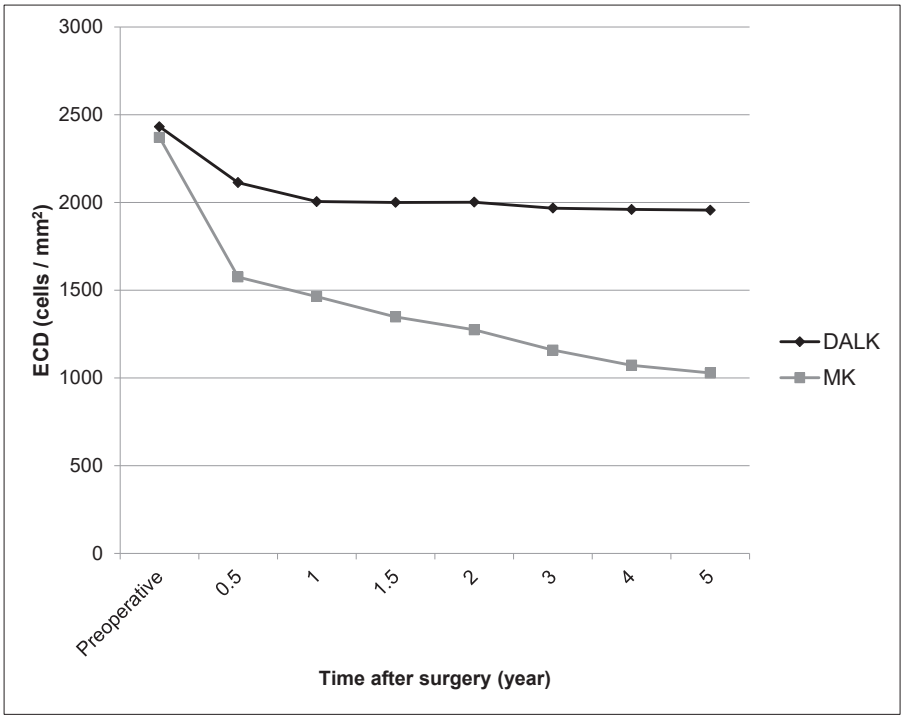

FIGURE 3. Mean ECD density over 5 years following DALK and MK. DALK = deep anterior lamellar keratoplasty, ECD = endothelial cell density, MK = mushroom keratoplasty

diameter full-thickness graft, sized to simultaneously minimize postoperative refractive error and the risk of immunologic rejection.[7] A strategy to manage conversion from DALK to PK has therefore evolved to using a 2-piece mushroom-shaped graft, which aims to minimize the endothelium transplanted in these keratoconic patients with otherwise healthy host endothelium to a 6-mm posterior lamella[8] while benefiting from the wide anterior lamellar refractive surface of 9 mm. This strategy permits the safe attempt of 9-mm DALK in all keratoconic patients, knowing that cases requiring conversion still perform well with excellent outcomes at 5 years. In this series, most cases that required conversion were associated with manual lamellar dissection. Additionally, these authors have previously described significant independent risk factors associated with conversion from DALK to PK (in reducing order of risk) including occurrence of a type 2 bubble during pneumatic dissection, the need for manual dissection, the presence of corneal scarring and the relative inexperience of the surgeon.[17]

Comparing the outcomes of the MK with those of the DALK cohorts, the MK group had statistically higher refractive astigmatism but achieved the same BCVA. This finding reinforces the authors' clinical certainty that

TABLE 3. Postoperative Complications

	Deep Anterior Lamellar Keratoplasty	Mushroom Keratoplasty
Detachment	16 (4.60%) 1 failed (residual bed)	1 (1.47%) (posterior lamella)
Persistent epithelial defect	1 (0.29)	0 (0)
Glaucoma	2 (0.58)	0 (0)
High astigmatism	35 (10.06)	5 (7.35)
Cataract	9 (2.59)	5 (7.35)
Wound dehiscence	7 (2.01)	2 (2.94) 1 failed
Immune rejection	22 (6.31)	6 (8.82)
Stromal rejection	22 (6.31)	2 (2.94)
Endothelial rejection	0 (0)	4 (5.88) 2 failed
Interface infection	2 (0.58) 1 failed	1 (1.47) 1 failed
Graft failure	2 (0.58)	4 (5.88)

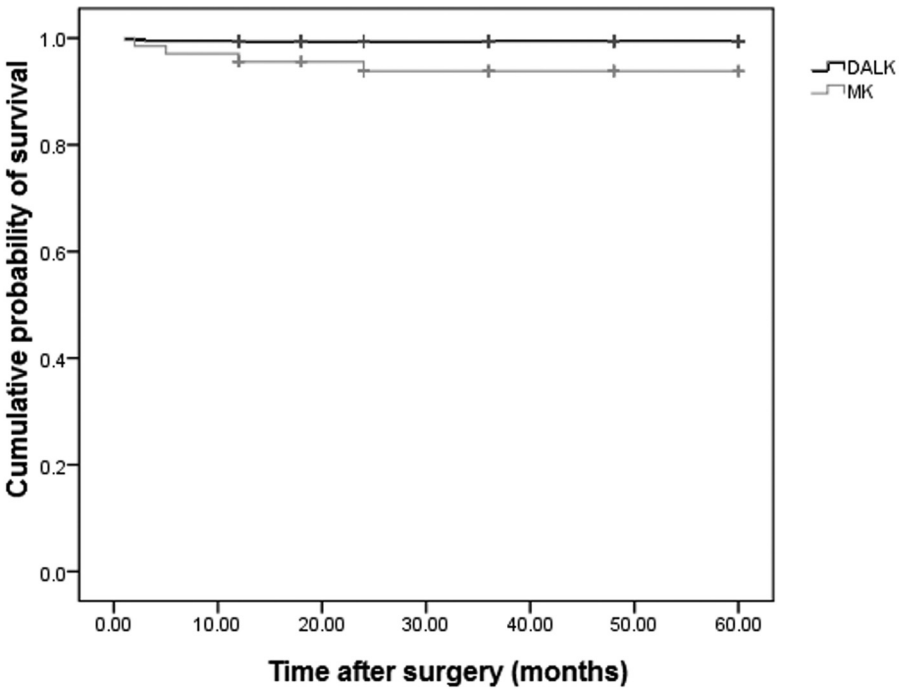

FIGURE 4. Kaplan-Meier survival curve of DALK and MK. DALK = deep anterior lamellar keratoplasty; MK = mushroom keratoplasty.

the microkeratome-dissected interface present in MK does not result in inferior visual outcomes compared with the interface created by pneumatic dissection during DALK. This is unsurprising given the clinical appearance of the interface postoperatively as can be seen in Figure 5.

The presence of any stromal interface may cause some degree of light scattering depending on the optical quality of the surfaces in contact. As shown after laser in situ keratomileusis or various other types of lamellar keratoplasty, microkeratome-assisted dissection produces smooth regular interfaces of a quality compatible with excellent vision whereas light scattering is usually of no clinical significance.[8,10,18,19] However, further comparative analyses of induced higher-order aberrations and light scatter are necessary to evaluate differences between the 2 procedures. Notably, the use of viscoelastic material during lamellar dissection for DALK often induces transient interface haze, thereby affecting early postoperative visual outcomes.[20]

ECL at 2 years following DALK was 17.70% versus 46.24% following MK ($P < .001$) (Table 2), which is to be expected from studies comparing DALK with PK.[21] However the ECL reported for the MK cohort is sampled from the 6-mm central stalk, which represents only 25% of the total endothelial population of the cornea[8] with the remaining

TABLE 4. Kaplan-Meier Analysis of Graft Survival Probabilities and Failures

	1 y	2 y	3 y	4 y	5 y
% of DALK	99.42	99.42	99.42	99.42	99.42
% of MK	95.59	94.12	94.12	94.12	94.12
Details of failed cases (all failed grafts were regrafted)					
DALK					
1	Persistent Descemet membrane detachment with repeated rebubbling after 1.5 months: endothelial KP (converted to MK) (3-y Snellen BSCVA 0.4)				
2	Interface infection: therapeutic penetrating keratoplasty: (1-y Snellen BSCVA: 0.4)				
MK					
1	Wound dehiscence secondary to trauma with ruptured globe: Tectonic PK: vascularized corneal opacity				
2	Infection after 3 weeks: Repeat MK (4-y Snellen BSCVA 0.6)				
3	Endothelial rejection at 5 months: Posterior lamella exchange (2-y Snellen BSCVA 0.5)				
4	Endothelial rejection at 2 y: Posterior lamella exchange (1-y Snellen BSCVA 0.9)				

BCVA = best corrected visual acuity; DALK = deep anterior lamellar keratoplasty; MK = mushroom keratoplasty.

healthy host endothelium being left intact. Because it has been shown that host endothelium may migrate across the posterior graft-host junction, preserving an even greater area of peripheral host will only provide a greater reservoir of native healthy endothelium.[22] This may account for why there was not a single episode of graft failure in the MK group secondary to endothelial decay in the absence of rejection. In comparison to other studies which have reported no worse outcomes for their cohorts converted to PK compared to uncomplicated DALK,[6,9] the greater failure rates of 4 of 68 (5.88%) in the MK cohort is more consistent with reported failures rates of DALK in the medical literature.[6,23] One failure was due to traumatic dehiscence, 1 due to infection, and 2 were subsequent to episodes of endothelial rejection (Table 4); all were regrafted with good outcomes. In both cases of graft failure following endothelial rejection, only the 6-mm posterior lamella was exchanged with a similar one prepared by means of microkeratome-assisted dissection, punched to a 6-mm diameter and delivered bimanually through a 3-mm nasal clear-cornea incision according to the authors' standard descemet stripping automated endothelial keratoplasty technique.[19]

As expected, given the larger diameter, the BCVA and refractive astigmatism outcomes of both the 9-mm DALK and MK groups compare favorably with a 2017 systematic review of DALK and PK for keratoconus.[24] Furthermore, respective graft survival probabilities of 99.42% and 94.12% at 5 years also compare favorably with published studies, with a meta-analysis reporting average DALK survival rate to be 100%, 92%, and 90% (86.0%-94.8%) at 1, 3, and 5 years, respectively.[16]

Same size donor and recipient trephines and punches were used for the 9-mm anterior and the 6-mm posterior lamellae. In the deep plane, this results in the diameter of the donor button being slightly smaller than that of the recipient bed, thus avoiding formation of clinically evident Descemet folds, which may affect vision.

With the 2-piece MK, although the proximity of the larger 9-mm anterior lamella (mushroom "hat") to the limbal vascular arcade may theoretically increase the risk of immune rejection, an increased risk of stromal rejection, even among high-risk eyes, was not observed.[8,13,25] On the other hand, the smaller 6-mm posterior lamella (mushroom "stem") decreases the endothelial antigenic load, therefore reducing the primary alloimmune target for endothelial rejection. In addition, as at least two-thirds of the healthy host endothelium is preserved with this design, even if an immunologic rejection were to occur, endothelial cell migration from the large healthy recipient bed could theoretically replace all the donor rejected endothelium, similar to what is seen in Descemet stripping without endothelial keratoplasty.[26]

Clearance of central corneal stroma in DALK and excision of central full-thickness cornea in MK were limited to the 6-mm optical zone, resulting in a posterior stromal crown (Figure 5) approximately 1.5 mm in width. This rim of overlap between the posterior surface of the anterior lamellar graft and the peripheral residual host stroma resulted in a wound configuration with several advantages. First, the manually dissected plane resulted in a far greater surface area of donor-host stromal contact than with a vertical wound in conventional PK or DALK, theoretically inducing superior wound strength and improved corneal biomechanics, as well as allowing earlier suture removal (all sutures are removed before 12 months). Although the thickness of posterior stromal shoulder cannot be determined exactly, aiming at a precise thickness is of negligible clinical importance, as stromal remodeling of the posterior shoulder occurs modifying over time both the thickness and the shape of this part of the residual bed.[27] Second, in cases of postkeratoplasty astigmatism, this plane also facilitates

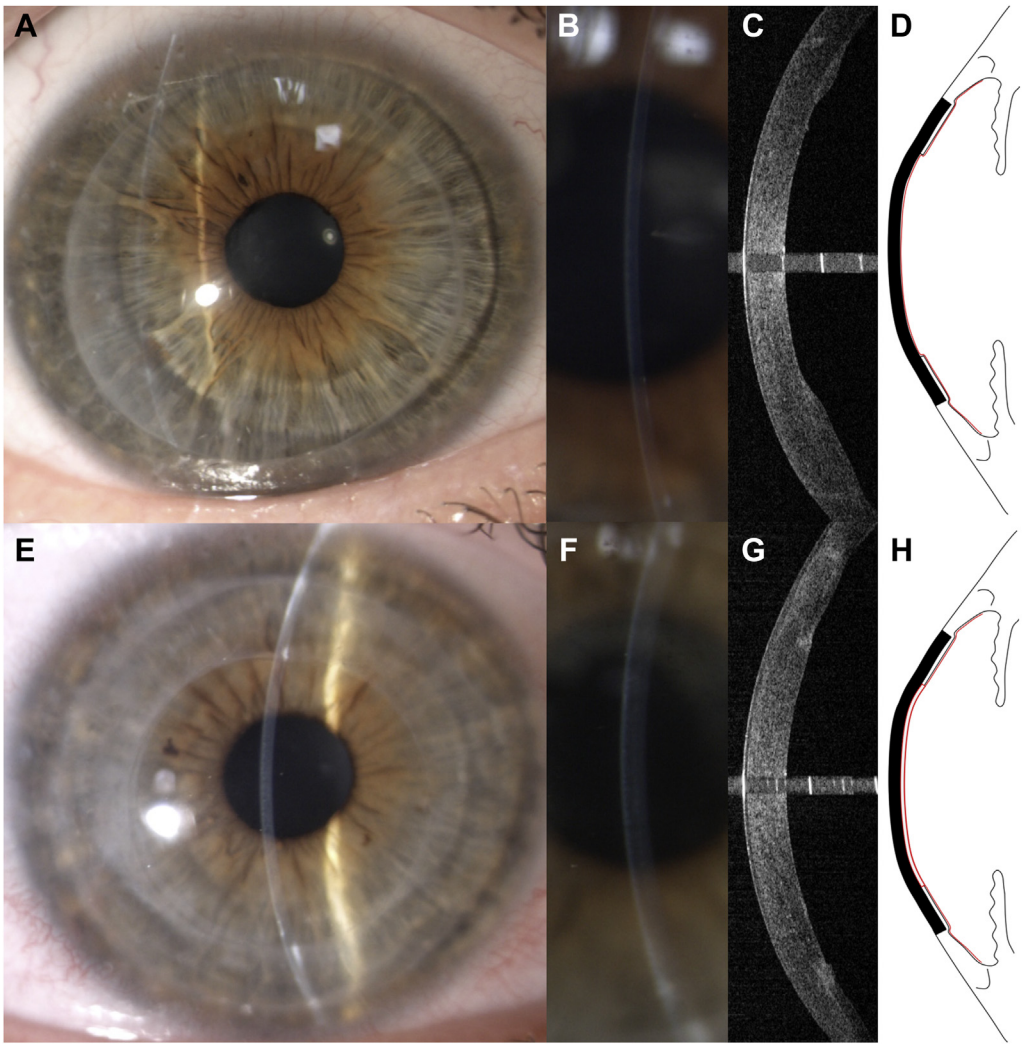

FIGURE 5. (A-D) DALK and (E-H) MK. (A, E) Views obtained 5 years postoperatively. (B, F) High zoom optical section 5 years postoperatively. (C, G) Anterior segment optical coherence tomography 5 years after DALK. (D, H) Schematic diagrams. DALK = deep anterior lamellar keratoplasty; MK = mushroom keratoplasty.

the safe creation of predictable, deep, and consistent in-the-wound blunt relaxing incisions without risk of perforation into the anterior chamber.[28] Finally, large-diameter grafting according to the techniques used in this series maximizes removal of ectatic tissue while extending "capping" of the residual bed further into the corneal periphery. Theoretically, this may also reduce the rate of late recurrence of ectasia, which is typically characterized by progressive thinning of the residual recipient bed, resulting in elongation and slippage of the original PK wound.[8,29,30] Because some cones can extend beyond an 8-mm trephination, it is likely that recurrence of ectasia is further reduced by the fact that 9-mm grafts are more likely to excise the entire cone in such patients. However, longer follow-up is required to evaluate recurrence of ectasia in these cases.

The present study has several limitations. First, it has a retrospective design, which may decrease the validity of the study findings. However, all previously mentioned studies of the same topic have also had a retrospective design, most with lower sample sizes. Including many patients in this study can compensate at least to some extent for the limitations inherent in the retrospective design. Besides, all data were entered prospectively at regular intervals postoperatively, with consistent results up to 5 years. Studies with even longer follow-up would be interesting in future to determine whether the rate of ectasia recurrence was indeed lower in eyes with wide-diameter grafts or those with increased surface area of the graft-host interface.

In conclusion, the excellent 5-year visual and clinical outcomes associated with a 2-piece mushroom keratoplasty in cases converted from intended DALK mandate large-diameter DALK (9 mm) as the optimal surgical approach to keratoconus.

ALL AUTHORS HAVE COMPLETED AND SUBMITTED THE ICMJE FORM FOR DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST and none were reported.

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