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Ultrastructural findings in graft failure after Descemet membrane endothelial keratoplasty (DMEK) and new triple procedure

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Abstract

To investigate factors that influence graft failure after Descemet membrane endothelial keratoplasty (DMEK) based on transmission electron microscopy results.

Retrospective observational case series.

This single center study included 16 eyes of 16 patients with penetrating keratoplasty (n = 14) or repeat DMEK (n = 2) following graft failure after DMEK. The main outcome measures were ultrastructural changes in the explanted graft on transmission electron microscopy, best-corrected visual acuity, and central corneal thickness.

The mean preoperative and postoperative best-corrected visual acuity was 1.01 ± 0.54 logMAR and 0.56 ± 0.37 logMAR. The mean central corneal preoperative and postoperative thickness was 667 ± 187 μm and 511 ± 42 μm. Visual acuity and central corneal thickness improved significantly ($P = .001$/$P = .003$) after repeat surgery. Electron microscopy showed that 3 of 14 corneas showed upside down transplantation, and 3 corneas had pigmented cells or pigment granules at the Descemet–stroma interface. Further, 9 of 16 specimens showed a posterior collagenous layer deposited onto the Descemet membrane (average thickness 5.1 ± 6.2 μm; ranged 0.65–20 μm); this did not correlate significantly with the time between the original and repeat keratoplasty. Of 16 original grafts, 7 showed ultrastructural anomalies of the Descemet membrane, but one excised cornea showed no Descemet membrane pathologies.

The majority of eyes with graft failure after DMEK showed ultrastructural changes in the Descemet membrane. It is crucial to assess donor tissue quality and to conduct graft marking before surgery to avoid immediate or delayed graft failure after DMEK. Nevertheless, repeat keratoplasty provided significant improvement in central corneal thickness and visual acuity.

Abbreviations: ABL = anterior banded layer, BCVA = best-corrected visual acuity, CCT = central corneal thickness, DMEK = Descemet membrane endothelial keratoplasty, MAR = minimum angle of resolution, PCL = posterior collagenous layer, PEX = pseudoexfoliation syndrome, PNBL = posterior nonbanded layer, YAG = yttrium aluminum garnet.

Keywords: Descemet membrane, DMEK, graft failure, transmission electron microscopy, ultrastructural findings

1. Introduction

Descemet membrane endothelial keratoplasty (DMEK) is a relatively new and promising technique and is one of the most common methods of corneal transplantation. The DMEK procedure was first described by Melles et al[1] and represents an advancement of previous methods of posterior lamellar keratoplasty without transfer of stromal tissue. Since its development, DMEK has become a safe and thus very popular method for curing endothelial pathologies, such as Fuchs' endothelial dystrophy and bullous keratopathy, without stromal scars. The combined surgery of cataract extraction, intraocular lens implantation, and DMEK is usually called the new triple procedure, a term based on the term triple procedure that was used to describe the classic trio of cataract extraction, intraocular lens implantation, and penetrating keratoplasty.

In 2016, 57% of the corneal transplantations performed in Germany were posterior lamellar keratoplasties (90% DMEK).[2] The advantages of DMEK are its short surgical time, quick visual recovery, low risk of graft rejection, and little change in refraction.[3,4] Its disadvantages are the unpredictability of graft adhesion,[5,6] possible failure in graft preparation,[7,8] difficulties in graft unfolding (especially in young donors),[9] and damage to endothelial cells due to intraoperative iatrogenic maneuvers.

The purpose of this retrospective single-center study was to investigate factors that might influence graft failure after DMEK and the new triple procedure based on an ultrastructural analysis of explanted grafts.

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2. Material and methods

This single-center observational study included 16 eyes of 16 patients (mean age, 70 ± 9 years; 7 women, 9 men). The patients underwent repeat DMEK (n = 2) or penetrating keratoplasty (n = 14) at the Department of Ophthalmology, Saarland University Medical Center UKS, Homburg/Saar because of graft failure after DMEK (n = 11) or after new triple procedure (n = 5). Of the 16 patients, 8 were referred to us by external ophthalmic surgeons. The excised DMEK grafts (n = 2) and host corneas (n = 14) were examined by transmission electron microscopy at the Department of Ophthalmology, Friedrich-Alexander-University Erlangen-Nürnberg, Erlangen, Germany.

The study complied with the tenets of the Declaration of Helsinki. The Institutional Review Board waived the need for approval. Written informed consent was obtained from all patients. The patients underwent complete ophthalmological examinations, including Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany).

The main outcome measures included an indication for repeat keratoplasty, pre- and postoperative best-corrected visual acuity, pre- and postoperative central corneal thickness, (CCT, Pentacam) and ultrastructural findings.

2.1. Transmission electron microscopy

The explanted DMEK grafts (n = 2) and corneal buttons (n = 14) were processed for electron microscopy as previously described[10] and examined with a transmission electron microscope (EM 906E; Carl Zeiss Microscopy, Oberkochen, Germany). The tissues were examined for ultrastructural anomalies, including irregularities of the anterior banded layers and posterior nonbanded layers, and for the presence/thickness of a posterior collagenous layer (PCL) as well as orientation of the transplant.

2.2. Statistical analysis

The descriptive statistical analysis was performed using IBM SPSS Statistics 20.0 (IBM Corp., Armonk, NY), and data were reported as averages with standard deviations (minimums and maximums). Preoperative and postoperative visual acuity were compared using the non-parametric paired Wilcoxon test. The thickness of the PCL was correlated with the time period after primary surgery using bivariate correlation. Differences with $P \leq .05$ were considered statistically significant.

3. Results

The indication for initial DMEK or new triple procedure were Fuchs' endothelial corneal dystrophy in 9 eyes, bullous keratopathy in 5 eyes, posterior polymorphous corneal dystrophy in one eye, and cornea plana in one eye.

The indication for repeat keratoplasty was primary graft failure in 9 patients within 9 ± 4 months of the graft (Table 1). In these patients, the cornea became never clear after DMEK (n = 6) or after a new triple procedure (n = 3). The indication was secondary graft failure in 2 patients within 25 and 29 months, respectively. In these 2 patients, after initial clearing, the cornea again showed edema and/or scarring. In most cases of graft failure, we decided to perform penetrating keratoplasty because of corneal scarring. In 2 cases, there was no corneal scarring; thus, repeat DMEK could be performed.

Immunologic graft rejection was seen in 5 patients after 1, 2, 4, 6, and 11 months, respectively. The average preoperative best-corrected visual acuity was 1.0 ± 0.54 logMAR, and the average postoperative best-corrected visual acuity was 0.56 ± 0.38 logMAR one year after surgery. The mean preoperative CCT was 667 ± 187 μm (range 461–1073 μm). The average postoperative CCT was 511 ± 42 μm (range 426–563 μm). Postoperative visual acuity improved significantly after repeat surgery compared to the preoperative value ($P = .001$). The CCT decreased significantly after repeat surgery ($P = .003$).

Electron microscopy analysis found that in 3 of 14 corneal specimens, upside down transplantation was the obvious cause of primary graft failure, as evidenced by apposition of the posterior nonbanded layer of the donor Descemet membrane to the recipient's stroma (Fig. 1A and B). Pigmented cells or isolated pigment granules were observed in the Descemet–stroma interface in 3 corneas, which resulted in poor adhesion and focal detachment of the grafts (Fig. 1C and D). In 1 case, abnormal pigmentation was also documented by histology (Fig. 2B).

In 9 of 16 specimens, there was an abnormal PCL of variable thickness (0.65–20 μm), and this was sometimes covered by degenerated fibroblast-like endothelial cells (Fig. 3A and B). This layer consisted of loosely arranged collagen fibers that were deposited onto the posterior surface of the Descemet membrane, and it provides circumstantial evidence of peri- and postoperative damage to endothelial cells.[10] Retrocorneal collagenous tissue was also seen during histological examination in 1 case (Fig. 2A). The mean thickness of this PCL was 5.1 ± 6.2 μm (range 0.65–20 μm). There was no obvious correlation between the thickness of the PCL and the time to repeat surgery ($P = .73$) (Fig. 4).

Intrinsic ultrastructural abnormalities of the Descemet membrane were observed in 7 of 16 grafts; this included abnormal banded and fibrillary collagen inclusions within the normally non-banded posterior layer, which is indicative of pre-existing corneal endothelial dysfunction (Fig. 3B–D).[10] Abnormal fibrillary inclusions and posterior deposition of collagen fibers were also found in some of the specimens (Fig. 3B). Of the 7 specimens, 1 showed signs of beginning guttae formation, indicating the presence of early stages of Fuchs' dystrophy in the donor (Fig. 3D). Only 1 of 16 specimens showed no abnormalities of the Descemet membrane.

4. Discussion

Donor graft preparation, a successful surgical procedure, and a lack of postoperative complications[10] are crucial for the success of DMEK. Complications in any surgical step can lead to primary or secondary graft failure.

Of the 16 specimens that we analyzed, 3 showed upside down transplantation that led to graft failure. We strongly recommend presurgical marking of the donor Descemet membrane to avoid this complication.[11,12] We think that the need for numerous failing re-bubbling procedures may be a strong sign of upside down transplantation.

Studies show that graft failure after DMEK occurs in 1.6% to 8% of patients.[13–15]

The majority of patients with primary or secondary graft failure show ultrastructural anomalies of the donor Descemet membrane, including intrinsic abnormal inclusions in the Descemet membrane and/or posterior collagenous layers deposited onto the membrane.[5,16] Abnormal inclusions within the Descemet membrane may reflect pre-existing subclinical endothelial dysfunction prior to

Table 1

Characteristics of the 16 patients in this study.

Patient	Age, years	Gender	Type of surgery	Indication for initial DMEK/new triple DMEK	Number of Re-Bubblings	BCVA preoperative (decimal)	BCVA postoperative (decimal)	Pachymetry preoperative (μm)	Pachymetry postoperative (μm)	Date of repeat surgery	Indication for surgery	Type of repeat surgery	Time to repeat surgery, months	Results of electron microscopy	Thickness of PCL (μm)
1	63	Female	New triple DMEK 02/2015 "in home"	Fuchs' endothelial corneal dystrophy	2	0.4	0.5	n.a.	536	04/2015	Primary graft failure	PKP	2	Upside-down transplantation	
2	80	Male	New triple DMEK 01/2015 "in home"	Fuchs' endothelial corneal dystrophy	3	0.3	0.8	565	504	04/2015	Primary graft failure	PKP	9	Degenerated endothelial cells, abnormal PCL	0.65
3	83	Male	DMEK 01/2015 Repeat DMEK 02/2015 "elsewhere"	Bullous keratopathy after glaucoma surgery	n.a.	0.16	0.16	682	563	12/2015	Primary graft failure	PKP	10	Pigmented cells in the interface (PEX)	
4	75	Male	DMEK 10/2015 "in home"	Posterior polymorphous corneal dystrophy	1	0.1	0.5	n.a.	n.a.	06/2016	Immunologic rejection (after 1 month)	PKP	8	Abnormal PCL, Pigmented granules in the Interface	1.5
5	67	Male	New triple DMEK 07/2014 "elsewhere"	Fuchs' endothelial corneal dystrophy	1	0.5	0.8	n.a.	n.a.	12/2016	Secondary graft failure	Repeat DMEK	29	Degenerated endothelial cells	
6	79	Female	DMEK 01/2015 "elsewhere"	Bullous keratopathy after glaucoma surgery	1	0.01	0.3	1025	515	06/2016	Primary graft failure	PKP	18	Abnormal PCL, degenerated endothelial cells	9.0
7	68	Female	New triple DMEK 12/2014 "elsewhere"	Fuchs' endothelial corneal dystrophy	1	0.04	0.8	1073	549	08/2015	Primary graft failure	PKP	9	Thick abnormal PCL, degenerated endothelial cells	3.75
8	67	Male	DMEK 04/2015 "elsewhere"	Fuchs' endothelial corneal dystrophy	n.a.	0.2	0.3	509	476	01/2016	Primary graft failure	PKP	9	Normal Descemet's membrane	
9	85	Female	DMEK 06/2015 "in home"	Pseudophakic bullous keratopathy	3	0.1	0.1	607	542	04/2016	Primary graft failure	PKP	10	Thick abnormal PCL	20.0
10	70	Male	1. new triple DMEK 01/2013 2. DMEK 10/2015 3. Repeat DMEK 10/2015 "elsewhere"	Fuchs' endothelial corneal dystrophy	n.a.	0.3	0.6	674	426	04/2016	Primary graft failure	PKP	6	Upside-down transplantation	
11	56	Female	New triple DMEK 07/2014 "elsewhere"	Cornea plana, Axenfeld-Rieger syndrome	n.a.	0.05	0.2	665	543	08/2016	Secondary graft failure	PKP	25	Thick abnormal PCL	4.25
12	76	Male	DMEK 05/2016 "in home"	Pseudophakic bullous keratopathy	n.a.	n.a.	0.05	660	511	09/2017	Primary graft failure	PKP	8	Thick abnormal PCL, Pigment in the interface	3.5
13	64	Male	DMEK 11/2015 "in home"	Fuchs' endothelial corneal dystrophy	n.a.	0.01	0.25	473	455	01/2017	Immunologic rejection	Repeat DMEK	13	Thick Descemet's membrane, thin abnormal PCL, Degenerated endothelial cells	0.9
14	81	Male	DMEK 11/2014 "elsewhere"	Fuchs' endothelial corneal dystrophy	n.a.	0.3	0.4	461	476	02/2017	Immunologic rejection	PKP	39	Thin abnormal PCL, fibroblastic endothelial cells, pigment granules	1.9
15	52	Female	DMEK 07/2016 "in home"	Bullous keratopathy congenital glaucoma	n.a.	0.05	0.1	580	550	02/2017	Primary graft failure	PKP	7	Upside-down transplantation	
16	76	Female	1. DMEK 09/2013 2. Repeat DMEK 04/2015 "elsewhere"	Fuchs' endothelial corneal dystrophy	n.a.	0.05	0.1	696	n.a.	01/2018	Immunologic rejection	PKP	21	Pigmented cells, degenerated endothelial cells	

BCVA = best-corrected visual acuity, DMEK = Descemet membrane endothelial keratoplasty, PCL = posterior collagenous layer, PEX = pseudoexfoliation syndrome, PKP = penetrating keratoplasty.

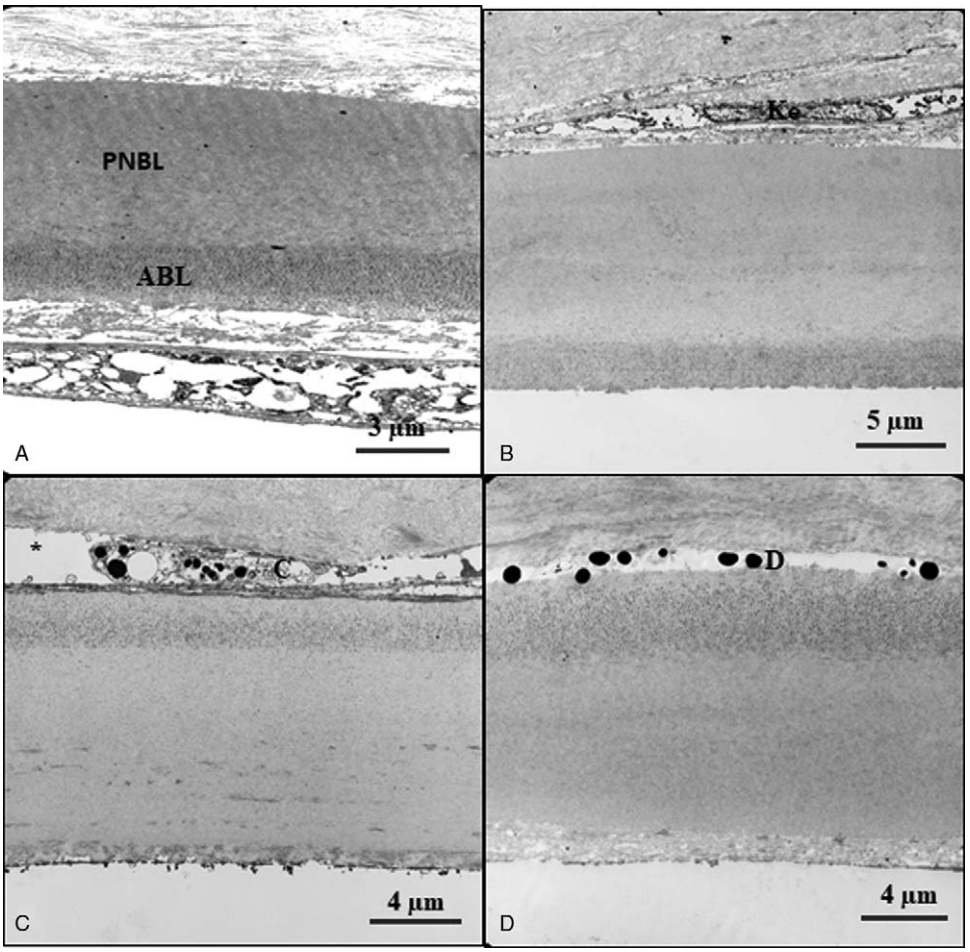

Figure 1. Transmission electron micrographs of explanted corneal buttons after DMEK failure. (A, B) Inverted transplantation: the posterior nonbanded layer (PNBL) of the donor graft adjoines the host corneal stroma, whereas the anterior banded layer (ABL) of the Descemet membrane borders the anterior chamber or is overgrown by stromal keratocytes (Ke). (C, D) The accumulation of pigmented cells (C) or isolated pigment granules (D) in the Descemet-stromal interface (*). ABL = anterior banded, DMEK = Descemet membrane endothelial keratoplasty, PNBL = posterior nonbanded layer.

transplantation, whereas retrocorneal collagen deposits and fibroblast-like endothelial cells indicate peri- and postoperative endothelial damage.[10]

Ultrastructural changes with abnormal banded and fibrillary collagen inclusions (like a duplicated anterior banded layer within the posterior nonbanded layer in Fig. 3B) within the

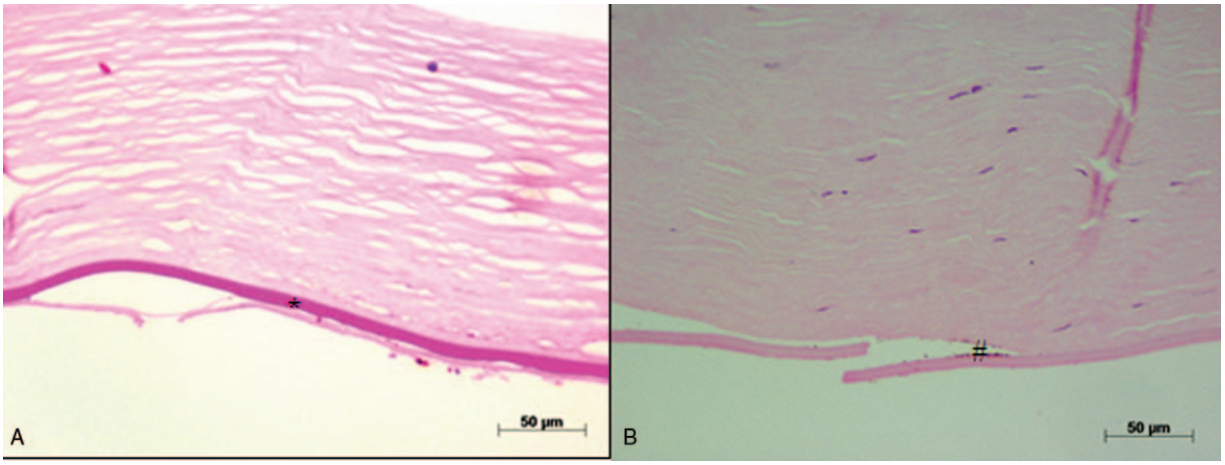

Figure 2. Histological findings in graft failure after DMEK. (A) Retrocorneal collagenous tissue (*) and (B) pigmented tissue (#) at the interface. The break in the Descemet membrane is an artifact. DMEK = Descemet membrane endothelial keratoplasty.

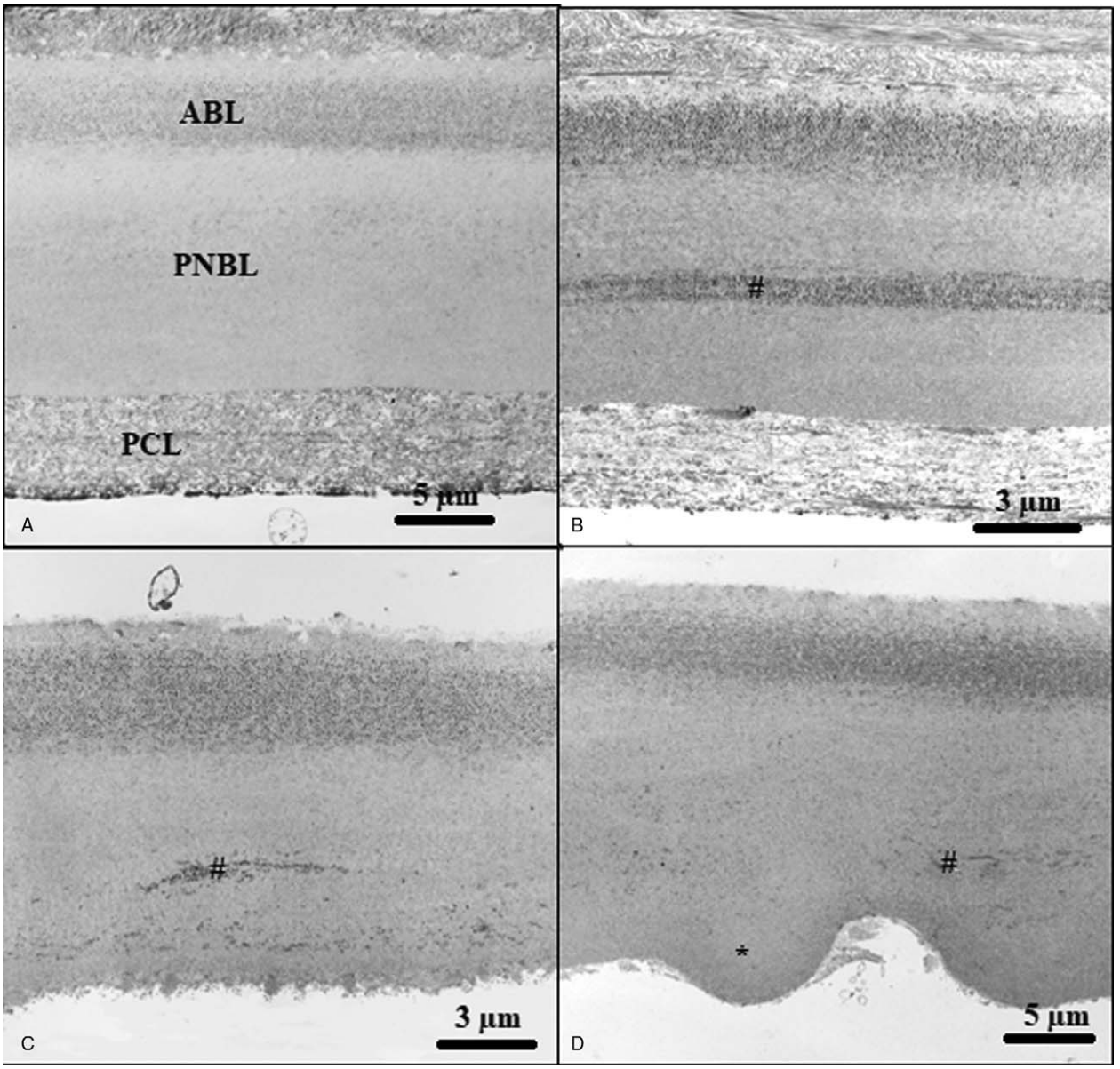

Figure 3. Transmission electron micrographs of explanted corneal buttons or Descemet membranes after DMEK failure. (A) Deposition of a posterior collagenous layer (PCL) onto Descemet's membrane consisting of a normal anterior banded (ABL) and posterior non-banded layer (PNBL). (B) In addition to a PCL, abnormal banded material (#) can be seen within the PNBL. (C) Abnormal banded material inclusions (#) within the PNBL in the absence of a PCL. (D) Abnormal fibrillary inclusions (#) and guttae-like formations (*) of the PNBL. ABL = anterior banded, PCL = posterior collagenous layer, PNBL = posterior nonbanded layer.

normally nonbanded posterior layer may also be a sign of incomplete removal of recipient's Descemet membrane. Brockmann et al[6] found that incomplete removal of the Descemet membrane from the recipient's stroma can increase the detachment rate. They discovered an increased thickness of the anterior banded layer in patients with graft detachment and concluded that residual anterior banded layer fragments on the recipients' stroma can create an anatomical border.[6]

Ultrastructural changes observed in a donor Descemet membrane may be preexisting or may be acquired during tissue harvesting, tissue storage, graft preparation, or surgery. Weller et al[10] also concluded that ultrastructural anomalies can be signs of preoperative corneal endothelial dysfunction. The donor tissue we used did not show any noticeable problems during examination in our eye bank. However, the presence of early stages of pseudoexfoliation-associated keratopathy and cornea guttata may have gone undetected.

Of the 16 specimens, 9 showed an abnormal PCL. Weller et al[10] postulated that a PCL may be indicative of intraoperative or postoperative trauma and is thought to be produced by damaged, fibroblast-like endothelial cells. In our study, there was no mathematical correlation between the thickness of the abnormal PCL (which ranged from 0.65 to 20 µm) and the time period until repeat surgery (which ranged from 2 to 39 months). However, this could be due to the small number of cases. In our case series, we could not evaluate potential risk factors during organ culture, graft preparation, or intraoperative manipulation in all patients, because 8 of the patients were referred to our department from other hospitals.

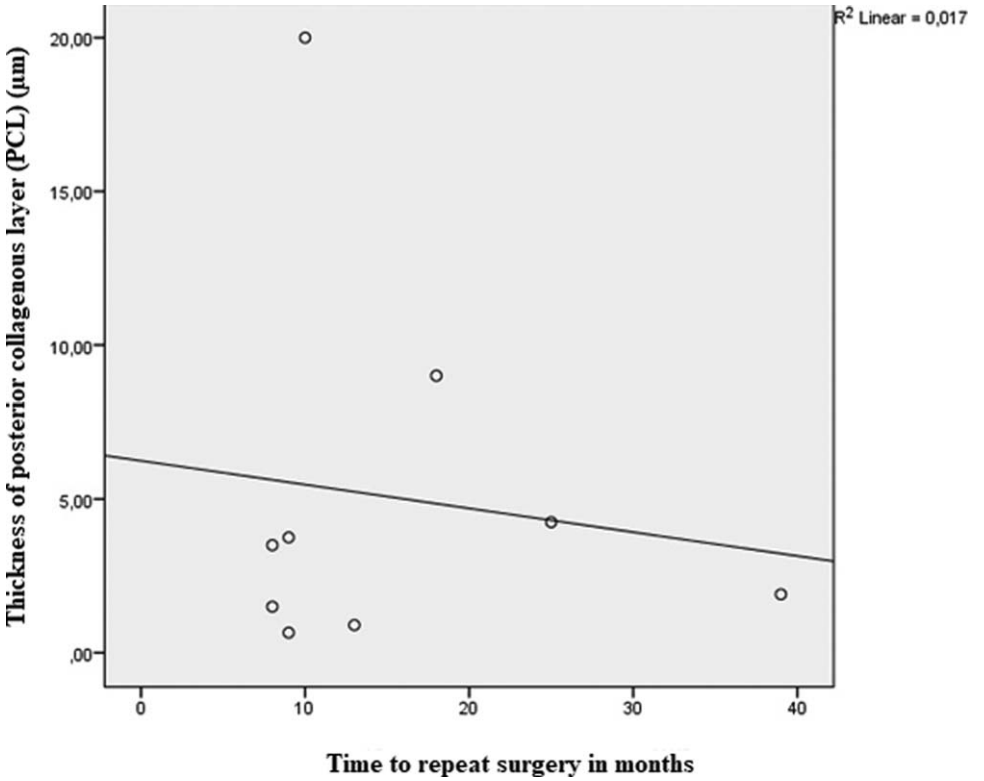

Figure 4. Regression analysis of the thickness of the posterior collagenous layer (PCL) (μm) (*y*-axis) and the time to repeat surgery in months (*x*-axis). There was no correlation between the thickness of the collagenous layer and the time to repeat surgery. PCL = posterior collagenous layer.

Important indicators for graft preparation and unfolding include donor age, the presence of diabetes mellitus, previous phacoemulsification of the donor, and storage medium during organ culture.[7,9,10] The storage medium may also influence the detachment rate.[17] Heinzelmann et al[18] discussed storage in dextran as a risk factor for ultrastructural anomalies that could lead to primary graft failure after DMEK, especially in precut tissues, but the study only included 11 eyes. We also found that dextran in prestripped tissue had a negative impact on graft survival because there was a higher rate of repeat keratoplasty after DMEK when the tissues were stored in culture medium with dextran.[19] On the other hand, Yoeruek and Bayyoud reported only a moderate loss of endothelial cells in precut tissue and safe donor graft preparation with or without dextran.[20,21] Parekh et al[22] concluded that dextran should be used in precut tissues to prevent the loss of endothelial cells.

We think that the presence of pigment granules in the interface may decrease adhesion between the donor graft and recipient stroma. Pseudoexfoliation or pigment dispersion syndrome, both of which are associated with pigment liberation from the iris pigment epithelium, may cause pigment accumulation in the interface. However, further investigations in a larger study population are required. Peri-operative YAG iridotomy is another potential source of pigment, so we now perform YAG iridotomy at the 6 o'clock position many weeks before DMEK rather than the day before surgery.[23] This may help avoid pigment dispersion during DMEK surgery.

To summarize, major causes of graft failure include previously undetected endothelial dysfunction or disease in the donor, endothelial damage during surgery, or surgical mistakes, such as inverted transplantation and damage to iris tissue, that results in the accumulation of pigmented cells or pigment granules in the Descemet–stroma interface, resulting in poor graft adhesion.[10,16,24]

After repeat surgery, postoperative visual acuity improved significantly in all of our patients, and central cornea thickness decreased significantly. We conclude that repeat penetrating keratoplasty and repeat DMEK can lead to satisfactory functional results after failed DMEK and new triple procedure.

This study had some limitations, in that it was a retrospective study with a small number of cases. Prospective studies are warranted, including a larger case series, especially to investigate the culture conditions (e.g. role of dextran) to strengthen the interpretation of our results. A better understanding of graft failure may help in the development of preventive methods in the future.

Author contributions

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Validation: Achim Langenbucher, Berthold Seitz.

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References

[1] Melles GR, Ong TS, Ververs B, et al. Descemet membrane endothelial keratoplasty (DMEK). Cornea 2006;25:987–90.
[2] Flockerzi E, Maier P, Böhringer D, et al. Trends in corneal transplantation from 2001 to 2016 in Germany: a report of the DOG-section cornea and its keratoplasty registry. Am J Ophthalmol 2018;188:91–8.
[3] Röck T, Bartz-Schmidt KU, Röck D, et al. Refractive changes after Descemet membrane endothelial keratoplasty. Ophthalmologe 2014;111:649–53.
[4] Li S, Liu L, Wang W, et al. Efficacy and safety of Descemet's membrane endothelial keratoplasty versus Descemet's stripping endothelial keratoplasty: a systematic review and meta-analysis. PLoS One 2017;12:12epub, doi://10.1371/journal.pone.0182275.
[5] Cirkovic A, Schlötzer-Schrehardt U, Weller JM, et al. Clinical and ultrastructural characteristics of graft failure in DMEK: 1-year results after repeat DMEK. Cornea 2015;34:11–7.
[6] Brockmann T, Brockmann C, Maier AK, et al. Clinicopathology of graft detachment after Descemet's membrane endothelial keratoplasty. Acta Ophthalmol 2014;92:e556–61.
[7] Greiner MA, Rixen JJ, Wagoner MD, et al. Diabetes mellitus increases risk of unsuccessful graft preparation in Desemet membrane endothelial keratoplasty: a multicenter study. Cornea 2014;33:1129–33.
[8] Schlötzer-Schrehardt U, Bachmann BO, Laaser K, et al. Characterization of the cleavage plane in Descemet's membrane endothelial keratoplasty. Ophthalmology 2011;118:1950–7.
[9] Heinzelmann S, Hüther S, Böhringer D, et al. Influence of donor characteristics on Descemet membrane endothelial keratoplasty. Cornea 2014;33:644–8.
[10] Weller JM, Schlötzer-Schrehardt U, Tourtas T, et al. Influence of ultrastructural corneal graft abnormalities on the outcome of Descemet membrane endothelial keratoplasty. Am J Ophthalmol 2016;169:58–67.
[11] Matsuzawa A, Hayashi T, Oyakawa I, et al. Use of four asymmetric marks to orient the donor graft during Descemet's membrane endothelial keratoplasty. BMJ Open Ophthalmol 2017;1:e000080.
[12] Bachmann BO, Schrittenlocher SA, Schaub F, et al. Complications of DMEKeratoplasty: Avoid, recognize and treat. Klin Monbl Augenheilkd 2017;234:1354–61.
[13] Quilendrino R, Rodriguez-Calvo de Mora M, Baydoun C, et al. Prevention and management of Descemet membrane endothelial keratoplasty complications. Cornea 2017;36:1089–95.
[14] Peraza-Nieves J, Baydoun L, Dapena I, et al. Two-year clinical outcome of 500 consecutive cases undergoing Descemet membrane endothelial keratoplasty. Cornea 2017;36:655–60.
[15] Guerra FP, Anshu A, Price MO, et al. Descemet's membrane endothelial keratoplasty: prospective study of 1-year visual outcomes, graft survival and endothelial cell loss. Ophthalmology 2011;118: 2368–73.
[16] Ham L, van der Wees J, Melles GRF. Causes of primary donor failure in Descemet membrane endothelial keratoplasty. Am J Ophthalmol 2008;145:639–44.
[17] Laaser K, Bachmann BO, Horn FU, et al. Donor tissue culture conditions and outcome after Descemet membrane endothelial keratoplasty. Am J Ophthalmol 2011;151:1007–18.
[18] Heinzelmann S, Böhringer D, Eberwein P, et al. Graft dislocation and graft failure following Descemet membrane endothelial keratopasty (DMEK) using precut tissue: a retrospective cohort study. Graefes Arch Clin Exp Ophthalmol 2017;255:127–33.
[19] Abdin A, Daas L, Pattmöller M, et al. Negative impact of dextran in organ culture media for pre-stripped tissue preservation on DMEK (Descemet membrane endothelial keratoplasty) outcome. Graefes Arch Clin Exp Ophthalmol 2018;256:2135–42.
[20] Yoeruek E, Hofmann J, Bartz-Schmitz KU. Comparison of swollen and dextran deswollen organ-cultured corneas for Descemet membrane dissection preparation: Histological and ultrastructural findings. Invest Ophthalmol Vis Sci 2013;54:8036–40.
[21] Bayyoud T, Röck D, Hofmann J, et al. Precut technique for Descemet's membrane endothelial keratoplasty, preparation and storage in organ culture. Klin Monbl Augenheilkd 2012;229:621–3.
[22] Parekh M, Ruzza A, Ferrari S, et al. Preservation of preloaded DMEK lenticules in dextran and non-dextran-based organ culture medium. J Ophthalmol 2016;2016:5830835.
[23] Seitz B, Daas L, Bischoff-Jung M, et al. Anatomy-based DMEK wetlab in Homburg/Saar: Novel aspects of donor preparation and host maneuvers to teach Descemet membrane endothelial keratoplasty. Clin Anat 2018;31:16–27.
[24] Yoeruek E, Hoffmann J, Bartz-Schmidt KU. Histological and ultrastructural findings of corneal tissue after failed Descemet membrane endothelial keratoplasty. Acta Ophthalmol 2014;92:213–6.