Five-Year Outcomes of Ultrathin Descemet Stripping Automated Endothelial Keratoplasty

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Purpose: To report 5-year outcomes of ultrathin Descemet stripping automated endothelial keratoplasty (UT-DSAEK) with a central graft thickness intended to be <100 μm.

Methods: This retrospective, consecutive, interventional case series included 354 eyes with endothelial decompensation due to various causes (Fuchs endothelial dystrophy, pseudophakic or aphakic bullous keratopathy, failed previous graft, herpetic endothelitis, or buphthalmos). Donor tissue was prepared using the microkeratome-assisted double-pass technique aiming at a graft thickness <100 μm. The Descemet membrane was stripped under air. The graft was delivered into the anterior chamber using the pull-through technique through a 3.2-mm clear corneal incision using a modified Busin glide. The best spectacle-corrected visual acuity (BSCVA), endothelial cell loss, graft survival rates, and immunologic rejection rates were evaluated.

Results: Follow-up data at 1, 2, 3, and 5 years after UT-DSAEK were collected from 214, 172, 147, and 105 eyes, respectively. After excluding eyes with comorbidities, BSCVA better than or equal to 20/20 was recorded in 36.3%, 37.4%, 46.4%, and 53.4% of eyes, respectively, whereas BSCVA better than or equal to 20/40 was documented in 95.5%, 95.3%, 96.0%, and 96.6% of eyes, respectively. The mean endothelial cell loss was 35.4%, 42.3%, 43.3%, and 52.3%; Kaplan–Meier graft survival probability was 99.1%, 96.2%, 94.2%, and 94.2%, and Kaplan–Meier cumulative probability of a rejection episode was 3.4%, 4.3%, 5%, and 6.9% at 1, 2, 3, and 5 years, respectively.

Conclusions: UT-DSAEK grafts allow excellent 5-year outcomes, including BSCVA, endothelial cell density, and survival rates comparable with those recorded post-Descemet membrane endothelial keratoplasty, but with a higher immunologic rejection rate.

Key Words: endothelial keratoplasty, penetrating keratoplasty, ultrathin Descemet stripping automated endothelial keratoplasty

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Endothelial keratoplasty (EK) represents the gold standard for surgical treatment of eyes with endothelial failure because of undisputed advantages over penetrating keratoplasty, including faster visual recovery, minimal postoperative refractive error, and lower rates of immunologic rejection.[1,2]

Since its introduction in 1999, EK has evolved into 2 types: Descemet stripping automated endothelial keratoplasty (DSAEK) and Descemet membrane endothelial keratoplasty (DMEK). Although DSAEK was still the more popular type of EK in 2016, mainly because it is relatively easy to master, the number of DMEK procedures being performed has been increasing constantly since the first report in 2006 because this procedure allows faster visual recovery and a higher percentage of eyes with 20/20 vision, at least in the short to medium term.[3]

In 2009, ultrathin DSAEK (UT-DSAEK) was proposed as a "middle way" between the 2 techniques, combining the technical ease of DSAEK with the better visual outcomes of DMEK.[4] Theoretically, minimizing the stromal component to a thin pre-Descemetic layer could eliminate its possibly detrimental effect on vision by optimizing the shape and regularity of the graft as well as the transparency of the interface.[5] The 2-year results of this type of procedure did not differ substantially from those of DMEK, except for a somewhat slower visual recovery and a higher rate of immunologic rejection.[6] We present herein the 5-year outcomes of UT-DSAEK, including also all eyes considered in the publication of the 2-year results, and compare them with those of other EK techniques.

MATERIALS AND METHODS

Medical charts of all consecutive patients undergoing UT-DSAEK by the same surgeon (M.B.) using the

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microkeratome-assisted double-pass technique[6] at Ospedali Privati Forlì (Forlì, Italy) from January 2010 to June 2012 were reviewed.

The study followed the tenets of the 2013 Declaration of Helsinki, and approval from the ethics committee of Ospedali Privati Forlì (Forli, Italy) was obtained. Informed consent was provided by all patients undergoing UT-DSAEK. Preoperatively, all patients underwent a complete ophthalmological examination, including slit-lamp examination, evaluation of uncorrected visual acuity and best spectacle-corrected visual acuity (BSCVA), manifest refraction, applanation tonometry, funduscopy, and B-scan ultrasonography (if required).

Each patient was also scheduled for a complete ophthalmological examination at least 1, 2, 3, and 5 years post-DSAEK, including slit-lamp examination, BSCVA, manifest refraction, and applanation tonometry. Baseline donor endothelial cell density (ECD) was measured by the provider eye bank using specular microscopy. Postoperative ECD was measured using noncontact specular microscopy (EM-3000; Tomey Gmbh, Erlangen, Germany). Graft thickness at 6 months postoperatively was determined for each patient using anterior segment optical coherence tomography (OCT) (Spectralis HRA+OCT; Heidelberg Engineering, Heidelberg, Germany). Patients who did not attend their scheduled examinations were contacted by telephone and asked for the reason for their absence.

Snellen BSCVA was converted to the logarithm of the minimum angle of resolution (LogMAR). Bonferroni correction was used for multiple comparisons. Normally distributed values were reported as mean ± SD. Kaplan–Meier analysis was used to calculate the graft survival probability and cumulative probability of a rejection episode.

The details of graft preparation (double-pass technique), surgical technique, and postoperative treatment were published previously.[6] We aimed for a graft thickness <100 μm. Graft thickness was measured only after the first pass. Measurement of the graft after the second pass was not performed, so as not to cause postoperative interface infection.

RESULTS

Three hundred fifty-four UT-DSAEK procedures were performed on 348 patients during the study period. Patient demographics and indications for surgery are presented in Table 1. The different procedures performed at the time of UT-DSAEK are listed in Table 2.

One hundred forty (39.5%) eyes were excluded from the analysis of visual outcomes because of preexisting ocular comorbidities, including retinal disease (n = 58), advanced glaucoma (medically treated: n = 49; surgically treated: n = 24), and amblyopia (n = 9). Neither phakic patients who had visual significant cataracts nor eyes with significant posterior capsule opacification were excluded from the visual analysis. Follow-up data were obtained for 214, 172, 147, and 105 eyes at 1, 2, 3, and 5 years, respectively. The number of eyes included in this study as part of the 2-year UT-DSAEK study at 1, 2, 3, and 5 years was 112, 82, 71, and 65, respectively.

TABLE 1. Demographics and Indications of UT-DSAEK

Mean age ± SD (Range)	**69.8 ± 15.5 (24–90)**
Gender (Female:Male)	**210:138**
Indications for UT-DSAEK	**No. of Eyes (%)**
Fuchs dystrophy	218
Pseudophakic/aphakic corneal edema	72
Regraft	
Decompensated EK	40
Decompensated PK	19
Other	
Herpetic endothelitis	2
Posterior polymorphous dystrophy	2
Irido-corneo endothelial syndrome	1

PK, penetrating keratoplasty.

At 5 years from surgery, 42 patients had died and 67 of the remaining could not be reached.

For eyes without comorbidities, the mean BSCVA improved significantly ($P < 0.0001$) from 0.94 ± 0.75 LogMAR preoperatively to 0.11 ± 0.13 LogMAR 1 year post-DSAEK, with no significant change at the later postoperative examinations (Table 3). In addition, BSCVA ≥ 20/20 was recorded in 36.3%, 37.4%, 46.4%, and 53.4% of eyes and BSCVA ≥ 20/40 was recorded in 95.5%, 95.3%, 96%, and 96.6% of eyes at 1, 2, 3, and 5 years after UT-DSAEK, respectively.

The mean refractive cylinder increased from 1.2 ± 1.3 (range, 0–5 D) preoperatively to 1.3 ± 1.1 (range, 0–4.5 D) at 1 year postoperatively; the difference was not statistically significant ($P = 0.377$). No significant difference was observed 5 years postoperatively, with an average value of 1.1 ± 0.7 D ($P = 0.249$). In the 39 eyes that underwent stand-alone UT-DSAEK, the average spherical equivalent increased from −0.58 ± 2.45 D preoperatively to 0.19 ± 2.61 D 1 year postoperatively, resulting in a mean hyperopic shift of 0.69 ± 1.39 D (range, 0.25–2.00 D), which was not statistically significant ($P = 0.107$). The hyperopic shift decreased after 5 years to 0.22 ± 0.47 D, which was statistically significant ($P = 0.017$).

TABLE 2. Types of UT-DSAEK Procedures and/or Associated Surgeries

Type of Surgical Procedure	**No. of Eyes**
Phakic UT-DSAEK	33
UT-DSAEK in pseudophakia (PC-IOL)	182
UT-DSAEK + phaco + PC-IOL implantation	114
UT-DSAEK in aphakia	12
UT-DSAEK + pupilloplasty	6
UT-DSAEK + anterior vitrectomy	3
UT-DSAEK + AC-IOL removal + PC-IOL implantation	3
UT-DSAEK + pIOL removal + phaco + PC-IOL implantation	1

AC-IOL, anterior chamber intraocular lens; PC-IOL, posterior chamber intraocular lens; pIOL, phakic intraocular lens.

TABLE 3. BSCVA Results After UT-DSAEK in All Eyes Without Comorbidities

		BSCVA*				
	No.	Mean (LogMAR)	Mean (Snellen)	≥20/20 (% Eyes)	≥20/40 (% Eyes)	*P* (*t* Test)†
Preoperative	214	0.94 ± 0.75	20/174	0.00	3.41	
Year 1	214	0.11 ± 0.13	20/25	36.3	95.5	<0.0001
Year 2	172	0.10 ± 0.12	20/25	37.4	95.3	0.4375
Year 3	147	0.08 ± 0.13	20/24	46.4	96.0	0.1799
Year 5	105	0.09 ± 0.14	20/24	53.4	96.6	0.6468

*The results are compared with the previous year's results.
†*P* value is calculated with parametric *t* test.

Graft thickness at 6 months postoperatively was available for 58% of eyes. It averaged 74 ± 35 μm (range, 19–209 μm) and was <100 μm in 80% of the eyes and <130 μm in 94% of the eyes.

The preoperative mean ECD calculated from the eye bank values was 2523 ± 152 (range, 2100–3000 cell/mm). The mean endothelial cell loss (ECL) was 35.4% ± 11.1%, 42.3% ± 18.4%, 43.3% ± 13.9%, and 52.3% ± 9.7% at 1, 2, 3, and 5 years, respectively. If all eyes with postsurgical glaucoma were excluded, the mean ECL was not significantly increased, amounting to 34.2%, 36.5%, 41.1%, and 51.5%, respectively, at 1, 2, 3, and 5 years after UT-DSAEK.

Table 4 lists all types of complications documented during UT-DSAEK. Most complications were microkeratome-related and occurred in 29 (8.2%) of 354 donor tissue dissections performed intraoperatively.

TABLE 4. Intraoperative and Postoperative Complications of UT-DSAEK

Complication	No. of Eyes (%)
Intraoperative complications	
Microkeratome-related complication	29 (8.2%)
Tissue loss	9 (2.5%)
Hand refinement of the donor tissue	20 (5.6%)
Early postoperative complications	
Graft detachment treated with air injection	14 (3.9%)
Persistent epithelial defect	2 (0.5%)
Interface infection	2 (0.5%)
Urrets–Zavalia syndrome	1 (0.2%)
Late postoperative complications	
Cystoid macular edema	15 (4.2%)
Graft failure	14 (3.9%)
Primary failure	5 (1.4%)
Secondary failure	9 (2.5%)
Endothelial immunologic rejection	14 (3.9%)
Reversed with treatment	13 (3.6%)
Not reversed with treatment	1 (0.2%)
PCO	9 (2.5%)
Postoperative cataract	4 (1.1%)*
Persistent interface haze	2 (0.5%)

*12.1% of a total of 33 phakic eyes.
PCO, postoperative capsular opacification.

After surgery, graft detachment was seen in 14 cases (3.9%), and all graft detachments (partial and total) were managed successfully by rebubbling with air (single injection, n = 13; triple injection, n = 1) within 1 week after surgery.

Cystoid macular edema was observed on OCT in 15 cases (4.2%) during the first year after surgery. All cases were resolved with conservative medical treatment including oral acetazolamide (Diamox).

Fifteen grafts failed. Five of those grafts did not clear the cornea by the 1-month examination and were considered primary failures (1.4%). Ten additional grafts cleared primarily but showed late endothelial decompensation and had to be exchanged and thus were considered secondary failures (n = 9; 2.5%). Graft failure was caused in 1 case (0.2%) by endothelial rejection that could not be reversed with steroid treatment. None of the eyes with primary failures after UT-DSAEK that had repeat ultrathin DSAEK were included in this study.

Kaplan–Meier graft survival probability at 1, 2, 3, and 5 years was 99.1% (212/214 eyes), 96.2% (167/172 eyes), 94.2% (144/147 eyes), and 94.2% (105/105 eyes), respectively (Fig. 1). The range of follow-up within which the Kaplan–Meier graft survival probability rate was calculated is 1 to 12, 13 to 24, 25 to 36, and 37 to 60 months, in years 1, 2, 3, and 5, respectively. After excluding glaucomatous eyes, the values were 99.3%, 99.3%, 95.9%, and 95.9%, respectively. Differences in the survival rates between the groups (all eyes vs. exclusion of glaucomatous eyes) were very small if not negligible (0.2%, 3.1%, 1.7%, and 1.7% at 1, 2, 3, and 5 years, respectively). The values calculated exclusively for patients with Fuchs endothelial dystrophy were 99.4%, 99.4%, 97.4%, and 97.4%, respectively (Fig. 1).

Endothelial rejection was documented in 14 eyes (3.9%), of which 4 were in the high-risk group. All 14 eyes had 1 episode of rejection, and all rejection episodes, except 1, were reversed with corticosteroids (starting with 1 mg/kg single daily dose) and dexamethasone 1.5% eye drops (given hourly and then tapered off over a 4–6-month period of time). Kaplan–Meier cumulative probability of a rejection episode at 1, 2, 3, and 5 years was 3.4%, 4.3%, 5%, and 6.9%, respectively (Fig. 1).

DISCUSSION

Since its introduction in the late 1990s, EK has continuously evolved in surgical technique, with corresponding

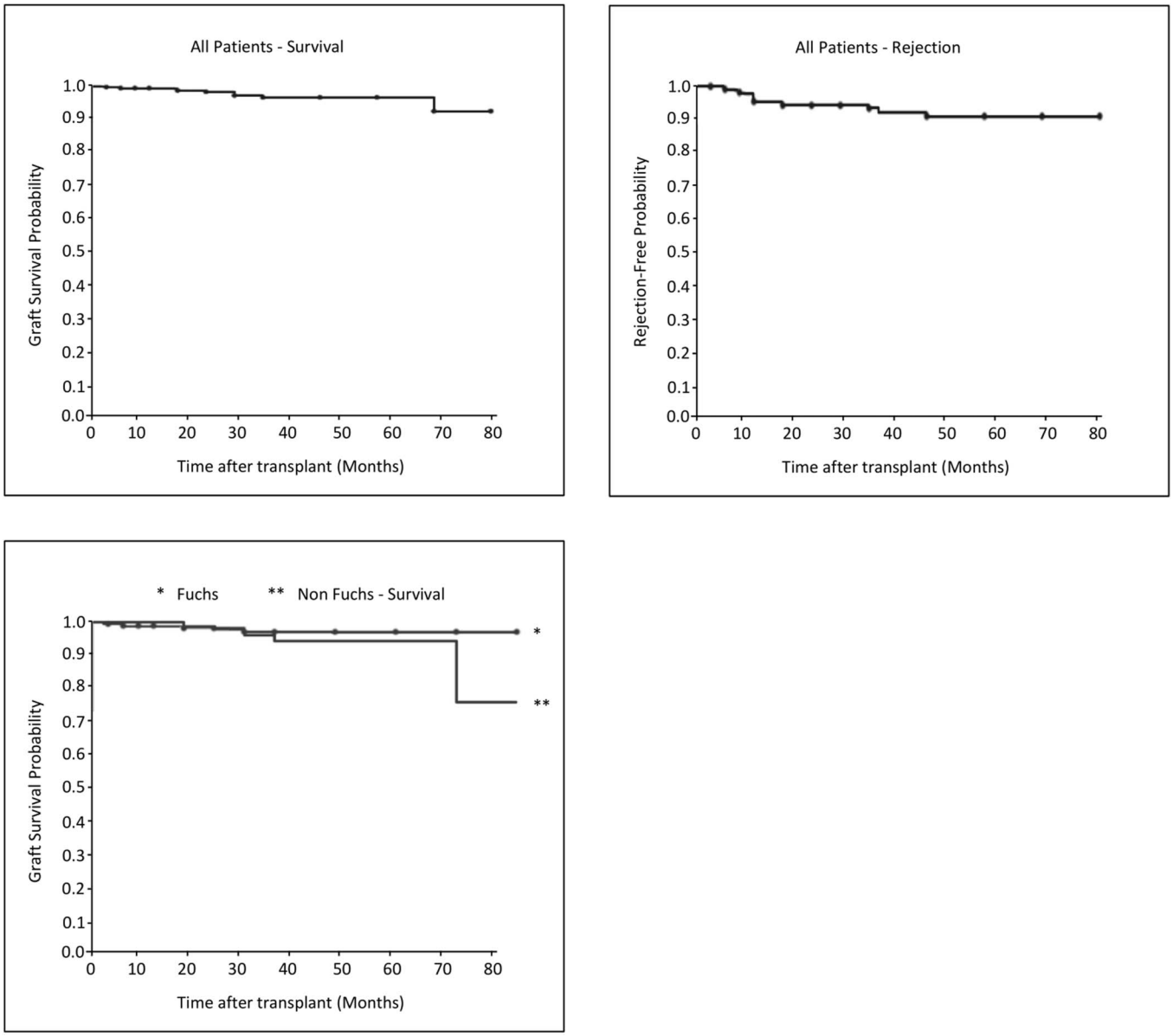

FIGURE 1. Kaplan–Meier survival curves of patients after UT-DSAEK. The upper left image shows Kaplan–Meier graft survival in all patients after UT-DSAEK. The lower left image shows Kaplan–Meier graft survival curve in patients after UT-DSAEK—Fuchs endothelial dystrophy versus non-Fuchs endothelial dystrophy patients. The upper right image shows Kaplan–Meier graft survival curve for rejection-free probability in patients after UT-DSAEK.

improvements in clinical outcomes.[1] In an attempt at maximizing postoperative visual acuity and the speed of visual rehabilitation, this evolution has taken 2 different directions. On one hand, grafts consisting of only Descemet membrane and endothelium have been used with DMEK, aiming at restoring normal corneal anatomy as the ideal condition required for best visual performance.

However, because DMEK is more demanding in both graft preparation and surgical skills, a different approach has also been attempted to optimize the structure and optical quality of the stroma of DSAEK grafts, thus eliminating possible adverse effects of this component on postoperative vision. In fact, despite the presence of the intracorneal interface, post-DSAEK 20/20 vision is achieved by a variable percentage of patients,[6–8] and the challenge has been to identify which variables determine how high this percentage can be. Neff et al[9] reported in 2011 that eyes with DSAEK grafts thinner than 131 μm achieved significantly better BSCVA than those with thicker grafts. Similarly, Terry et al[7] have shown that DSAEK grafts thinner than 100 μm allowed better BSCVA than thicker grafts. Nevertheless, the subsequent attempts at correlating central graft thickness and postoperative BSCVA have yielded contradictory results.[5] A significant correlation between graft thickness, asymmetry of the posterior corneal curvature, and lower postoperative visual acuity, as demonstrated by Dickman et al,[10] indicates

that thinner grafts cause less contour changes in the posterior surface of the host cornea and therefore minimize higher order aberrations (HOAs). In other words, there seem to be higher chances of creating asymmetry, and therefore HOAs with reduced vision, when cutting a thick DSAEK graft, whereas the "space" for asymmetry is reduced in thin or very thin grafts. This rather intuitive finding confirms the importance of the "quality" of the entire stromal component of DSAEK grafts, thus also explaining the failure of other authors trying to demonstrate a clear relationship between the central point measurement of graft thickness and visual performance.[5]

Striving for an ideal DSAEK graft, microkeratome dissection has been modified to minimize the stromal component, and the concept of UT-DSAEK has been introduced.[6] UT-DSAEK was shown to yield visual outcomes comparable with those of DMEK as early as 1 year postoperatively.[6] The better performance of thinner DSAEK grafts is confirmed in the only prospective and multicenter study published to date comparing UT-DSAEK with DSAEK[11]; within 1 year from DSAEK, ultrathin grafts (average central thickness = 101 μm) provided significantly faster visual rehabilitation than conventional grafts (average central thickness = 209 μm).

Our present data confirm the previous observation that the percentage of eyes showing recovery of 20/20 vision with UT-DSAEK grafts increases with time and exceeds 50% at 5 years postoperatively. This value is similar to those reported after DMEK[12,13] but more than double that recorded 5 years after conventional DSAEK (Table 3).[8] Instead, when considering the 20/40 visual threshold, differences of percentages among all series are negligible.

In addition, the speed of visual recovery differs substantially among the 3 methods, with DMEK maximizing the visual outcome as early as 3 months postoperatively[3,12,13] and conventional DSAEK showing a continuous significant improvement, still taking place as late as 5 years after surgery.[8] UT-DSAEK is positioned in between the previous 2, with no statistically significant improvement in BSCVA recorded later than 1 year from surgery (Table 3). This may contrast with what Chamberlain et al[14] reported; however, that randomized control trial included a small number of cases in the 2 groups (25 eyes in each group) and with only 1-year follow-up.

When considering the post-EK visual performance, another important variable is the preoperative condition of the host cornea. It has been demonstrated that anterior HOAs, mainly related to subepithelial fibrosis, can greatly affect the postoperative visual outcome[15] and are probably responsible for suboptimal vision (<20/20) in eyes with 20/20 potential.[16] It is therefore to be expected that EK performed in corneas with minimal or absent stromal changes, such as those with only central guttae in the absence of evident corneal edema, will yield optimal visual outcomes in a time shorter than that required by eyes suffering from long-standing bullous keratopathy. The different proportion of cornea guttata versus bullous keratopathy as an indication for EK introduces another variable that can strongly affect the results and mislead to conclusions possibly unrelated to the surgical method used. In fact, most DMEK series include even eyes with preoperative 20/20 vision, whereas DSAEK and UT-DSAEK series usually do not have eyes with preoperative BSCVA better than 20/30.

ECL 5 years after UT-DSAEK averaged 52.3% ± 9.7%, a value similar to that reported after conventional DSAEK by Price et al[17] (53%), Wacker et al[8] (55%), and Ang et al (48.7%),[18] similar to that reported after DMEK by Schlögl et al[13] (44%), and superior to that reported after DMEK by Ham et al[12] (34% at 6 months and then a yearly loss rate of 9%).

Previous reports have described increased ECL in glaucomatous eyes undergoing DSAEK. We did not find such a difference, maybe because of the small number of glaucomatous eyes included in this cohort.[1,2,6,19–21]

Microkeratome-related complication rate was 8.2%, with tissue loss amounting to 2.5%. Most of the tissue loss occurred in the first year because of the learning curve of the procedure. With further experience and adjustment of the lamellar dissection nomogram, the rate of complication has gradually decreased.

Intraoperative and early postoperative complications have been reported almost completely in our previous article[6] (Table 4). The most frequent complication (4.2% of eyes) was transient cystoid macular edema, which responded to conservative treatment in all cases. This rate was lower than that published recently by Kitazawa et al[22] (12.7%). Graft detachment and graft failure, both primary and secondary, were much less frequent than after conventional DSAEK[2,18,23,24] or DMEK.[3,12,25] In particular, the rebubbling rate was within 4%, that is, lower than any DMEK statistic published to date.[3] In our series, all graft detachments (partial and total) were managed with reinjection of air into the anterior chamber. In DMEK, small peripheral detachments are sometimes left to attach spontaneously.[26] Nevertheless, the rate of rebubbling in our series was still lower in comparison with these reports.[3]

The Kaplan–Meier cumulative probability of a rejection episode at 1, 3, and 5 years post-UT-DSAEK was 3.4%, 5%, and 6.9%, respectively. Anshu et al[27] have reported the cumulative probability of rejection episodes 1 and 2 years postoperatively to be 1% and 1%, respectively, for DMEK, 8% and 12%, respectively, for DSAEK, and 14% and 18%, respectively, for penetrating keratoplasty. In another series evaluating immunologic rejection post-DMEK, Hos et al[28] found that the estimated probability of a rejection episode was 0.9% by 1 year and 2.3% by 4 years post-DMEK.

From these data, it appears that immunologic rejection occurs less frequently after UT-DSAEK than after DSAEK, but the frequency is still greater than that of post-DMEK. It might be that the relatively high proportion of patients who had previous failed keratoplasty in our study contributed to this. In our study, rejection caused graft decompensation in only 1 of 14 eyes, whereas for DMEK, up to 50% graft failure rates were reported after rejection.[12]

Our study has confirmed that minimizing the thickness of the stromal component does not have any detrimental effect on graft survival. Our overall survival rate of 94.2% at 5 years after UT-DSAEK does not differ from the data published by Price et al[17] for conventional DSAEK: in particular, our cumulative probability of graft survival was

significantly higher for Fuchs patients (97.4%) than for non-Fuchs patients, again as also described previously for conventional DSAEK.[17] Finally, the survival rate of UT-DSAEK is also similar to that reported by Ham et al and by others[3,12] for DMEK. These data indicate that UT-DSAEK grafts may benefit from reduced surgical manipulation and lower rates of postoperative complications, balancing off the advantage of DMEK in immunogenicity.

A limitation of our study is the high number of patients lost to follow up, which might affect the outcomes recorded at later time points. The main reason for this was the difficulty of elderly patients to move from remote areas or even foreign countries. In an attempt at increasing our 5-year data, we contacted all patients telephonically but could only minimally increase the number of patients in comparison with the number seen at the 3-year follow-up examination. Interestingly, the main reason for skipping the 5-year follow-up examination was the patient's satisfaction with the visual outcome. Also in view of this, the percentage of eyes examined 5 years after UT-DSAEK (43.8%) appears sufficient to evaluate the overall outcome of the procedure. Another limitation is the absence of graft thickness in 42% of the eyes, which may confound the visual results. But we believe that the graft thickness in these patients is not different than that reported.[2]

In conclusion, our prospective evaluation of UT-DSAEK demonstrates that this procedure allows excellent visual outcomes comparable with those of DMEK, while minimizing the risk of complications. Visual recovery is somewhat slower than that of post-DMEK, and patients should therefore weigh this transient disadvantage against the reduced risk of secondary intervention for graft reattachment or regrafting.

REFERENCES

1. Anshu A, Price MO, Tan DTH, et al. Endothelial keratoplasty: a revolution in evolution. *Surv Ophthalmol.* 2012;57:236–252.
2. Lee WB, Jacobs DS, Musch DC, et al. Descemet's stripping endothelial keratoplasty: safety and outcomes: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2009;116:1818–1830.
3. Deng SX, Lee WB, Hammersmith KM, et al. Descemet membrane endothelial keratoplasty: safety and outcomes: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2018;125:295–310.
4. Busin M, Patel AK, Scorcia V, et al. Microkeratome-assisted preparation of ultrathin grafts for Descemet stripping automated endothelial keratoplasty. *Investig Ophthalmol Vis Sci.* 2012;53:521–524.
5. Busin M, Albé E. Does thickness matter: ultrathin Descemet stripping automated endothelial keratoplasty. *Curr Opin Ophthalmol.* 2014;25:312–318.
6. Busin M, Madi S, Santorum P, et al. Ultrathin Descemet's stripping automated endothelial keratoplasty with the microkeratome double-pass technique: two-year outcomes. *Ophthalmology*. 2013;120:1186–1194.
7. Terry MA, Straiko MD, Goshe JM, et al. Descemet's stripping automated endothelial keratoplasty: the tenuous relationship between donor thickness and postoperative vision. *Ophthalmology*. 2012;119:1988–1996.
8. Wacker K, Baratz KH, Maguire LJ, et al. Descemet stripping endothelial keratoplasty for Fuchs' endothelial corneal dystrophy: five-year results of a prospective study. *Ophthalmology*. 2016;123:154–160.
9. Neff KD, Biber JM, Holland EJ. Comparison of central corneal graft thickness to visual acuity outcomes in endothelial keratoplasty. *Cornea*. 2011;30:388–391.
10. Dickman MM, Cheng YYY, Berendschot TTJM, et al. Effects of graft thickness and asymmetry on visual gain and aberrations after Descemet stripping automated endothelial keratoplasty. *JAMA Ophthalmol.* 2013;131:737–744.
11. Dickman MM, Kruit PJ, Remeijer L, et al. A randomized multicenter clinical trial of ultrathin Descemet stripping automated endothelial keratoplasty (DSAEK) versus DSAEK. *Ophthalmology*. 2016;123:2276–2284.
12. Ham L, Dapena I, Liarakos VS, et al. Midterm results of Descemet membrane endothelial keratoplasty: 4 to 7 years clinical outcome. *Am J Ophthalmol.* 2016;171:113–121.
13. Schlögl A, Tourtas T, Kruse FE. Long-term clinical outcome after Descemet membrane endothelial keratoplasty. *Am J Ophthalmol.* 2016;169:218–226.
14. Chamberlain W, Lin CC, Austin A, et al. Descemet endothelial thickness comparison trial: a randomized trial comparing ultrathin Descemet stripping automated endothelial keratoplasty with Descemet membrane endothelial keratoplasty. *Ophthalmology*. 2019;126:19–26.
15. Patel SV, Baratz KH, Maguire LJ, et al. Anterior corneal aberrations after Descemet's stripping endothelial keratoplasty for Fuchs' endothelial dystrophy. *Ophthalmology*. 2012;119:1522–1529.
16. Dapena I, Yeh RY, Baydoun L, et al. Potential causes of incomplete visual rehabilitation at 6 months postoperative after Descemet membrane endothelial keratoplasty. *Am J Ophthalmol.* 2013, 156;780–788.
17. Price MO, Fairchild KM, Price DA. Descemet's stripping endothelial keratoplasty: five-year graft survival and endothelial cell loss. *Ophthalmology*. 2011;118:725–729.
18. Ang M, Soh Y, Htoon HM, et al. Five-year graft survival comparing Descemet stripping automated endothelial keratoplasty and penetrating keratoplasty. *Ophthalmology*. 2016;123:1646–1652.
19. Nahum Y, Mimouni M, Busin M. Risk factors predicting the need for graft exchange after Descemet stripping automated endothelial keratoplasty. *Cornea*. 2015;34:876–879.
20. Aldave AJ, Chen JL, Zaman AS, et al. Outcomes after DSEK in 101 eyes with previous trabeculectomy and tube shunt implantation. *Cornea*. 2014;33:223–229.
21. Kim P, Amiran MD, Lichtinger A, et al. Outcomes of Descemet stripping automated endothelial keratoplasty in patients with previous glaucoma drainage device insertion. *Cornea*. 2012;31:172–175.
22. Kitazawa K, Kayukawa K, Wakimasu K, et al. Cystoid macular edema after Descemet's stripping automated endothelial keratoplasty. *Ophthalmology*. 2017;124:572–573.
23. Ratanasit A, Gorovoy MS. Long-term results of Descemet stripping automated endothelial keratoplasty. *Cornea*. 2011;30:1414–1418.
24. Koenig SB, Covert DJ, Dupps WJ. Visual acuity, refractive error, and endothelial cell density six months after Descemet stripping and automated endothelial keratoplasty (DSAEK). *Cornea*. 2007;26:670–674.
25. Meisler M, Leon P, Ruzza A, et al. Graft detachment and rebubbling rate in Descemet membrane endothelial keratoplasty. *Surv Ophthalmol.* 2017;63:245–250.
26. Dirisamer M, van Dijk K, Dapena I, et al. Prevention and management of graft detachment in Descemet membrane endothelial keratoplasty. *Arch Ophthalmol.* 2012;130:280–291.
27. Anshu A, Price MO, Price FW. Risk of corneal transplant rejection significantly reduced with Descemet's membrane endothelial keratoplasty. *Ophthalmology*. 2012;119:536–540.
28. Hos D, Tuac O, Schaub F, et al. Incidence and clinical course of immune reactions after Descemet membrane endothelial keratoplasty: retrospective analysis of 1000 consecutive eyes. *Ophthalmology*. 2017;124:512–518.