Survey of Ophthalmology 69 (2024) 427–434

Contents lists available at ScienceDirect

Survey of Ophthalmology

journal homepage: www.elsevier.com/locate/survophthal

Review article

Hitting the refractive target in corneal endothelial transplantation triple procedures: A systematic review

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ARTICLE INFO

Keywords:
Cataract surgery
Descemet's membrane endothelial keratoplasty
Descemet's stripping automated endothelial keratoplasty
Triple procedure
Refractive error
IOL power calculation

ABSTRACT

In phakic patients Descemet stripping automated endothelial keratoplasty (DSAEK) or Descemet membrane endothelial keratoplasty (DMEK) are frequently combined with phacoemulsification and intraocular lens (IOL) implantation (triple procedure). This surgery might cause a refractive shift difficult to predict. Early DMEK and DSAEK results have shown a tendency toward a hyperopic shift. Myopic postoperative refraction is typically intended to correct this postoperative refractive defect and to bring all eyes as close to emmetropia as possible. We sought to understand the mechanism underlying the hyperopization and to identify predictive factors for poorer refractive outcomes, the most suitable target refraction and IOL calculation methods in patients undergoing combined cataract extraction and lamellar endothelial corneal transplantation (DSAEK or DMEK) for endothelial dysfunctions. Of the 407 articles analyzed, only 18 were included in the analysis. A myopic target between −0.50 D and −0.75 was the most common (up to −1.50 for DSAEK triple procedures), even though no optimum target was found. Hyperopic surprises appeared more frequently in corneas that were flatter in the center than in the periphery (oblate posterior profile). Among the numerous IOL calculation formulas, there was no apparent preference.

1. Introduction

The endothelium, the cornea's deepest layer, consists of a monolayer of hexagonal cells derived from the neural crest. Its primary function is to maintain the status of corneal deturgescence, ensuring corneal transparency. The endothelial cell count steadily declines from the intrauterine stage till death. It is commonly acknowledged that endothelial cell loss happens at a rate of 0.6% annually. This process can be accelerated by primary or secondary corneal endotheliopathies, such as Fuchs endothelial corneal dystrophy (FECD) or corneal endothelial trauma respectively.[38] Cataract surgery represents a major cause of endothelial damage. If surgery is performed on eyes with a corneal endothelial cell density (ECD) of less than 1000 cells/mm^2, the patient is exposed to an increased risk of subsequent corneal decompensation. To avoid this complication, a combined procedure of cataract extraction, intraocular lens (IOL) insertion, and lamellar endothelial corneal transplantation, is frequently recommended.[24] The triple procedure refers to this combined surgery. Patients scheduled for a triple procedure have high expectations of visual recovery; however, accurate IOL power calculation and predictable refractive results can be difficult to achieve. Indeed, the posterior lamellar graft may alter the corneal power computed before surgery to calculate the proper IOL power.[16,31,46] Descemet stripping automated endothelial keratoplasty (DSAEK) and Descemet membrane endothelial keratoplasty (DMEK) are the two most common types of endothelial lamellar keratoplasty. Both techniques have been associated with an unintended hyperopic shift. The main source of the refractive hyperopic shift has been recognized as changes in the posterior corneal curvature.[1,10,25,30,43] In these procedures, the patient's Descemet membrane and endothelium are selectively removed, followed by donor lenticule transplantation. The DSAEK lenticule includes a portion of the posterior corneal stroma and it is generally thicker than in DMEK, measuring nearly 100–200 μm.[18] In DMEK, the graft tissue has a thickness of 10–15 μm, including only endothelium and Descemet membrane.[32,39] The purpose of this systematic review was to identify predictive factors for poorer refractive outcomes, the most appropriate target refraction, and IOL calculation methods in patients undergoing combined cataract extraction and lamellar endothelial corneal transplantation (DSAEK or DMEK) for endothelial dysfunctions.

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https://doi.org/10.1016/j.survophthal.2024.01.003
Received 22 August 2023; Received in revised form 24 January 2024; Accepted 30 January 2024
Available online 2 February 2024

2. Methods

This systematic review was conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[36] The review protocol was not recorded, and no registration number is available for consultation. We performed a systematic search for all available articles exploring corneal changes, the target refraction and/or IOL calculation methods in cases of combined cataract extraction and lamellar endothelial corneal transplantation (DSAEK or DMEK) for endothelial dysfunction. For studies including lamellar endothelial corneal transplantation with and without cataract extraction, only articles having distinct findings for each group were evaluated. A literature search of all original articles published up to July, 2022, was performed in parallel by three authors (A.L.V., S.M. and A.G.) using the PubMed database.

Furthermore, the reference lists of all identified articles were examined manually to identify any potential study not captured by the electronic searches. After the preparation of the list of all electronic data captured, 3 reviewers (A.L.V., S.M. and A.G.) examined the titles and abstracts independently and selected relevant articles identified by the initial search using Rayyan QCRI Software. The full texts of the relevant articles were then analyzed, and the bibliography of eligible articles was assessed to identify any study not obtained through electronic search.

Only original studies on adults were included in the current review. Exclusion criteria were review studies, pilot studies, case reports, letters, photo essays, and studies written in languages other than English. Articles dealing with animal models and/or pediatric patients were excluded as well. Automated topography and tomography have shown comparable or even better results than manual keratometry while being less time-consuming.[28] Thus articles including manual keratometry were excluded. The same reviewers registered and selected the captured studies according to the inclusion and exclusion criteria by examining the full text of the articles. Any disagreement was assessed by consensus, and a fourth reviewer (R.G.) was consulted when necessary. No effort was made to contact the corresponding authors for further unpublished data. The level and quality of evidence of the selected studies were evaluated based on the Oxford Center for Evidence-Based Medicine (OCEM) 2011 guidelines[37] and the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system,[21] respectively.

3. Results

The results are summarized in a flow diagram according to PRISMA guidelines (Fig. 1). Of the initially extracted 407 articles, 36 abstracts met the inclusion/exclusion criteria for full-text review. Two additional articles included in the analysis were derived from the selective review of the list of references during the full-text review of the original articles (Fig. 1). After full-text reading 18 articles were excluded because of the following reasons: triple procedures were not included, early graft failure was included, data between triple procedure and endothelial keratoplasty only were not divided, and use of manual keratometry. Studies' characteristics, main results, level, and grade of the available evidence are summarized in Supplementary Material Table 1 for DSAEK and Supplementary Material Table 2 for DMEK. No data synthesis was possible because of the heterogeneity of available data and the design of the available studies. Thus, the current review reports a qualitative analysis, narratively detailed issue-by-issue below.

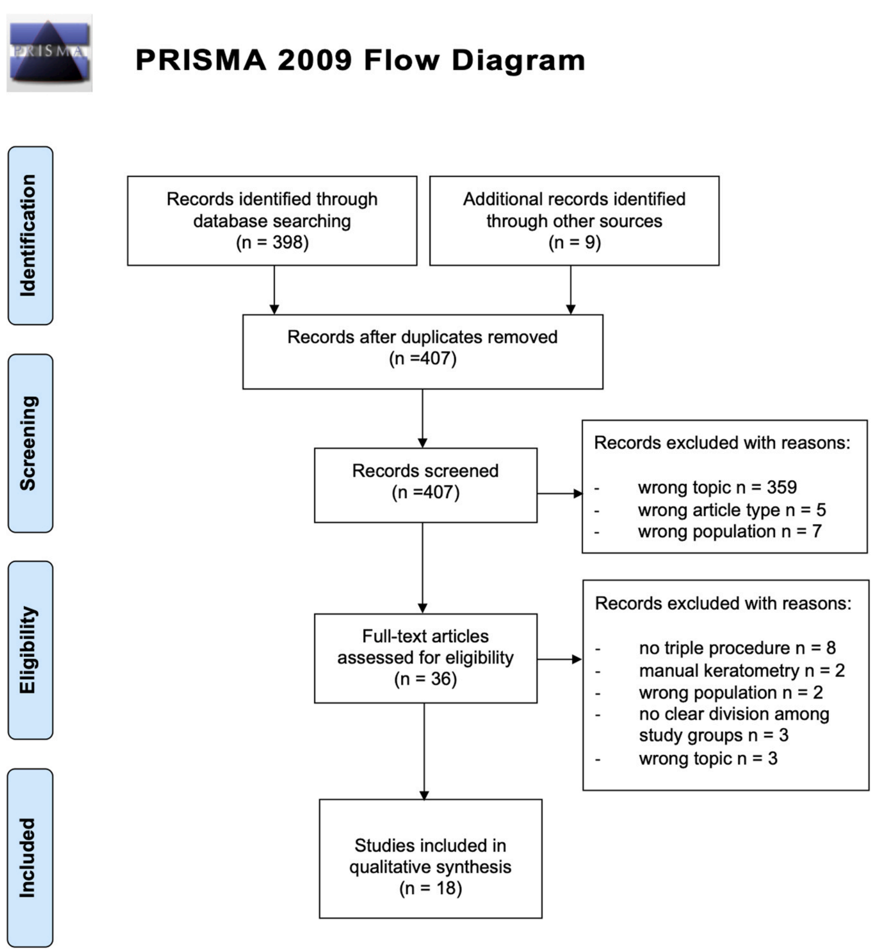

Fig. 1. PRISMA flow chart. Flow diagram of the study according to PRISMA guidelines.

3.1. The triple procedure of DSAEK combined with cataract surgery

In 2007 Covert and coworkers prospectively analyzed 21 DSAEK procedures combined with cataract surgery (triple procedure) in FECD patients. Eyes were targeted between −0.50 and −1.15 Diopters (D) preoperatively (mean −0.68 ± 0.33 D).[11] No statistically significant differences were reported in mean preoperative and postoperative refractive (from 1.46 ± 0.95 D to 1.56 ± 1.0 D), and keratometric astigmatism (1.37 ± 0.85 D to 1.41 ± 0.88 D). No statistically significant change was noted even in spherical equivalent (SE) with an average preoperative SE of + 0.53 ± 3.2 D and an average postoperative value of + 0.45 ± 1.1 D. Thirteen patients had both preoperative and postoperative automated keratometry (corneal topography, version A11.2 atlas, Zeiss Humphrey Systems, Dublin, CA). The authors reported a trend toward flattening of the cornea by 0.46 D, although this change was not statistically significant ($p = 0.13$).[11]

Yoo and coworkers retrospectively analyzed the results of 12 DSAEK triple procedures after at least 1 year from surgery.[52] For IOL power calculation, a postoperative target refraction of −1.21 to 0.75 D (mean−0.36 ± 0.60 D) was used. A statistically significant mean difference of 1.46 ± 0.76 D (range −0.05 to 3.14 D) was found between the targeted postoperative refraction and the actual one. The mean preoperative keratometric value (TMS-1; Tomey, Nagoya, Japan) was 43.57 ± 1.53 D (range, 40.16–45.37 D), while at the last follow-up was 43.39 ± 1.48 D (range, 40.11–44.99 D) but the difference wasn't statistically significant. The authors used an anterior segment optical coherence tomography (AS-OCT) (Visante; Carl Zeiss Meditec, Dublin, California) to calculate what they defined as the C:P ratio. It should represent an indicator of DSAEK donor corneal lenticule shape: C stands for central graft thickness, and P for the peripheral graft thickness at 3 mm (P derives from the mean of 4 peripheral corneal DSAEK button measurements at 2 perpendicular axes). The mean C:P ratio was 0.85 ± 0.10 (range 0.70–1.00) and it statistically significantly correlated with the induced hyperopic effect ($R^2 = 0.65$, $p < 0.001$).[52]

Jun and coworkers retrospectively analyzed 45 cases of DSAEK to study the correlation between the refractive changes induced by surgery and graft thickness and diameter.[26] At the last follow-up (mean 4.73 months), the mean postoperative change in refraction expressed as SE was + 0.88 D ± 1.02 (range −1.75 to +3.0). Seventeen cases underwent triple procedures because of FECD and cataracts. For IOL power calculation, a mean target power of refraction of −0.39 ± 0.28 D (range −0.82 to −0.02) was used. At the last follow-up, they achieved a mean postoperative BCVA of 20/44 (range 20/100 to 20/25), with a mean SE refraction of + 0.76 D ± 0.79 D (range −0.5 to +2.75). The remaining 28 cases were pseudophakic eyes undergoing DSAEK for FECD or bullous keratopathy/pseudophakic bullous keratopathy. At the last follow-up, the mean postoperative BCVA was 20/40 (range 20/70 to 20/20), with a mean SE refraction of −0.15 D ± 2.3 (range −9.13 to +3.5). No statistically significant difference was noted between the mean postoperative refractive change of the 2 groups: it was + 1.15 D ± 1.15 (range −0.02 to +2.87) in the triple procedure group and + 0.71 D (range −1.75 to +3.0, SD 1.11) in DSAEK only population. The average graft thickness was 124.36 mm ± 29.1; a small, but not statistically significant, negative correlation existed between refractive change and graft thickness ($r = -0.16$, bivariate Pearson correlation, $p = 0.31$). The average graft diameter was 8.39 mm ± 0.44, and a modest positive correlation between refractive change and graft diameter was found. As the inserted graft diameter increased, the hyperopic shift also increased ($r = 0.29$ bivariate Pearson correlation, $p = 0.05$).[26]

Scorcia and coworkers correlated the postoperative changes in posterior corneal curvature with the post-DSAEK refraction.[48] Corneal measurements were made using the Pentacam Scheimpflug imaging system (Oculus, Wetzlar, Germany). A standard DSAEK operation was conducted in 34 eyes, with the graft delivered by the pull-through approach. When cataract was present ($n = 7$), phacoemulsification with posterior chamber IOL implantation was combined. The average mean radius of posterior corneal curvature (Rm) varied from 6.50 ± 0.56 mm before surgery to 5.52 ± 0.39 mm at 1 month, 5.83 ± 0.37 mm at 3 months, and 5.92 ± 0.35 mm at 12 months after surgery. The change was statistically significant at all examination times ($p < 0.0001$). They also measured the mean graft thickness at different time points and at 3 different levels: centrally, in the mid periphery (2 mm from the center) and in the periphery (0.5 mm from the edge of the 9 mm graft). Two Scheimpflug camera images were captured at the 12- and 3-o′clock meridians. Five values were recorded from each meridian (1 centrally, 2 in the mid periphery, and 2 in the periphery). Then the mean central, midperipheral, and peripheral data was calculated for every patient. One month after surgery, the mean graft thickness was 362.2 ± 35.3 μm at the periphery, 251.0 ± 32.7 μm in the mid periphery and 196.0 ± 29.3 μm in the center. At 3 months, it decreased respectively to 303.4 ± 29.3 μm, 226.0 ± 31.9 μm and 181.8 ± 30.4 μm. At 1 year, further thinning respectively to 270.6 ± 28.4 μm, 213.0 ± 29.7 μm and 171.3 ± 29.5 μm was recorded. This led to an overall thinning of 25.3%, 15.3%, and 12.6%, respectively. Thinning was significant at each site at all time points ($p < 0.0001$). The grafts were significantly thicker in the periphery and mid-periphery than in the center at all examination times. Thickening diminished significantly over time at all locations. The average reduction of corneal thickness was higher at the edges (91.5 μm) than in the mid-periphery (38.3 μm) or in the center (24.2 μm). The average postoperative SE standard deviation changed from − 0.31 ± 2.35 D before surgery to 1.03 ± 2.21 D 1 month after surgery, 0.61 ± 2.07 D 3 months after surgery, and 0.31 ± 2.03 D 12 months after surgery. Between 1 and 12 months after surgery, the postoperative hyperopic shift decreased progressively along with the overall reduction of corneal thickness in general but correlated with the difference in thickness between central and peripheral cornea. The change in Rm over time was secondary to a relatively greater reduction in thickness or edema of the peripheral donor button than the central (25.3% vs. 12.6%). The changes of Rm values measured showed a good correlation with the spherical hyperopic error recorded, with a clear tendency to decrease over time along with the progressive peripheral graft thinning. The authors hypothesize that, early after surgery, aqueous enters easily into the DSAEK graft through the exposed stroma at its edge. As healing takes place, scar tissue formation blocks this inflow and progressive deswelling of the peripheral part of the graft is seen.[48]

In their prospective case series, Terry and coworkers reported the results of 315 eyes of 233 patients affected by FECD undergoing DSAEK (of which 225 were triple procedures).[50] For triple procedures the IOL was calculated with a target refraction from −0.8 up to −1.25 D. The mean refractive SE in the DSAEK-only group was associated with a statistically significant higher hyperopic shift than the triple procedure group both at 6 and 12 months. The first group reported mean shift values of + 0.76 D at 6 months and + 0.82 D at 12 months, while the latter reported no statistically significant changes. The mean refractive SE was 0.09 ± 2.32 D (range, −6.35 to 4.25 D) before surgery, 0.11 ± 1.08 D (range, −2.38 to 5.00 D) at 6 months, 0.10 ± 0.94 D (range, −1.75 to 3.75 D) at 12 months.[50]

Lombardo and coworkers investigated the influence of donor graft parameters on refractive outcome after the DSAEK triple procedure for FECD.[34] A total of 23 eyes of 23 patients were included in this study. The mean refractive IOL target was –1.04 ± 0.09 D (range –0.81 D to –1.16 D). The average difference in refraction between the targeted postoperative refraction and the 1-year postoperative refraction was 0.98 ± 0.87 D. A two-predictor model containing the graft central thickness and the curvature coefficient for the graft thickness profile explained approximately two-thirds of the induced refractive shift. Correlations of refractive change with central graft thickness ($r = 0.36$, $p = 0.05$) and graft diameter ($r = 0.45$; $p = 0.03$) were statistically significant. AS-OCT analysis revealed how the graft shape, with the graft thicker in the periphery compared with the center, contributed to reducing the radius of curvature of the posterior cornea, thus favoring the hyperopic shift postoperatively. The biggest hyperopic refractive shift was associated with grafts thicker than 170 μm, whereas the best postoperative refractive neutrality was associated with grafts of 150 ± 20 μm. The thinnest grafts (<130 μm) were associated with a mean myopic shift in the refraction of approximately –0.50 D. Preoperatively, the mean central graft thickness was 160 ± 34 μm. One year after surgery, it decreased to 151 ± 28 μm (p = 0.47); it was thinner than in the mid-peripheral (2.50 mm from the vertex) and in the periphery (±4.00 from the vertex), where it measured respectively 186 ± 26 μm and 247 ± 27 μm. The average difference between the targeted postoperative refraction and the 1-year postoperative SE refraction was + 0.98 ± 0.87 D. The mean preoperative refractive astigmatism was 0.85 ± 0.77 D; at the end of follow-up, the mean refractive astigmatism measured 0.91 ± 0.62 D (p = 0.47). No statistically significant changes in the anterior corneal topography between the preoperative and 1-year postoperative examinations (<0.10 D; p = 0.56) were measured. In addition, no statistically significant changes between the preoperative and 1-year postoperative central corneal thickness (CCT) measurements (<25 μm; p = 0.20) were found.[31] Lenticule diameter ranged between 8.00 and 9.00 mm (9% of eyes received 9.00 mm donor button, 50% 8.50 mm and 41% 8.00 mm). A statistically positive correlation between graft diameter and induced hyperopic shift was found (r = 0.45, p = 0.03).[34]

Prasher and coworkers evaluated alterations in corneal power parameters after DSAEK using rotating Scheimpflug imaging (Oculus Optikgeräte GmbH).[41] The outcome measures included corneal volume, true net power, mean zonal-equivalent K readings, mean anterior and posterior keratometry, mean anterior and posterior radius of curvature, anterior and posterior astigmatism, and CCT. These values were compared with those in a control group of age and sex-matched normal eyes. There were 32 eyes in the DSAEK group (28 patients) and 32 eyes in the control group. Sixteen eyes had DSAEK only, and 16 eyes had triple-DSAEK.

They found that the total mean true net power of the cornea was lower by 1.94 D in eyes that had DSAEK than in eyes with a normal cornea. The DSAEK group had a thicker central cornea, greater corneal volume; a higher radius of anterior surface curvature, suggesting relative flattening; and a lower radius of posterior surface curvature, suggesting relative steepening. In eyes with just DSAEK, there was a strong correlation between corneal volume and the true net power, posterior/anterior K ratio, and postoperative SE. There was a significant correlation between CCT and postoperative SE in eyes that had DSAEK only. This shows that thicker corneas and corneas with greater volume tend to have a more negative true net corneal power and a hyperopic shift. The mean SE postoperatively was 0.79 ± 1.69 D. The SE in triple DSAEK (0.47 ± 1.29 D) was lower than in eyes having DSAEK only (1.04 ± 1.95 D), likely because the targeted refraction in the combined procedure was − 1.00 D. The K values for the anterior surface in the DSAEK group were statistically significantly lower than in the control group, which indicates flattening of the anterior surface, probably the consequence of the temporal clear cornea incisions used. Corneas after DSAEK had a significantly lower true net power than age- and sex-matched normal eyes; this finding could be mainly attributed to the effect of increased posterior curvature after DSAEK. The mean anterior K, posterior K, and true net power were 42.53 D ± 1.52, − 6.80 ± 0.55 D, and 40.55 ± 1.79 D, respectively, in the DSAEK group and 43.60 ± 1.62 D, − 6.20 ± 0.31 D, and 42.49 ± 1.57 D, respectively, in the control group. True net power, anterior and posterior K values, and the posterior radius of curvature were all statistically lower in DSAEK eyes than in control eyes (p=0.01). The mean posterior corneal astigmatism was statistically significantly higher in the DSAEK group (0.59 ± 0.64 D; range 0.00 to 3.40 D) than in the control group (0.32 ± 0.20 D; range 0.10 to 1.00 D) (P 0.029). Comparing DSAEK eyes to control eyes, the equivalent K readings were considerably lower in all zones in DSAEK eyes (p = 0.01). When compared to control eyes, DSAEK eyes' mean CCT was significantly higher (628 ± 46 mm versus 553 ± 35 mm) (p = 0.01).[41]

In 2013, Bonfadini and coworkers analyzed the refractive error after the DSAEK triple procedure in a case series of 30 eyes.[7] The predicted postoperative refraction was calculated using the SRK/T Formula and the manufacturer's IOL constant. Postoperatively, the deviation of the target refraction was analyzed and used to calculate a new optimized constant with the Holladay IOL Consultant software (version 1.0; Consulting, Inc., Houston, TX). The new constant and the power of the implanted IOL were finally entered into the SRK/T formula: the optimized predicted refraction was thus calculated. The error of prediction (actual minus predicted postoperative SE) indicated how close the postoperative refraction was to the target one. The mean preoperative SE was −0.9 ± 3 D (range, −7.13 to 3.5 D), while the mean postoperative SE was −0.72 ± 0.7 D (range, −1.88 to 0.88 D). The original formula produced both a mean absolute error (MAE) and a mean arithmetic error of 1.09 ± 0.63 D (range, 0.12–2.41 D). With the optimized formula, the MAE was 0.61 ± 0.4 D (range 0.00– 1.58 D), while the mean arithmetic error was −0.22 ± 0.7 D (range −1.58 to 1.09 D). The difference in the mean arithmetic error between the two formulas was 1.32 D while the difference in the MAE was 0.481 D; both were significant. A statistically significant difference was found in the number of eyes with a deviation of > 1.0 D from the target refraction in the two groups (50% vs.17%). According to the Pearson correlation test, no correlation was found neither between the refractive postoperative SE shift and the mean preoperative or postoperative K, the preoperative anterior chamber depth (ACD), the preoperative axial length (AL), the patients' preoperative or postoperative CCT, the graft thickness, nor between the preoperative AL and the postoperative K.[7]

3.2. *The triple procedure of DMEK combined with cataract surgery*

Laaser and coworkers described the 6-month results of triple-DMEK, including the refractive outcomes. Triple DMEK was performed on 61 eyes of 56 patients suffering from FECD or bullous keratopathy.[33]

IOL power calculations were performed using data from the IOL-Master (V. 4.08; Carl Zeiss Meditec, Jena, Germany) and the Haigis formula in all patients. In three patients it was necessary to use an A-scan (CinescanS; Haag-Streit Deutschland GmbH, Wedel, Germany) due to media opacification to measure the AL. The topographic cylinder was measured using a topographic modeling system (TMS-4, version 3.5 D; Tomey, Erlangen, Germany). All eyes had a mean target refraction of −0.53 ± 0.95 D. Within the first six months, a small hyperopic shift was observed. The preoperative refractive SE was −0.3 ± 2.8 D (n = 27), and the postoperative refractive SE was 0.9 ± 1.5 D (n = 27) after 6 months. Six months after surgery the percentage of eyes within 1D of emmetropia was 54.5% (n = 12) while 77.3% were within 2D of emmetropia (n = 22). The topographic cylinder changed significantly between 3 months (2.2 ± 2.2 D) and 6 months (1.7 ± 1.1 D). Based on their observations the authors suggested a target refraction of −0.75 D for triple DMEK.[33]

Gundlach and coworkers investigated outcomes and postoperative complications in patients undergoing isolated DMEK in phakic eyes compared to patients undergoing triple-DMEK.[20] In their retrospective analysis, 13 phakic eyes undergoing DMEK and 54 eyes undergoing the triple procedure were included. For IOL power calculation they employed the IOL-Master V.3.01 (Carl Zeiss Meditec AG, Jena, Germany) or Lenstar LS900® (Haag Streit, Wedel, Germany) and the SRK-T formula was used. In 31 cases, the measurement of AL and keratometry values was possible thanks to relatively clear media. In all other cases, standard-K keratometry values, or K values of the fellow eye were used. Emmetropia was chosen as the target refraction in all patients. Because of the known hyperopic shift −0.5 D was added. Refraction seemed stable in the group of phakic patients. The mean refractive SE in the phakic group was −0.75 ± 3.53 D preoperatively and −0.63 ± 3.53 D after 6 months (p = 0.261). In the group after the triple procedure the SE was 0.19 ± 3.14 D preoperatively and −0.20 ± 1.14 D after 6 months (p = 0.425). The refractive cylinder was 1.22 ± 1.16 D preoperatively and 1.00 ± 1.13 D 6 months after surgery in the group of phakic eyes;

however, there were no statistically significant changes. Two eyes of the phakic group required later cataract surgery. In the group after the triple procedure, 62.8% of eyes were within 1 D of emmetropia.[20]

Schoenberg and coworkers retrospectively collected data on 108 patients with a diagnosis of FECD who had combined DMEK and cataract surgery.[47] Biometry was performed using partial coherence interferometry (PCI) (IOLMaster, version 4.08, Carl Zeiss Meditec AG). AL was confirmed and phakic lens thickness was obtained by noncontact ultrasound biometry. Keratometry from the PCI device was compared with topography obtained by the Tomey TMS-4 keratometer (Tomey Corp.). Moreover, in a subset of patients, both PCI keratometry and Scheimpflug imaging (Pentacam, Oculus, Wetzlar, Germany) were available preoperatively and at least 6 months postoperatively. IOL power calculation was performed using the Holladay 2 formula. The refractive target was shifted from the patient's preference (emmetropia, n = 101; intermediate vision, n = 4; near vision, n = 3) by 0.50 D. An Acrysof IQ toric IOL (Alcon Surgical, Inc.) was used in patients with greater than + 1.75 D of regular topographic astigmatism who chose to receive a toric IOL; all other patients received a Softec HD IOL (Lenstec, Inc.). With a mean follow-up of 11.9 months, the median refractive error was + 0.43 D (interquartile range −0.34 to +1.17 D). Aspheric intraocular lenses (IOLs) (n = 91) did not significantly change the refractive astigmatism (mean: preoperative +0.926 ± 0.144; postoperative +0.945 ± 0.129 D) (p = 0 .83), while toric IOLs (n = 9) did (mean: preoperative +2.47 ± 0.36 D; postoperative +0.94 ± 0.90 D) (p = 0.0015). The anterior curvature measured by Scheimpflug imaging did not significantly change (mean −0.06 ± 0.47 D) (p = .41); however, keratometry by PCI did (mean −0.6 ± 0.9 D) ($p < 0.0001$). A significant increase in posterior K was demonstrated (from −5.9 ± 0–4 D to −6.5 ± 0.2 D; mean change −0.5 ± 0.4; $p < 0.001$), but a correlation with the refractive error was not found ($R^2 = 0.05$). The authors concluded that a target of − 0.75 D appeared most functional for DMEK triple procedures, theoretically resulting in 75% of postoperative SE refractions between − 1.09 D and + 0.37 D.[47]

Fritz and coworkers analyzed if the preoperative corneal asphericity (Q value) could help in the identification of those FECD eyes that were more likely to manifest a postoperative hyperopic shift.[17] According to the arithmetic error, the 112 enrolled patients were divided into 3 groups: > +0.5 D hyperopia (52 eyes, 46%; median arithmetic error = 0.84 D, range: 0.51 to 3.19), > −0.5 D myopia (13 eyes, 24%; range, −0.56 to −2.87 D, median −0.77), and emmetropia (± 0.5 D: 42 eyes, 38%). The risk of a hyperopic shift was 3.0-fold higher in oblate corneas (positive posterior Q) compared with prolate ones (negative posterior Q); the former showed a 0.50 D higher postoperative arithmetic error compared to the latter. Moreover, corneas with a posterior Q within the highest quartile (range, 0.4 to 1.6) had a 6.7-fold higher risk of hyperopia compared to the lowest one (normal, prolate cornea; range, −1.2 to −0.3). The authors stated that a + 0.5 D more myopic target refraction in oblate corneas would result in a lower median arithmetic error (−0.16 D); 19 (17%) eyes would have presented a hyperopic arithmetic error of > +0.50 D, 7 eyes (6%) would have presented a > +1 D arithmetic error. Associations between arithmetic error and both posterior radii of curvature and preoperative corneal thickness were demonstrated. In particular, an increase in postoperative mean radius of curvature by 1 mm correlated with a 0.3 D increase in refractive error; however, both associations were lost when adjusting for posterior Q. Positive posterior Q was associated with 0.49 D higher arithmetic error compared with eyes with negative posterior Q, and the association remained significant when adjusting for thickness or radius of curvature. However, 39% of oblate corneas resulted in postoperative emmetropia or myopia. A similar analysis was conducted for the anterior corneal surface; no correlation was found between preoperative anterior Q or anterior keratometry and refractive error.[17]

Bae and coworkers evaluated the refractive outcomes of triple DMEK in a retrospective analysis of 68 eyes of patients affected by FECD.[3] The mean target refraction was − 0.69 D (interquartile range: −0.80 to −0.50 D). A mean hyperopic shift of 0.55 D from target refraction occurred after triple DMEK and 47% of eyes were within 0.50 D of target refraction at 6 months postoperatively. The refractive shift was greater in eyes with a preoperative CCT of 640 μm or greater versus eyes with a CCT of fewer than 640 μm (+1.20 ± 0.92 vs +0.40 ± 0.99 D, p = 0.02).[3]

Augustin and coworkers conducted a retrospective study on 127 patients who underwent the DMEK triple procedure in both eyes for FECD to analyze whether the refractive outcome of the first eye could be used for predicting the refractive target in the second eye.[2] For IOL power calculation the IOLMaster (version 4.08; Carl Zeiss Meditec, Jena, Germany) and the Haigis formula were used. Comparing the first eye and the second eye groups, a steepening in posterior corneal curvature (respectively of 0.57 ± 0.35D and 0.58 ± 0.46D), a reduction in CCT (respectively of 104.27 ± 98.69 mm and 90.52 ± 48.78 mm) and a decrease in posterior densitometry (respectively of −9.0 ± 8.0 gray scale units and −8.7 ± 7.7 gray scale units) were noted 3 months after surgery. However, the differences were not statistically significant between the 2 groups. The refractive shift was calculated by comparing the predicted refractive outcome (based on preoperative IOLMaster IOL calculation) and the actual postoperative refractive outcome (best corrected SE). A mean hyperopic shift was noted three months after surgery: 1.03 ± 0.93 D in the first eyes and 0.92 ± 1.02 D in the second eyes, respectively, however, no statical difference was found between the 2 groups. In a paired analysis between the first and second eyes, the mean difference of the postoperative refractive shift was 0.49 ± 0.43 D. The refractive shift after DMEK triple procedure in the first eye was comparable with the shift in the second eye.[2]

Boutillier and coworkers found that the DMEK triple procedure limited postoperative refractive errors compared to the classical triple procedure which combines penetrating keratoplasty and cataract.[8] This is due to the preservation of most of the corneal structure and the anterior surface in the case of DMEK. This retrospective multicenter study enrolled consecutive patients with symptomatic corneal endothelial decompensation and cataract. The primary outcome was refractive accuracy at months 2 and 6. A total of 130 eyes of 111 patients (50 men and 61 women) were included. Surgery indications of the triple procedure were FECD for 122 eyes (94%), bullous keratopathy for 3 eyes (2.25%), decompensation associated with a myopic phakic eye for 3 eyes (2.25%) and decompensation in acute angle-closure glaucoma for 2 eyes (1.5%). The mean AL was 23.7 ± 1.8 mm (range, 20.1–30.5 mm). It was measured using interferometry for 113 eyes (87%) and ultrasonography mode A for 17 eyes (13%). Keratometry of the eye to be operated on was performed with IOLMaster® (Zeiss-Meditec, Germany) for 113 eyes (87%). For 17 eyes (13%), keratometry was not possible and the values of the contralateral eye were used for 15 eyes or a reference mean value for the 2 other eyes (43 D for the two axes). IOL power was calculated using the SRK/T formula for 122 eyes (94%) with an AL > 22 mm, Holladay's formula for 4 eyes (3%) and Hoffer Q for 4 eyes (3%) with an AL < 22 mm. The mean refractive target was − 0.50 ± 0.57 D. The mean SE was − 0.01 ± 0.96 D at 2 months and − 0.04 ± 0.94 D at 6 months. The mean (95% CI) refractive error (difference between refractive target and post-operative refraction) was hyperopia of + 0.49 (0.314; 0.664) D at 2 months and + 0.46 (0.299; 0.619) D at 6 months. Mean corneal thickness decreased from 621.6 ± 37.6 μm to 515.2 ± 42.6 μm at 2 months and 539.0 ± 39.0 μm at 6 months. At 2 months and 6 months, mean keratometry values were 43.3 ± 1.6 D and 43.5 (± 1.57) D, respectively, corresponding to a decrease of 0.5 D at 2 months (CI 95%, 0.226; 0.886) and 0.3 D at 6 months (CI 95%, 0.234; 0.791). The authors suggested a mean target of − 0.5 D to improve post-operative refractive accuracy.[8]

Campbell and coworkers studied whether a modification in corneal power calculation could minimize prediction error in the DMEK triple procedure.[9] To do this, the modified corneal power was calculated with a thick lens equation (based on preoperative Pentacam anterior and posterior corneal radii and corneal thickness). This value was subtracted from corneal power acquired with biometers (IOLMaster 500, software V.5.1, Carl Zeiss Meditec AG, Jena, Germany; IOLMaster 700, software V.1.0, Carl Zeiss Meditec AG, Jena, Germany; or Lenstar 900, Haag-Streit AG, Köniz, Switzerland). The difference was converted to the vertex. Then, predicted refraction was calculated for each implanted IOL based on preoperative biometry. The Hoffer Q, Holladay I, SRK/T, Barrett Universal II, and Haigis formulas were used, together with ULIB-optimized constants. For each formula, the error was calculated as the difference between the actual postoperative SE and the predicted SE. Finally, the vertex was subtracted from the error for each formula. The Haigis formula resulted in the smallest MAE and median (MedAE) absolute error, followed by the SRK/T formula, Holladay I formula and the Hoffer Q formula, while the Barrett Universal II formula resulted in the largest ones. The mean SE was -0.29 ± 1.16 D. No significant absolute error difference was noted among all five formulas. The mean modified corneal power was significantly smaller than the biometrical one; the two values were strongly correlated. Compared with biometric corneal power, the application of the modified corneal power was associated with significantly lower MAE and MedAE using the Hoffer Q (0.82 D and 0.62 D, respectively), Holladay I (0.85 D and 0.62 D, respectively), SRK/T (0.85 D and 0.63 D, respectively) and Barrett Universal II (0.90 D and 0.75 D, respectively) formulas, but not using the Haigis formula. No statistical significance was noted among the 5 formulas neither in the absolute error difference nor in the percentage of eyes within $\pm$ 0.50 D and $\pm$ 1.00 D of the predicted error. A significant weak positive correlation was shown between the refractive error and both the posterior corneal curvature, and the posterior Q: corneas with flatter posterior central curvature (that is, corneas with greater edema) were weakly associated with hyperopic errors. Refractive error was not correlated with CCT, anterior corneal curvature, anterior Q, ACD and AL.[9]

In their prospective interventional case series, Knutsson and coworkers included 37 eyes of patients undergoing combined DMEK and phacoemulsification.[29] The study had 3 purposes: (1) to assess the accuracy of different preoperative and postoperative corneal power measurements for IOL power calculation in eyes undergoing combined DMEK and cataract surgery; (2) to evaluate whether any IOL power formula offers any advantage; and (3) to investigate whether any preoperative parameter can predict a worse refractive outcome.

The postoperative subjective refraction was measured at 6 months (when all sutures had been removed at least 1 month earlier). ULIB constants resulted in the highest hyperopic prediction error (PE) ($p < 0.0001$). The results were enhanced by constant optimization since the absolute Pes decreased and the PE was wiped out. Using preoperative AL measured by optical biometry and 6-month postoperative AS-OCT keratometry values and total corneal power (TCP), constants were optimized retrospectively to give an arithmetic PE of zero.

In particular, AS-OCT measurements were taken preoperatively and at 6 months. Average anterior K decreased (from 43.70 ± 1.87 to 43.00 ± 1.75, mean $= -0.71 \pm 0.97$ D), while average posterior K increased (from -5.80 ± 0.33 to -6.29 ± 0.26 D), with subsequent TCP reduction (from 43.61 ± 2.08 to 42.22 ± 1.80 D, mean $= -1.31 \pm 1.35$ D). The mean anterior corneal radius increased (from 7.74 ± 0.34 to 7.86 ± 0.32, mean 0.12 ± 0.16 mm) while the mean posterior corneal radius decreased (from 6.91 ± 0.38 mm to 6.37 ± 0.26 mm, mean 0.55 ± 0.33 mm). A greater modification in posterior radius was thus demonstrated, determining an increase in anterior/posterior radii ratio (from 1.12 ± 0.06 to 1.24 ± 0.05). Mean posterior Q decreased (from 0.10 ± 0.52 to -0.31 ± 0.25). Anterior Q decreased as well but not significantly. No significant difference was found among the Barrett Universal II, Emmetropia Verifying Optical 2.0, Haigis, Hoffer Q, Holladay 1, Kane, and SRK/T formulas. Calculations based on the preoperative TCP and constant optimization also provided poor outcomes and were less accurate than those based on standard keratometry. This finding was likely to depend on the higher dependence of TCP on the posterior corneal curvature, which was altered by surgery. Therefore, the authors didn't recommend preoperative TCP for calculating the IOL power in eyes undergoing DMEK. Corneas with a lower anterior-to-posterior ratio (A/P) were likely to experience higher amounts of flattening after DMEK.[29]

Recently, Semler-Collery and coworkers compared triple-DMEK to DMEK in pseudophakic patients affected by FECD.[49] The triple-DMEK group was composed of 40 eyes and the pseudophakic-DMEK group of 55 eyes. The refractive target chosen in triple-DMEK was a residual myopia of about -0.5 to -1.00 diopters to compensate for the hypermetropic effect of the surgery. No details about IOL power formulas were reported. At 12 months, the triple-DMEK group had significantly less residual hyperopia than the pseudophakic-DMEK group, i.e., 0.75 (−1.75–5.75) D vs. 1.0 (−1.0–4.5) D ($p = 0.04$). Triple-DMEK postoperative SE was 0 (−1.88–4.88) D vs. 0.5 (−1.5–4.25) D ($p = 0.02$) in the pseudophakic-DMEK. Astigmatism did not differ between the groups.[49]

4. Conclusion

In the surgical management of corneal endothelial diseases, DSAEK and even more DMEK are gaining popularity because of their intrinsic advantages over penetrating keratoplasty, including quicker visual rehabilitation, nearly full visual recovery, and lower rejection risk.[5,14,15,19,22,23,35,42,51] Moreover, compared with sequential management of patients with concomitant cataract and endothelial dysfunction, triple DSAEK and DMEK might be an effective strategy that offers the advantage of a 1-stage procedure, with reduced risks and costs.[10,14,33] Unfortunately, because the posterior lamellar graft affects the corneal power that was calculated before surgery, accurate IOL power calculation and, as a result, predicted refractive results, may be challenging to accomplish. Hyperopization appears to be linked to endothelial graft rather than cataract surgery.[8] In addition to inducing changes in corneal power from deturgescence and remodeling, DSAEK might introduce a variably thick donor lenticule to the posterior corneal surface with optical characteristics partially unknown during preoperative planning and IOL selection.[47] According to some investigators, after DSAEK, hyperopization could be connected to changes in keratometry (reduced corneal edema) and posterior corneal geometry caused by a graft that is thinner in the center than it is at the edges. This conformation is maintained one year after surgery, even if the thinning rate seems to be greater at the periphery than at the center.[48] Moreover, a statistically significant positive correlation has been found between graft diameter and postoperative hyperopic refractive shift.[26,34] In triple DMEK postoperative hyperopic surprises might be more common in corneas that are flatter in the center than in the periphery due to edematous changes (oblate posterior profile).[8,17] Others have reported that the preoperative conventional keratometry in eyes with FECD undergoing DMEK underestimated postoperative posterior corneal power and thus overestimated postoperative total corneal power.[13] Some sources of errors might be represented by averaging values acquired from a wider corneal surface than that generally affected by FECD.

Some authors analyzed posterior curvature modifications after DSAEK or DMEK, demonstrating a postoperative steepening of the posterior surface.[2,17,29,41,47] Prasher and coworkers reported an increased posterior corneal astigmatism in patients who underwent triple procedures compared to controls.[41] In existing literature posterior corneal astigmatism following DSAEK has been attributed to factors such as graft decentering, off-center donor cutting with the microkeratome, or off-center punching.[4] A recent report suggests that alterations in posterior astigmatism may, at least in part, be intrinsic to the microkeratome donor preparation process.[6]

Other authors have analyzed the correlation between refractive error and corneal posterior surface changes after triple DMEK.[17,47] Schoenberg and coworkers didn't find any correlation, while Fritz and coworkers demonstrated that an increase in postoperative mean radius of curvature by 1 mm was associated with a 0.3 D increase in arithmetic error; however, the correlation was lost when adjusting for posterior Q.

A 0.49 D higher error was found in eyes with positive posterior Q (that is, more edematous corneas) compared with negative posterior Q.[17,47] This finding is in accordance with the work from Campbell and coworkers.[9] Consequently, the relationship between the peripheral and central posterior cornea seems to play a major role in refractive outcome: it seems the whole geometry to be affected after surgery. Interestingly, Debellemanière and coworkers have proposed to distinguish two separate causes leading to the postoperative refractive shift: a DMEK-induced refractive shift (DIRS) and IOL calculation error (DICE). They observed that the main factors for both DIRS and DICE were anterior average radii of curvature (ARC), posterior average radii of curvature (PRC), and posterior Q.[12]

As lamellar endothelial corneal grafts are overtaking conventional full-thickness procedures consistency in tissue preparation and postoperative complication such as graft separation are among the new challenges that have emerged. To overcome these problems and drastically lower the learning curve, eye banks have begun to supply tissue that has been prestripped and/or preloaded. Many authors have already analyzed the results between surgeon-stripped tissues and transplants prepared by eye banks, and further studies will be required to assess the variations, if any, in combined treatments as well.[27,40,44,45]

In conclusion, there is still no consensus on how much of a hyperopic shift should be expected and, more crucially, which subgroup of patients becomes more hyperopic than expected. It appears that additional prospective randomized studies are required to develop a method to individualize IOL calculations more precisely in patients undergoing triple procedures. Most of the authors generally delineated a myopic target overall ranging between − 0.50 and − 0.75 D for triple DMEK and up to − 1.50 D for DSAEK; however, the majority of the studies were retrospective and had small samples. Thus, no definite target, nor a most suitable formula for IOL calculation, could be established as preferable with a high level of evidence.

Method of literature search

The following terms were combined as shown: ("Descemet Stripping Endothelial Keratoplasty" or "DMEK" OR "DSAEK" OR "triple procedure" OR "endothelial keratoplasty") AND ("Lenses, Intraocular" or "Phacoemulsification"). A literature search of all original articles published up to July 2022 was performed in parallel by three authors (A.L.V., S.M. and A.G.) using the PubMed database. Three reviewers (A.L.V, S.M and A.G.) independently screened articles' titles and abstracts identified by the initial search using Rayyan QCRI Software. The full texts of the relevant articles were then analyzed, and the bibliography of eligible articles was assessed to identify any study not obtained through electronic search. A fourth reviewer (R.G.) was consulted in case of disagreement. The same reviewers independently extracted the following data: study title, year of publication, author, number of participants, study design, type of graft, follow-up period, main outcomes measured and main results.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Milan Serena: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Grotto Alberto:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Vinciguerra Alex Lucia:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Giglio Rosa:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Tognetto Daniele:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.survophthal.2024.01.003.

References

1. Augustin VA, Son HS, Yildirim TM, et al. Refractive outcomes after Descemet Membrane Endothelial Keratoplasty: a meta-analysis. *J Cataract Refract Surg*. 2023;49(9):982–987. https://doi.org/10.1097/j.jcrs.0000000000001212.
2. Augustin VA, Weller JM, Kruse FE, Tourtas T. Refractive outcomes after Descemet Membrane Endothelial Keratoplasty + Cataract/Intraocular lens triple procedure: a fellow eye comparison. *Cornea*. 2021;40(7):883–887. https://doi.org/10.1097/ICO.0000000000002602.
3. Bae SS, Ching G, Holland S, et al. Refractive outcomes of Descemet Membrane Endothelial Keratoplasty combined with cataract surgery in Fuchs Endothelial Dystrophy. *J Refract Surg*. 2020;36(10):661–666. https://doi.org/10.3928/1081597X-20200729-02.
4. Bahar I, Kaiserman I, Livny E, Slomovic A, Slomovic A. Changes in corneal curvatures and anterior segment parameters after descemet stripping automated endothelial keratoplasty. *Curr Eye Res*. 2010;35(11):961–966. https://doi.org/10.3109/02713683.2010.506967.
5. Bahar I, Kaiserman I, McAllum P, Slomovic A, Rootman D. Comparison of posterior lamellar keratoplasty techniques to penetrating keratoplasty. *Ophthalmology*. 2008;115(9):1525–1533. https://doi.org/10.1016/j.ophtha.2008.02.010.
6. Bhogal MS, Allan BD. Graft profile and thickness as a function of cut transition speed in Descemet-stripping automated endothelial keratoplasty. *J Cataract Refract Surg*. 2012;38(4):690–695. https://doi.org/10.1016/j.jcrs.2011.09.046.
7. Bonfadini G, Ladas JG, Moreira H, et al. Optimization of intraocular lens constant improves refractive outcomes in combined Endothelial Keratoplasty and cataract surgery. *Ophthalmology*. 2013;120(2):234–239. https://doi.org/10.1016/j.ophtha.2012.08.003.
8. Boutillier G, Bernheim D, Denoyer A, et al. Refractive accuracy and visual outcomes after combined descemet membrane endothelial keratoplasty and cataract surgery: a French multicentric study. *J Fr Ophtalmol*. 2021;44(6):792–798. https://doi.org/10.1016/j.jfo.2020.06.052.
9. Campbell JA, Ladas JG, Wang K, Woreta F, Srikumaran D. Refractive accuracy in eyes undergoing combined cataract extraction and Descemet membrane endothelial keratoplasty. *Br J Ophthalmol*. 2022;106(5):623–627. https://doi.org/10.1136/bjophthalmol-2020-317247.
10. Chaurasia S, Price FW, Gunderson L, Price MO. Descemet's membrane endothelial keratoplasty: clinical results of single versus triple procedures (combined with cataract surgery). *Ophthalmology*. 2014;121(2):454–458. https://doi.org/10.1016/j.ophtha.2013.09.032.
11. Covert DJ, Koenig SB. New triple procedure: Descemet's stripping and automated Endothelial Keratoplasty combined with phacoemulsification and intraocular lens implantation. *Ophthalmology*. 2007;114(7). https://doi.org/10.1016/j.ophtha.2006.12.030.
12. Debellemanière G, Ghazal W, Dubois M, et al. Descemet Membrane Endothelial Keratoplasty-induced refractive shift and Descemet Membrane Endothelial Keratoplasty-Induced Intraocular lens calculation error. *Cornea*. 2023;42(8):954–961. https://doi.org/10.1097/ICO.0000000000003100.
13. Diener R, Treder M, Lauermann JL, Eter N, Alnawaiseh M. Assessing the validity of corneal power estimation using conventional keratometry for intraocular lens power calculation in eyes with Fuch's dystrophy undergoing Descemet membrane endothelial keratoplasty. *Graefe's Arch Clin Exp Ophthalmol*. 2021;259(4):1061–1070. https://doi.org/10.1007/s00417-020-04998-w.
14. van Dijk K, Ham L, Tse WHW, et al. Near complete visual recovery and refractive stability in modern corneal transplantation: Descemet membrane endothelial keratoplasty (DMEK). *Cont Lens Anterior Eye*. 2013;36(1):13–21. https://doi.org/10.1016/j.clae.2012.10.066.
15. Dirisamer M, Ham L, Dapena I, et al. Efficacy of descemet membrane endothelial keratoplasty: clinical outcome of 200 consecutive cases after a learning curve of 25 cases. *Arch Ophthalmol*. 2011;129(11):1435–1443. https://doi.org/10.1001/ARCHOPHTHALMOL.2011.195.
16. Dupps WJ, Qian Y, Meisler DM. Multivariate model of refractive shift in Descemet-stripping automated endothelial keratoplasty. *J Cataract Refract Surg*. 2008;34(4):578–584. https://doi.org/10.1016/J.JCRS.2007.11.045.
17. Fritz M, Grewing V, Böhringer D, et al. Avoiding hyperopic surprises after Descemet Membrane Endothelial Keratoplasty in Fuchs Dystrophy eyes by assessing corneal shape. *Am J Ophthalmol*. 2019;197(1):1–6. https://doi.org/10.1016/j.ajo.2018.08.052.

18. Gorovoy MS. Descemet-stripping automated endothelial keratoplasty. *Cornea*. 2006;25(8):886–889. https://doi.org/10.1097/01.ICO.0000214224.90743.01.
19. Guerra FP, Anshu A, Price MO, Giebel AW, Price FW. Descemet's membrane endothelial keratoplasty: prospective study of 1-year visual outcomes, graft survival, and endothelial cell loss. *Ophthalmology*. 2011;118(12):2368–2373. https://doi.org/10.1016/j.ophtha.2011.06.002.
20. Gundlach E, Maier AKB, Tsangaridou MA, et al. DMEK in phakic eyes: targeted therapy or highway to cataract surgery? *Graefe's Arch Clin Exp Ophthalmol*. 2015;253(6):909–914. https://doi.org/10.1007/s00417-015-2956-8.
21. Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction - GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. 2011;64(4):383–394. https://doi.org/10.1016/j.jclinepi.2010.04.026.
22. Ham L, Dapena I, van Luijk C, van der Wees J, Melles GRJ. Descemet membrane endothelial keratoplasty (DMEK) for Fuchs endothelial dystrophy: review of the first 50 consecutive cases. *Eye*. 2009;23(10):1990–1998. https://doi.org/10.1038/eye.2008.393.
23. Ham L, Dapena I, Moutsouris K, et al. Refractive change and stability after Descemet membrane endothelial keratoplasty. Effect of corneal dehydration-induced hyperopic shift on intraocular lens power calculation. *J Cataract Refract Surg*. 2011;37(8):1455–1464. https://doi.org/10.1016/J.JCRS.2011.02.033.
24. Hayashi K, Yoshida M, Manabe S ichi, Hirata A. Cataract surgery in eyes with low corneal endothelial cell density. *J Cataract Refract Surg*. 2011;37(8):1419–1425. https://doi.org/10.1016/j.jcrs.2011.02.025.
25. Holz HA, Meyer JJ, Espandar L, et al. Corneal profile analysis after Descemet stripping endothelial keratoplasty and its relationship to postoperative hyperopic shift. *J Cataract Refract Surg*. 2008;34(2):211–214. https://doi.org/10.1016/J.JCRS.2007.09.030.
26. Jun B, Kuo AN, Afshari NA, Carlson AN, Kim T. Refractive change after descemet stripping automated endothelial keratoplasty surgery and its correlation with graft thickness and diameter. *Cornea*. 2009;28(1):19–23. https://doi.org/10.1097/ICO.0B013E318182A4C1.
27. Juratli L, Qureshi S, Liles N, et al. Clinical outcomes of prestripped, prestained, and preloaded Descemet's membrane endothelial keratoplasty ('P3 DMEK'). *Taiwan J Ophthalmol*. 2023;13(1):55–61. https://doi.org/10.4103/tjo.TJO-D-22-00155.
28. Khandpur RS. *Keratometer*. *Compendium of biomedical instrumentation*. Wiley; 2020:1109–1112. https://doi.org/10.1002/9781119288190.ch206.
29. Knutsson KA, Savini G, Hoffer KJ, et al. IOL power calculation in eyes undergoing combined Descemet Membrane Endothelial Keratoplasty and cataract surgery. *J Refract Surg*. 2022;38(7):435–442. https://doi.org/10.3928/1081597X-20220601-02.
30. Koenig SB, Covert DJ. Early results of small-incision Descemet's Stripping and automated Endothelial Keratoplasty. *Ophthalmology*. 2007;114(2):221–226.e1. https://doi.org/10.1016/j.ophtha.2006.07.056.
31. Koenig SB, Covert DJ, Dupps WJ, Meisler DM. Visual acuity, refractive error, and endothelial cell density six months after Descemet stripping and automated endothelial keratoplasty (DSAEK). *Cornea*. 2007;26(6):670–674. https://doi.org/10.1097/ICO.0b013e3180544902.
32. Kwon RO, Price MO, Price FW, Ambrósio R, Belin MW. Pentacam characterization of corneas with Fuchs dystrophy treated with Descemet membrane endothelial keratoplasty. *J Refract Surg*. 2010;26(12):972–979. https://doi.org/10.3928/1081597X-20100212-08.
33. Laaser K, Bachmann BO, Horn FK, Cursiefen C, Kruse FE. Descemet membrane endothelial keratoplasty combined with phacoemulsification and intraocular lens implantation: advanced triple procedure. *Am J Ophthalmol*. 2012;154(1):47–55.e2. https://doi.org/10.1016/j.ajo.2012.01.020.
34. Lombardo M, Terry MA, Lombardo G, et al. Analysis of posterior donor corneal parameters 1 year after Descemet stripping automated endothelial keratoplasty (DSAEK) triple procedure. *Graefe's Arch Clin Exp Ophthalmol*. 2010;248(3):421–427. https://doi.org/10.1007/s00417-009-1284-2.
35. McCauley MB, Price MO, Fairchild KM, Price DA, Price FW. Prospective study of visual outcomes and endothelial survival with Descemet membrane automated endothelial keratoplasty. *Cornea*. 2011;30(3):315–319. https://doi.org/10.1097/ICO.0B013E3181EEB71B.
36. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339(7716):332–336. https://doi.org/10.1136/BMJ.B2535.
37. OCEBM Levels of Evidence Working Group. The Oxford 2011 Levels of Evidence. Oxford Centre for Evidence-Based Medicine.
38. Ong Tone S, Kocaba V, Böhm M, et al. Fuchs endothelial corneal dystrophy: the vicious cycle of Fuchs pathogenesis. *Prog Retin Eye Res*. 2021;80, 100863. https://doi.org/10.1016/j.preteyeres.2020.100863.
39. Padmanabhan P, Warade SK, Sejpal K. New endothelial keratoplasty, phacoemulsification, and intraocular lens implantation triple procedure: comparison with conventional triple procedure. *J Cataract Refract Surg*. 2010;36(7):1142–1148. https://doi.org/10.1016/J.JCRS.2010.01.022.
40. Pagano L, Gadhvi KA, Coco G, et al. Rebubbling rate in preloaded versus surgeon prepared DSAEK. *Eur J Ophthalmol*. 2022;32(2):880–884. https://doi.org/10.1177/11206721211014380.
41. Prasher P, Muftuoglu O, Bowman RW, et al. Corneal power measurement with a rotating Scheimpflug imaging system after Descemet-stripping automated endothelial keratoplasty. *J Cataract Refract Surg*. 2010;36(8):1358–1364. https://doi.org/10.1016/j.jcrs.2010.01.032.
42. Price MO, Giebel AW, Fairchild KM, Price FW. Descemet's Membrane Endothelial Keratoplasty. Prospective multicenter study of visual and refractive outcomes and endothelial survival. *Ophthalmology*. 2009;116(12):2361–2368. https://doi.org/10.1016/j.ophtha.2009.07.010.
43. Price MO, Price FW. Descemet's stripping with endothelial keratoplasty: comparative outcomes with microkeratome-dissected and manually dissected donor tissue. *Ophthalmology*. 2006;113(11):1936–1942. https://doi.org/10.1016/j.ophtha.2006.05.034.
44. Romano V, Kazaili A, Pagano L, et al. Eye bank versus surgeon prepared DMEK tissues: influence on adhesion and re-bubbling rate. *Br J Ophthalmol*. 2022;106(2):177–183. https://doi.org/10.1136/bjophthalmol-2020-317608.
45. Romano V, Parekh M, Kazaili A, et al. Eye bank versus surgeon prepared Descemet stripping automated endothelial keratoplasty tissues: influence on adhesion force in a pilot study. *Indian J Ophthalmol*. 2022;70(2):523–528. https://doi.org/10.4103/ijo.IJO_3637_20.
46. De Sanctis U, Angeloni M, Zilio C, Sacco D, Grignolo F. Corneal power after DSAEK using microkeratome-prepared tissues. *Optom Vis Sci*. 2011;88(6):697–702. https://doi.org/10.1097/OPX.0B013E3182160763.
47. Schoenberg ED, Price FW, Miller J, McKee Y, Price MO. Refractive outcomes of Descemet membrane endothelial keratoplasty triple procedures (combined with cataract surgery). *J Cataract Refract Surg*. 2015;41(6):1182–1189. https://doi.org/10.1016/j.jcrs.2014.09.042.
48. Scorcia V, Matteoni S, Scorcia GB, Scorcia G, Busin M. Pentacam assessment of posterior lamellar grafts to explain hyperopization after Descemet's stripping automated Endothelial Keratoplasty. *Ophthalmology*. 2009;116(9):1651–1655. https://doi.org/10.1016/j.ophtha.2009.04.035.
49. Semler-Collery A, Bloch F, Hayek G, Goetz C, Perone JM. Comparison of triple-DMEK to pseudophakic-DMEK: a cohort study of 95 eyes. *PLoS One*. 2022;17(5 May):1–15. https://doi.org/10.1371/journal.pone.0267940.
50. Terry MA, Shamie N, Chen ES, et al. Endothelial Keratoplasty for Fuchs' Dystrophy with cataract. Complications and clinical results with the new triple procedure. *Ophthalmology*. 2009;116(4):631–639. https://doi.org/10.1016/j.ophtha.2008.11.004.
51. Woo JH, Ang M, Htoon HM, Tan D. Descemet membrane Endothelial Keratoplasty Versus Descemet stripping automated Endothelial Keratoplasty and Penetrating Keratoplasty. *Am J Ophthalmol*. 2019;207:288–303. https://doi.org/10.1016/j.ajo.2019.06.012.
52. Yoo SH, Kymionis GD, Deobhakta AA, et al. One-year results and anterior segment optical coherence tomography findings of descemet stripping automated endothelial keratoplasty combined with phacoemulsification. *Arch Ophthalmol*. 2008;126(8):1052–1055. https://doi.org/10.1001/archopht.126.8.1052.