ORIGINAL ARTICLES

Paired-Eye Analysis of Deep Anterior Lamellar Keratoplasty Versus Mushroom Penetrating Keratoplasty Over 5 Years

LUIGI DE ROSA[#], ANDREA TALONI[#], RAPHAEL KILIAN, GEORGIANA CAMBURU, VALENTINO DE RUVO, NICOLÒ CIARMATORI, ROSSELLA SPENA, LINDA MARIE LOUISE BUSIN, CRISTINA BOVONE, ANGELI CHRISTY YU, NICCOLÒ SALGARI, AND MASSIMO BUSIN

• PURPOSE: To evaluate and compare the clinical outcomes of keratoconic patients who received deep anterior lamellar keratoplasty (DALK) in one eye and mushroom penetrating keratoplasty (MK) in the fellow eye.
• DESIGN: Retrospective interventional case series based on prospectively collected data.
• SUBJECTS: Keratoconic patients who underwent keratoplasty at the department of ophthalmology of "Villa Igea," Ospedali Privati Forlì (Forlì, Italy) between July 2006 and December 2023.
• INTERVENTION: Patients underwent DALK in one eye and converted MK from intended DALK in the fellow eye.
• MAIN OUTCOME MEASURES: The primary outcomes were best spectacle-corrected visual acuity (BSCVA), refractive astigmatism, and endothelial cell density (ECD). Kaplan-Meier curves were drawn for both DALK and MK to compare the cumulative probability of obtaining a BSCVA < 0.3 LogMAR (Snellen 20/40) within the end of follow-up.
• RESULTS: We included 46 keratoconic patients that underwent DALK in one eye and MK in the fellow eye. Mean follow-up was 5.4 ± 2.1 years (up to 10 years). During the first two years after surgery, BSCVA was significantly better in the DALK group (0.08 ± 0.11 vs 0.15 ± 0.20 LogMAR, $P = .05$); however, no significant differences between the 2 groups were found at later follow-up times. At 5 years, BSCVA values were 0.08 ± 0.10 and 0.12 ± 0.18 LogMAR, respectively for DALK and MK ($P = .305$). The 5-year probability of retaining a BSCVA < 0.3 LogMAR was 85.1% and 83.0%, respectively for DALK and MK ($P = .791$). Three years postoperatively, refractive astigmatism was significantly lower for DALK (at 5 years, 2.37 ± 1.21 D vs 2.97 ± 1.13 D; $P = .04$); however, the percentage of eyes with astigmatism higher than 4.5 D did not significantly differ between DALK ($n = 3$) and MK ($n = 2$) ($P > .99$). Five years postoperatively, ECD was 1837 ± 625 cells/mm² for DALK and 1083 ± 378cells/mm² for MK ($P < .001$). At 1 year, mean ECL was 20.3% for DALK and 35.4% for MK ($P = .008$). Thereafter, mean annual ECL was 1.4% for DALK and 5.9% for MK ($P = .021$).
• CONCLUSION: This study allowed direct intra-patient comparison between DALK and MK. Compared with MK, our findings showed for DALK better BSCVA during the first 2 years after surgery, lower refractive astigmatism from 3 years postoperatively on, and higher ECD at all time points. (Am J Ophthalmol 2026;285: 175–183.

INTRODUCTION

IDEALLY, DEEP ANTERIOR LAMELLAR KERATOPLASTY (DALK) is the surgical technique of choice for eyes with healthy endothelium and stromal disease, offering several advantages over full-thickness corneal transplantation. By preserving the host endothelium, DALK eliminates the risk of endothelial immunological rejection, which is a common cause of graft failure also for penetrating keratoplasty (PK) performed in keratoconic eyes.[1,2]

AJO.com Supplemental Material available at AJO.com.
Accepted for publication January 29, 2026.

From the Department of Translational Medicine (L.D.R., A.T., R.K., G.C., V.D.R., N.C., R.S., C.B., A.C.Y., N.S., M.B.), University of Ferrara, Ferrara, Italy; Department of Ophthalmology (L.D.R., A.T., R.K., G.C., V.D.R., N.C., R.S., L.M.L.B., C.B., A.C.Y., N.S., M.B.), Ospedali Privati Forlì "Villa Igea", Forlì, Italy; Istituto Internazionale per la Ricerca e Formazione in Oftalmologia (L.D.R., A.T., R.K., G.C., V.D.R., N.C., R.S., C.B., A.C.Y., N.S., M.B.), Forlì, Italy; Department of Ophthalmology (L.M.L.B.), Fatebenefratelli Hospital, Milano, Italy
Inquiries to Niccolò Salgari, Department of Ophthalmology, University of Ferrara, Forlì, Italy.; e-mail: slgncl@unife.it
[#] Luigi De Rosa and Andrea Taloni contributed equally to this work.

0002-9394/$36.00
https://doi.org/10.1016/j.ajo.2026.01.039

In addition, as full-thickness grafts larger than 8.0 mm are associated with a greater risk of endothelial rejection, they are not commonly used for PK, while DALK allows surgeons to safely utilize donor grafts of larger diameter, thereby minimizing postoperative astigmatism without compromising graft survival.[3,4] Despite these advantages, DALK has not achieved widespread adoption due to both its technical challenges and several misconceptions, including concerns about standardization, reproducibility, as well as doubts about its early visual and refractive benefits compared to PK.[5,6]

When macro-perforations occur during DALK, conversion to full-thickness keratoplasty is required. In order to preserve as much endothelium as possible, Busin et Arffa introduced the concept of a two-piece microkeratome-assisted mushroom PK (MK) that combines a large 9.0 mm anterior graft to optimize refractive outcomes, with a smaller 6.0 mm posterior lamella, thus minimizing the amount of endothelium transplanted.[7] This technique has been shown to allow higher probability of graft survival even in eyes at high risk of immunological rejection.[8]

Our research group previously reported the outcomes of DALK and MK for keratoconus and herpetic corneal scars.[9,10] However, these studies were limited by inter-patient variability, such as difference in age, disease severity, ocular and systemic comorbidities between study groups. The results of a paired-eye analysis that eliminates such confounding variables for these two techniques are presented herein.

METHODS

• **STUDY DESIGN:** This is a retrospective comparative interventional case series. Patients underwent keratoplasty at the tertiary care referral center of "Villa Igea," Ospedali Privati Forlì (Forlì, Italy) between July 2006 and December 2023. The study adhered to the tenets of the 2013 Declaration of Helsinki and was approved by the local Institutional Review Board (Comitato Etico della Romagna). Written informed consent was obtained from all patients before surgery.

This study included patients suffering from keratoconus, who had undergone DALK in one eye and converted two-piece microkeratome-assisted MK from intended DALK in the fellow eye. Exclusion criteria were previous ocular surgery, except corneal cross-linking as well as vision-impairing comorbidities, such as amblyopia, maculopathies, and uncontrolled glaucoma with IOP > 18 mm Hg or central visual field defects.

The primary outcomes were best spectacle-corrected visual acuity (BSCVA), refractive cylinder, endothelial cell density (ECD), endothelial cell loss (ECL), complications, and graft failure rates. Kaplan–Meier curves were drawn for both DALK and MK to cf the cumulative probability of obtaining a BSCVA <0.3 LogMAR and <0.1 LogMAR within the end of follow-up.

Graft rejection was diagnosed as the presence of epithelial rejection line, subepithelial or stromal infiltrates, keratic precipitates, and/or Tyndall/inflammatory cells in the anterior chamber with or without loss of transparency. Interface neovascularization accompanied by stromal infiltrates or other inflammatory signs would be classified as stromal rejection.

Graft failure was defined as the occurrence of any repeat keratoplasty; or in the absence of a re-graft, a cornea that was cloudy and did not clear; or a cornea that was initially clear after surgery and subsequently became irreversibly opaque.

Both preoperatively and at each postoperative follow-up visit, patients underwent a complete ophthalmologic examination including BSCVA, manifest refraction, slit-lamp biomicroscopy, applanation tonometry, fundoscopy, specular microscopy (EM-3000; Tomey Corporation, Japan), and anterior segment optical coherence tomography (CASIA-SS1000, Tomey Corporation, Japan).

• **SURGICAL TECHNIQUES:** In all cases, DALK was attempted according to the technique described by Busin et al.,[11] while manual layer-by-layer dissection was performed only when a type 1 bubble was not obtained. Briefly, a deep trephination of 9.0 mm diameter was performed 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). 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. Then air was injected using a Fogla cannula (Bausch & Lomb GmbH, Eppelheim, Germany) attached to a 5 cc syringe and an lamella of anterior stroma was removed taking care not to perforate the roof of the bubble A dermatologic 6.0 mm trephine was used to mark the central area of the bubble roof to be excised. Next, the bubble was entered centrally using a 15° blade under viscoelastic protection to reduce the risk of sudden collapse and consequent damage of the bubble floor. Blun Vannas scissors were used to remove the central part of the bubble roof following the 6.0 mm mark, thus baring the pre-Descemet Membrane (DM) layer in the central optical zone. A 9-mm anterior lamellar graft was prepared by means of a 400 to 450 μm microkeratome head and sutured in place with two 10-0 nylon running sutures.

Instead, in case of macro-perforations, the procedure was converted into a two-piece microkeratome-assisted MK, according to the technique previously described and also shown in a video in the supplemental materials.[10] This approach ensures consistent sizing and optimal fitting of the posterior lamella into the recipient bed, while leaving in place a surrounding crown of posterior stroma 1.5-

mm in width and approximately 100 to 150 μm thickness. Particular care was taken to obtain a rather loose fit between the two parts, thus avoiding formation of folds in the deep donor lamella; instead, when the fit resulted loose, the space was quickly filled by scar tissue, without consequences for the graft transparence. The donor stem of the mushroom (posterior lamella consisting of endothelium and deep stroma) was positioned in place of the excised portion of the bubble floor. The donor hat (anterior lamella consisting of anterior stroma) was sutured into the recipient bed with either a double running 10-0 nylon suture or 16 interrupted 10-0 nylon single stitches. Finally, the anterior chamber was filled with balanced saline solution. The stem of the mushroom was left free to adhere to the overlying hat with no need for any type of sutures.

Postoperatively, a fixed combination of dexamethasone phosphate 0.1% and tobramycin sulfate 0.3% ophthalmic solution was started every 2 hours daily and tapered off to 4 times daily over the first postoperative month. Subsequently, antibiotic treatment was discontinued, and dexamethasone was changed to fluorometholone and slowly tapered to once daily only for the first year in the DALK group and indefinitely for the MK group. All corneal sutures were removed approximately at 1 year after surgery. Follow-up visits were scheduled postoperatively at months 1, 3, 6, 12 and yearly thereafter.

• **STATISTICAL ANALYSIS:** All data were prospectively collected in our institutional database using Microsoft Excel 365 (Microsoft Corp., Redmond, WA) and analyzed with GraphPad Prism (v10.5.0; GraphPad Software Inc.). Continuous variables were reported as mean ± SD (95% CI). Categorical variables were reported as counts and percentages.

BSCVA was assessed with a Snellen chart and converted into the logMAR (LogMAR) for the purpose of statistical analysis. A biphasic linear regression model was applied to individual ECD measurements, with a fixed breakpoint at 1 year postsurgery separating an early phase (baseline to 1 year), primarily reflecting surgical trauma, from a late phase (1-5 years). For the late phase, ordinary least squares regression required a minimum of 3 ECD measurements per patient. Endothelial cell loss (ECL) was expressed as a percentage, calculated as the difference between the ECD at two time points, divided by the earlier ECD and multiplied by 100. Additionally, biexponential nonlinear regression was performed as described by Armitage et al.[12] This model fits ECD decline over time as the sum of fast and slow exponential components, allowing prediction of the time required to reach the critical threshold of 500 cells/mm^2. Data normality was assessed using the Shapiro-Wilk test. The Wilcoxon signed-rank test was used to cf continuous variables. Post-hoc power analysis was performed using G*Power (v3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The Chi-square test of independence and Fisher exact test were used to cf categorical variables, as appropriate. The log-rank test was performed to cf Kaplan-Meier curves. All tests were two-sided and a P value <.05 was considered statistically significant.

RESULTS

This study included 46 consecutive patients (35 males, 11 females) who underwent DALK in one eye and MK in the fellow eye. The mean age at the time of surgery was 35.8 ± 13.4 years (95% CI, 33.1-38.6), with a mean time interval of 3.6 ± 5.0 years (95% CI, 2.2-5.1) between procedures in the 2 eyes. Pneumatic dissection was successfully achieved in all eyes undergoing DALK. The mean follow-up time was 5.4 ± 2.1 years (95% CI, 5-5.8), up to 10 years.

Mean preoperative BSCVA was 0.78 ± 0.30 LogMAR [95% CI, 0.69-0.87] for DALK and 0.87 ± 0.30 LogMAR [95% CI, 0.78-0.96] for MK (P = .275). One year after surgery, following complete suture removal, BSCVA was significantly better in the DALK group (0.09 ± 0.12 LogMAR [95% CI, 0.06-0.12]) than in the MK group (0.16 ± 0.18 LogMAR [95% CI, 0.10-0.21], P = .03). Two years postoperatively, this difference was less marked, but DALK still scored significantly better (0.08 ± 0.11 LogMAR [95% CI, 0.04-0.11]) than MK (0.15 ± 0.20 LogMAR [95% CI, 0.09-0.21]) (P = .05). No significant differences between the 2 study groups were observed at later follow-up times. At 5 years after surgery, BSCVA values were 0.08 ± 0.10 (95% CI, 0.04-0.11) and 0.12 ± 0.18 LogMAR (95% CI, 0.05-0.18), respectively for DALK and MK (P = .305). Post-hoc power analysis for BSCVA comparisons revealed an achieved power of 30.9%, 15.5%, and 17.8% at years 3, 4, and 5, respectively. Figure 1 shows preoperative and postoperative BSCVA at each time point.

All eyes in the DALK group maintained a BSCVA ≥ 20/60 for the entire duration of the follow-up, whereas in the MK group 4 eyes failed to reach this visual acuity threshold. According to Kaplan-Meier analyses, the 5-year probability of retaining a BSCVA < 0.3 LogMAR (>20/40) was 85.1% and 83.0%, respectively for DALK and MK (P = .791) (Figure 2A), whereas the 5-year probability of retaining a BSCVA < 0.1 LogMAR (>20/25) was 41.4% and 50.0%, respectively for the 2 groups (P = .689) (Figure 2B).

For the first 2 years postoperatively, mean refractive astigmatism did not differ significantly between DALK (2.79 ± 1.54 D [95% CI, 2.31-3.28]) and MK (3.21 ± 1.30 D [95% CI, 2.80-3.62]) (P = .239). Conversely, between 3 and 5 years after surgery DALK showed significantly lower astigmatism than MK (at 5 years, DALK: 2.37 ± 1.21 D [95% CI, 1.91-2.82], MK: 2.97 ± 1.13 D [95% CI, 2.54-3.39]) (P = .04). At the last available follow-up, astigmatism greater than 4.5 D was observed in 3 eyes (6.5%) of the DALK group and in 2 eyes (4.3%) of the MK group

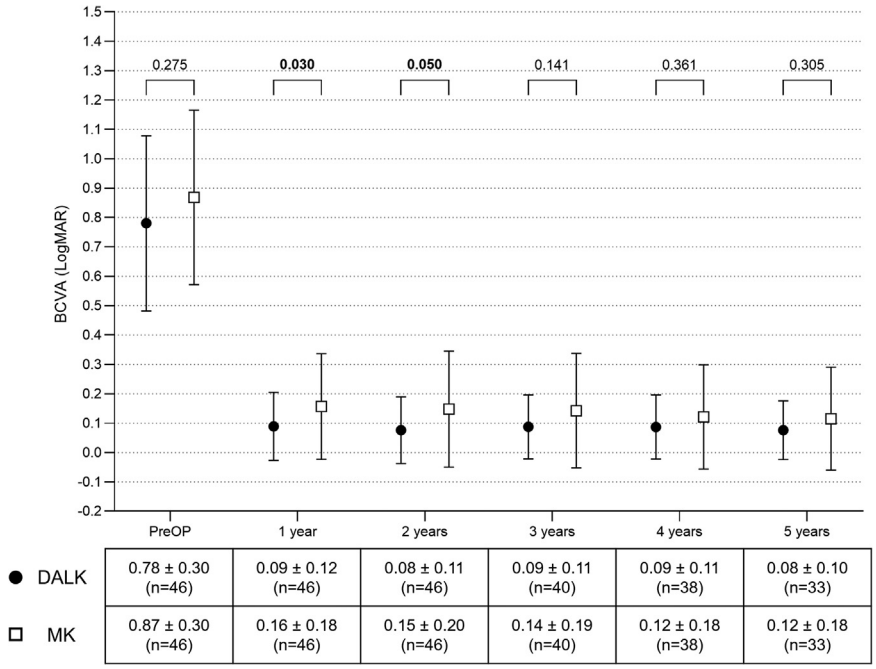

FIGURE 1. Preoperative and postoperative best spectacle-corrected visual acuity plotted as mean ± SD in deep anterior lamellar keratoplasty (DALK) and mushroom keratoplasty (MK).

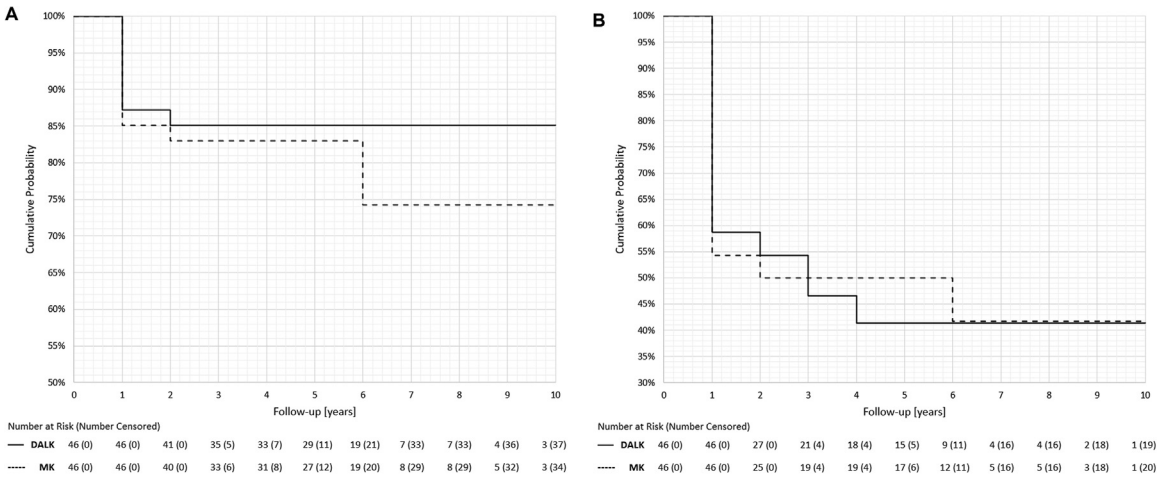

FIGURE 2. Kaplan-Meier curves showing the cumulative probability of retaining a best spectacle-corrected visual acuity (A) <0.3 LogMAR (>20/40) and (B) <0.1 LogMAR (>20/25) for deep anterior lamellar keratoplasty (DALK) (continue line) and mushroom keratoplasty (MK) (dashed line).

($P > .99$). Relaxing incisions were only necessary in 1 eye that underwent MK. Figure 3 shows postoperative refractive astigmatism at each time point.

Mean preoperative ECD before DALK was 2401 ± 388 cells/mm^2 (95% CI, 2267-2534), whereas donor ECD before MK was 2351 ± 237 cells/mm^2 (95% CI, 2270-2433) ($P = .232$). At all time-points, ECD in the DALK group was significantly higher than in the MK group (always $P < .001$). At 5 years, ECD was 1837 ± 625 cells/mm^2 (95% CI, 1579-2095) for DALK and 1083 ± 378 cells/mm^2 (95% CI, 927-1239) for MK ($P < .001$) (Figure 4A). At 1 year, mean ECL was 20.3% for DALK (−504 ± 453 cells/mm^2 [95% CI, −663 to − 344]) and 35.4% for MK (−835 ± 495 [95% CI, −1009 to − 661]) ($P = .008$). Between 1 and 5 years, biphasic linear regression yielded a mean annual ECL of 1.4% for DALK (−27 ± 119 cells/mm^2/year [95% CI, −70 to 15]) and 5.9% for MK (−90 ± 109 cells/mm^2/yr [95% CI, −129 to − 52]) ($P = .021$). According to the biexponential regression model (DALK, $R^2 = 0.98$; MK, $R^2 = 0.99$), considering our mean baseline ECD values, the predicted time

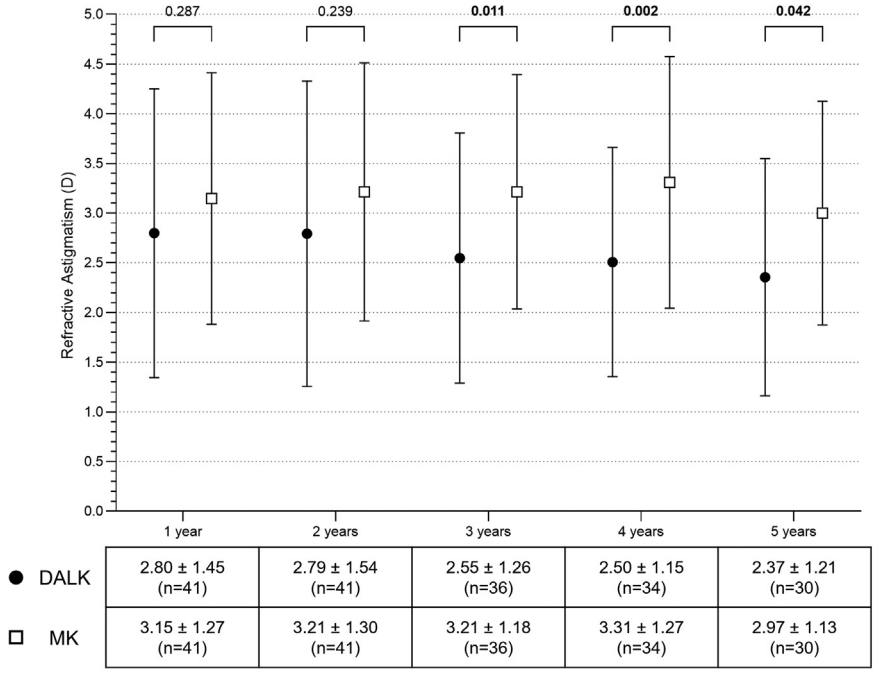

FIGURE 3. Postoperative refractive astigmatism plotted as mean ± SD in deep anterior lamellar keratoplasty (DALK) and mushroom keratoplasty (MK).

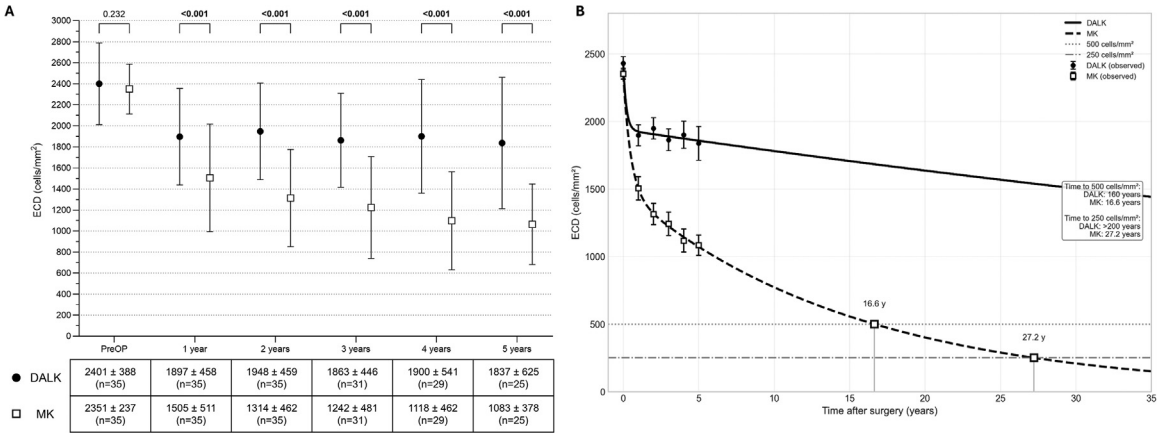

FIGURE 4. Endothelial cell density (ECD) in deep anterior lamellar keratoplasty (DALK) and mushroom keratoplasty (MK). (A) Preoperative and postoperative endothelial cell density plotted as mean ± SD. (B) Biexponential endothelial cell loss model showing long-term ECD prediction.

to reach the threshold of 500 cells/mm^2 was 160.1 years for DALK compared to approximately 16.6 years for MK, confirming higher long-term endothelial stability in DALK compared to MK (Figure 4B).

Concerning postoperative complications, stromal immune rejection rates were comparable between the two groups (DALK: 1 eye, 2.1%, MK: 2 eyes, 4.6%; $P > .99$). Endothelial immune rejection occurred only in 1 eye that underwent MK (2.1%). All cases were successfully treated conservatively. A single case of graft failure was reported in the MK group 2 years after cataract surgery. Kaplan-Meier analysis showed a 5-year graft survival probability of 100% for DALK and 97.8% for MK, with no statistically significant difference between the two groups ($P = .317$) (Figure 5).

DISCUSSION

Theoretically, DALK is the optimal type of keratoplasty to be performed for keratoconus, mainly because it preserves

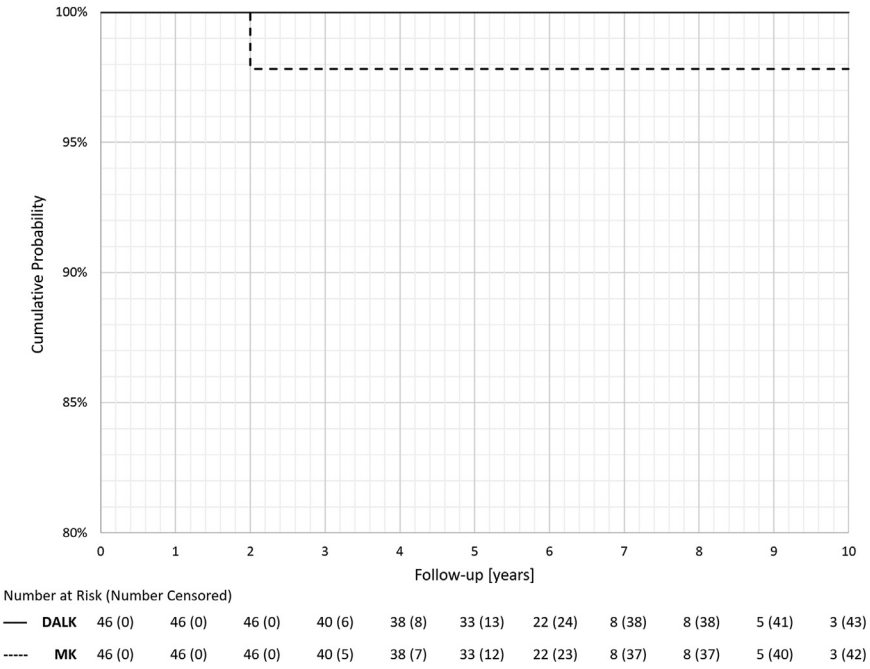

FIGURE 5. Kaplan-Meier curves showing the survival cumulative probability for deep anterior lamellar keratoplasty (DALK) (continue line) and mushroom keratoplasty (MK) (dashed line).

the host endothelium which is unnecessarily removed at the time of PK, thus eliminating the risk of endothelial immunologic rejection. As a corollary, grafts of large diameter, up to 9 mm and beyond, can be used for DALK[11] and visual and refractive outcomes can be consequently optimized.[3] In addition, DALK prevents any possible complications related to open-eye surgery.

Although pneumatic dissection has become the most popular technique for DALK due to its ability to create a smooth, optically clear stromal interface, with many techniques bubble formation cannot be reliably achieved in all cases. When pneumatic dissection fails, manual layer-by-layer dissection becomes necessary, increasing the risk of Descemet membrane macro-perforation and possibly requiring conversion to full-thickness keratoplasty. In these cases, to maintain the refractive benefits of 9.0 mm grafts, we have developed a two-piece mushroom keratoplasty technique that combines a 9.0 mm diameter anterior lamella with a 6.0 mm diameter posterior lamella. This configuration preserves the refractive benefits of the large anterior graft while transplanting only the central 6 mm of donor endothelium, thus significantly reducing the risk of endothelial decompensation. In this study, we analyzed the postoperative outcomes of patients affected by keratoconus who received DALK in one eye and MK in the contralateral eye. Comparing results obtained in 2 eyes in the same subjects eliminated inter-patient variability, avoiding confounding factors such as biological sex, systemic comorbidities, healing response, adherence to postoperative treatment protocols, environmental factors, and different sample sizes. Furthermore, the relatively short time interval between surgeries in the 2 eyes (3.6 ± 5.0 years) minimized the potential impact of age-related changes on surgical outcomes.

Concerning visual outcomes, DALK showed values significantly higher than those of MK, both at the 1-year and 2-year follow-up visits. At later time points, the difference was no longer statistically significant; however, post-hoc power analysis revealed low statistical power at these time points. Overall, the probability of retaining a BSCVA greater than 20/40 at 5 years was more than 80% for both DALK and MK. About 40% of the eyes in both groups retained visual acuity greater than 20/25. Only 4 eyes belonging to the MK group had visual acuity lower than 20/60.

From a refractive standpoint, both large diameter DALK and MK have been shown to provide superior outcomes with lower degree of astigmatism in comparison with techniques employing conventional 8.0 mm grafts.[13] The use of 9.0 mm diameter grafts allows to include the whole ectatic area in most eyes, especially when the keratoconus is of the broad-base type, often extending into the corneal periphery beyond the 8.0 mm central zone. In our case series, refractive astigmatism did not differ significantly between DALK and MK during the first 2 postoperative years. However, DALK demonstrated significantly lower values at all subsequent time points. Despite this refractive advantage reported for the DALK group, both types of keratoplasty resulted in a similarly low proportion of eyes with refractive astigmatism exceeding 4.5 D (<7.0%).

Preserving the recipient's endothelium is the main advantage of DALK. ECL was higher in MK, both during the first postoperative year and in the subsequent follow-up period . However, ECD remained compatible with a clear graft in almost all eyes, exception made for one case of endothelial failure following cataract surgery. Compared to conventional PK, MK involves the transplantation of the central 6 mm of the host endothelium, which corresponds to 25% of the posterior corneal surface, theoretically reducing the amount of antigenic load and therefore the risk of endothelial rejection. Long-term postoperative topical corticosteroid therapy may have further contributed to minimizing the risk of immunologic rejection as well as interface neovascularization. In addition, endothelial cells can migrate onto the posterior surface of the cornea across the junction between donor and recipient tissue, from the peripheral untouched and high-density endothelium into the central donor button, thus repopulating it in case of substantial cell loss.[8] Eventual gaps between the posterior donor lamella and the "crown" of peripheral residual stromal bed are closed by scar tissue within few weeks/months after surgery and should not therefore prevent cell migration. In addition, such gaps are never present all around the grafted posterior lamella, but they are usually limited to few hours of the clock, thus making endothelial migration possible through the areas of contact between donor and recipient tissue.

Some authors have compared the long-term outcomes of DALK and conventional PK in patients affected by keratoconus, although without a paired-eye analysis. Borderie et al. analyzed a large cohort of DALK ($n = 228$) and conventional PK ($n = 274$) for keratoconus over a maximum follow-up of 15 years.[14] At 10 years, no significant differences were observed in BSCVA (0.17 vs 0.23 LogMAR, $P = .21$) or refractive astigmatism (4.6 vs 4.5 D, $P = .84$), while ECD was significantly higher in the DALK group (1966 vs 827 cells/mm^2, $P < .001$). The 15-year graft survival rate was very similar (97.1% vs 96.4%, $P = .97$). Using a biphasic linear model, they reported 1-year ECL rates of 9.2%/year for DALK and 16.9%/year for PK, with late-phase rates of 2.3%/year and 5.5%/year, respectively. Graft survival rates and late-phase ECL were consistent with our findings; however, we observed lower refractive astigmatism and slightly better visual acuity in our cohort, possibly a consequence of the use of 9.0 mm grafts.[14]

Feizi et al.[15] compared DALK and PK in 411 eyes with advanced keratoconus (mean keratometry ≥60 D) over a mean follow-up of approximately 6 years. In contrast with our evidence, they reported significantly better visual outcomes after PK at the last follow-up visit (0.18 vs 0.26 LogMAR, $P < .001$), which may be due to the relatively high percentage of eyes (over 20%) that underwent manual dissection. Both study groups showed higher postoperative astigmatism (DALK, 4.36 D; PK, 4.44 D) compared to our cohort, arguably due to the use of grafts with a size smaller than that of the grafts employed in our study. Ten-year graft survival rates aligned with other authors (DALK, 93.8%; PK, 95.6%).[15]

Only a few authors performed paired-eye analyses to cf the results of lamellar and full-thickness keratoplasty techniques. Günaydın et al.[16] reported the results of 52 eyes of 26 patients who underwent big-bubble DALK in 1 eye and conventional PK in the contralateral eye, over a 3-year follow-up. The main indication was keratoconus ($n = 38$, 67.3%). At 3 years, no significant differences were observed between DALK and PK in BCVA (respectively, 0.18 vs 0.14 LogMAR; $P = .235$) and refractive astigmatism (3.36 vs 3.50 D; $P = .235$). After 2 years, ECD was significantly higher in DALK eyes compared to PK.

In a similarly designed study with smaller sample size, Kim et al. retrospectively analyzed the outcomes of 16 eyes of 8 patients who underwent DALK in one eye and conventional PK in the contralateral eye. Within a follow-up of 2 years, there was no significant difference in mean postoperative visual acuity between DALK and PK (respectively, 0.14 vs 0.13 LogMAR; $P = .870$). Refractive astigmatism was also comparable between the two techniques (3.46 vs 3.38 D; $P = .780$).[17]

Neither of these reports demonstrated significant advantages of DALK over PK, but in both studies the number of eyes was relatively small and the follow-up did not exceed 3 years.

In all these comparative studies, DALK outcomes were evaluated against those of conventional PK and not with MK. We acknowledge that MK is a technically demanding procedure. It requires a microkeratome, which may not be available in all operating rooms. Corneal surgeons unfamiliar with this technique may prefer to convert DALK into conventional PK. However, MK limits to 6.0 mm the diameter of the full-thickness part of the graft and minimizes the size of the area with higher ECL, which in a traditional 8.0 mm PK is about double as large; this may contribute to an improved long-term survival of the graft by minimizing the risk of both immunologic rejection and endothelial decay.

To the best of our knowledge, this is the first study to report a paired-eye comparison of DALK vs MK. Limitations of the study were the relatively small sample size and the retrospective design. An additional relevant bias relates to the fact that eyes were not randomly assigned to either of the two techniques but instead the choice of performing MK rather than DALK in one of the two eyes was a consequence of intraoperative macro-perforation, while attempting at performing DALK. However, the surgical technique employed for DALK after macro-perforation did not differ from that used in primary MK surgery.

In conclusion, the findings of this study mandate DALK as the procedure of choice in keratoconus patients with a healthy endothelium and adequate corneal thickness. DALK showed faster visual recovery than MK in the short-term after surgery, lower refractive astigmatism and higher postoperative ECD.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Luigi De Rosa: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrea Taloni:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Raphael Kilian:** Writing – original draft, Visualization, Validation, Investigation, Formal analysis. **Georgiana Camburu:** Visualization, Validation, Investigation. **Valentino de Ruvo:** Visualization, Validation, Investigation. **Nicolò Ciarmatori:** Visualization, Validation, Investigation. **Rossella Spena:** Visualization, Validation, Investigation. **Linda Marie Louise Busin:** Visualization, Validation, Investigation. **Cristina Bovone:** Writing – review & editing, Visualization, Validation, Supervision, Investigation. **Angeli Christy Yu:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Data curation. **Niccolò Salgari:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Massimo Busin:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Funding/Support: This study received no funding. Financial Disclosures: The authors indicate no financial support or conflicts of interest. All authors attest that they meet the current ICMJE criteria for authorship.
Declaration of competing interest: The authors have no relevant financial or non-financial interests to disclose.
Data Availability Statement: Data is available upon reasonable request by contacting Andrea Taloni, MD (email: andrea.taloni@unife.it)
Ethics Approval: Ethical approval was obtained from the local Ethics Committee (Comitato Etico della Romagna).
Informed Consent: Written informed consent was obtained from all patients before surgery.

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