Review Article

Component corneal surgery: An update

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Several decades ago, penetrating keratoplasty was a challenge to corneal surgeons. Constant effort by the corneal surgeon to improve the outcomes as well as utilization of the available resources has led to a revolutionary change in the field of keratoplasty. All these efforts have led to the evolution of techniques that allow a corneal surgeon to disease-specific transplant of individual layers of corneal "so-called component corneal surgery" depending on the layer of cornea affected. This has led to an improvement in corneal graft survival as well as a better utilization of corneal tissues. This article reviews the currently available literature on component corneal surgeries and provides an update on the available techniques.

Key words: Component corneal surgery, endothelial keratoplasty, keratoplasty, lamellar keratoplasty

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Conventional penetrating keratoplasty (PK) has beneath the standard procedure for transplanting corneal tissue in cases of corneal opacities in the past. Of late, it has been recognized that this may be too much and replacement of all layers of the cornea may not be required in cases, where the disease is limited to a particular layer of the cornea. This disease-specific corneal layer replacement has led to an evolution in the concept of customized component corneal surgery.[1]

Shimmura has conceptualized the idea of the component surgery of cornea in 2004.[1] Subsequently, Vajpayee *et al*. initiated the concept of using one donor cornea for three recipients, that is, the anterior lamellar disc for a case of macular corneal dystrophy, the posterior lamellar disc for a case of pseudophakic bullous keratopathy (PBK), and the peripheral corneoscleral rim for limbal stem cell transplantation for a case of limbal stem cell deficiency.[2]

Component surgeries of the cornea have several advantages that include decreased the risk of graft rejection and avoidance of complications associated with open-sky procedures.[3-8] Further, these surgical techniques entail the utilization of one donor cornea for multiple recipients, which have a value in developing countries such as ours where there is a paucity of good quality donor corneal tissue.[9] This review article will discuss the currently available component corneal surgeries in practice. The detailed description of the individual procedure is beyond the preview of this article; however, the article would attempt to provide an update on all the currently popular techniques.

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Classification

The classifications of the component corneal surgeries have been described in Table 1.

Bowman layer transplantation

Midstromal isolated Bowman layer transplantation is a new surgical technique to reduce and stabilize ectasia in eyes with advanced keratoconus. The stabilization occurs due to the splinting action of Bowman's layer and wound healing effect between the host stroma and Bowman layer graft.[10,11] In this technique, the corneal button is mounted on an artificial anterior chamber followed by careful removal of the epithelium using surgical spears. A 360° superficial incision is made using a 30-gauge needle just within the limbal corneal periphery. An isolated Bowman layer is dissected from the anterior stroma, using a McPherson forceps and a custom-made stripper, over 360° from the periphery toward the corneal center. A Bowman flap graft size of 9.0–11.0 mm diameter is the target. The isolated Bowman graft tends to roll on itself due to its elastic properties forming a Bowman roll spontaneously. The Bowman's roll is then submerged in 70% ethanol to remove the remnant epithelial cells. A midstromal pocket up to the limbus, over 360°, is created under air using the manual dissection technique. The Bowman's roll is then stained with trypan blue dye and is inserted into the stromal pocket using a special glide. It is then unfolded and centered by manipulating the graft with the help of balanced salt solution and a cannula. Van Dijk *et al*. have reported an increase in the corneal thickness,

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Table 1: Classification of component corneal surgery

Name of the layer	Level	Name of surgery	Indications
Bowman's layer	Anterior to midstroma	Isolated Bowman layer transplantation	Advanced keratoconus
Stroma	Superficial 130-150 μ	SALK	Anterior stromal corneal opacities Anterior stromal scarring following pterygium excision and trachomatous keratopathy Anterior corneal dystrophies and degenerations
	Superficial 250 or 350 μ	ALTK	Corneal ectasias (keratoconus, PMD, and Terrien's marginal degeneration) Corneal dystrophies and degenerations such as lattice dystrophy, SND, and spheroidal degeneration Postoperative complications of refractive surgery such as scars or ectasia Ocular surface diseases such as SJS, OCP, and chemical or thermal burns Corneal trauma and infections
	Superficial 90% of stroma	pdDALK	Anterior corneal opacities or scars Keratoconus Corneal dystrophies such as Avellino, granular, and lattice Ocular surface diseases, for example, SJS, OCP, chemical or thermal burns, and vernal keratoconjuctivitis with stromal opacity Infectious keratitis (therapeutic DALK) or Descemetocele Mucopolysaccharidosis sparing endothelium
	Complete baring of DM	MD-DALK/dDALK	Anterior corneal opacities or scars Keratoconus Corneal dystrophies such as Avellino, granular, and lattice Ocular surface diseases, for example, SJS, OCP, chemical or thermal burns, and vernal keratoconjuctivitis with stromal opacity Infectious keratitis (therapeutic DALK) or Descemetocele Mucopolysaccharidosis sparing endothelium
Endothelium-DM complex	Lenticule of posterior stroma with endothelium	DSAEK	Endothelial diseases, for example, FECD, PBK, and corneal graft failure
	Descemet membrane and endothelium	DMEK	Endothelial diseases, for example, FECD, PBK, and corneal graft failure
	Pre-Descemet's layer along with DM and endothelium	Pre-Descemetic endothelial keratoplasty	Endothelial diseases, for example, FECD, PBK, and corneal graft failure

DM: Descemet's membrane, SALK: Superficial anterior lamellar keratoplasty, ALTK: Anterior lamellar therapeutic keratoplasty, DALK: Deep anterior lamellar keratoplasty, MD: Maximum depth, dDALK: Descemetic DALK, pdDALK: Pre-Descemetic DALK, DSAEK: Descemet stripping automated endothelial keratoplasty, DMEK: DM endothelial keratoplasty, PMD: Pellucid marginal degeneration, SJS: Stevens-Johnson syndrome, OCP: Ocular cicatrical pemphigoid, FECD: Fuchs' endothelial corneal dystrophy, PBK: Pseudophakic bullous keratopathy, SND: Salzmann nodular degeneration

stabilization of keratometry, improvement in best-corrected visual acuity (BCVA), and stabilization of the corneal ectasia in two of their published case series.[10-12] Although the authors have reported intraoperative perforation of Descemet's membrane (DM) as a potential complication, long-term studies are needed to establish the safety and efficacy of this procedure. With the currently available literature, Bowman layer transplantation may become a supplementary treatment option in the management of advanced keratoconus, which may help to defer PK or deep anterior lamellar keratoplasty (DALK).[10-12]

Stroma

Lamellar keratoplasty is indicated in cases of stromal diseases that spare the corneal endothelium.[13] It can be broadly categorized into two groups, anterior lamellar keratoplasty (ALK) and posterior lamellar keratoplasty (PLK). The indications are summarized in Table 1. In ALK, the superficial layers of the host's cornea are removed leaving the deeper layers of the recipient cornea.[3] In PLK, which usually refers to DALK in modern-day surgery, the host cornea is excised up to the DM or near DM level. The major advantage of anterior lamellar transplantation is that it is free of any risk of endothelial graft rejection.[5] The other advantages are summarized in Table 2. The different techniques of ALK are described below:

Superficial anterior lamellar keratoplasty

Superficial ALK (SALK) involves microkeratome-assisted ALK for anterior stromal corneal opacities. A superficial keratectomy of around 130–150 μm is performed depending on the depth of scar. This is followed by the transplantation of an appropriately sized donor graft over the host corneal bed. A microkeratome is used to perform automated dissection of both the donor and host corneas in SALK. Patel *et al*. reported excellent outcomes in their series of cases that included recurrence in cases of dystrophy, postphotorefractive keratectomy haze, and scarring after stromal melt.[14] Although SALK was originally described with the help of microkeratome, the host and graft preparation can also be

Table 2: Comparison of deep anterior lamellar keratoplasty and penetrating keratoplasty

Parameter	DALK	PKP
Indication	Stromal opacification with healthy endothelium	Both endothelial failure and stromal opacification
Visual rehabilitation	Early	Delayed
Quality of vision	Poor than PKP	Best
Interface haze	Affects vision	None
Higher order aberrations	More	Less
Postoperative astigmatism	Less	More
Wound strength	Better	Poor
Open-sky procedure	None	Risk of expulsive hemorrhage
Intraocular surgery	None	Complications can occur
Globe strength	Better	Poor
Steroid use	Early taper	Prolonged
Donor criteria	Not stringent even nonoptical grade can be used	Only optical grade
Single donor multiple use	Possible	Not possible
Graft rejection	Low risk	High risk
Technique	Difficult	Easy
Learning curve	Steep	Less steep

DALK: Deep anterior lamellar keratoplasty, PKP: Penetrating keratoplasty

done manually or with the help of femtosecond laser (FSL). The graft apposition to the host is achieved using either fibrin glue or overlay suture. Potential complications of this surgical technique include interface haze, infection, recurrence of herpes simplex, and other routine complications of any keratoplasty.

Automated lamellar therapeutic keratoplasty

In automated lamellar therapeutic keratoplasty (ALTK), a microkeratome is used to remove the superficial diseased corneal stroma as well as preparation of the donor button. Usually, shaving off the anterior 250 or 350 μm of the corneal thickness (depending on the depth of the opacity) is done followed by the transplantation of a partial thickness donor corneal stromal button [Figs. 1 and 2].[14-18] The advantage of microkeratome is that a smooth optical interface is obtained, thereby leading to better visual outcomes compared to manual dissection.

A major limitation of using the microkeratome is that it is difficult to perform lamellar dissection in eccentrically steep or thin corneas. To circumvent this limitation, Yuen *et al*.[19] have described the hemi-automated lamellar keratoplasty (HALK) procedure. HALK is a hybrid technique that combines manual lamellar dissection of the recipient bed and microkeratome-assisted donor lenticule preparation.[19] The other important issue is graft-host matching. It is important to note that the side cut of ALTK graft is not vertical unlike the routine PKP that may lead to problems in wound apposition. This problem can be avoided by creating a small peripheral pocket extending about 0.5 mm all around the stromal corneal bed and tucking the donor lenticule into the pocket manually before corneal suturing. Tan and Ang, in a case report, described a two-staged procedure to overcome this problem, however, the technique needs further validation.[20]

Deep anterior lamellar keratoplasty

The indications are summarized in Table 1.[21-24] DALK may be classified into pre-Descemetic DALK (pdDALK) and the maximum depth/Descemetic DALK (MD-DALK/dDALK) where the DM is completely bared.[21-24] pdDALK is usually performed manually by dissecting the corneal stroma down to the posterior 10% without fully reaching the DM. In MD-DALK/dDALK, the entire corneal stroma is removed all the way down to the level of the DM.[13,24] This can be achieved by various techniques described below.

Layer-by-layer manual dissection

Manual dissection is a useful technique of DALK in cases of corneal ectasia associated with deep stromal/Descemet scar or severe corneal thinning. Such cases include scar due to healed hydrops, healed keratitis, and advanced ectasia. An initial partial trephination extending up to 50%–70% of corneal thickness is made using a vacuum trephine or a guarded trephine. This is followed by the removal of the anterior stroma using a lamellar dissector or crescent knife. Multiple lamellar dissections are done in an attempt to obtain a near descemet depth. This is followed by layer-by-layer stromal removal, often repeated multiple times, to reach as close as possible to the DM. The disadvantage of this technique is poor visual outcome due to retained stroma, irregular interface, and subsequent interface haze.[25,26]

Air-assisted deep anterior lamellar keratoplasty

In this technique, described by Archila, near DM depth of dissection is achieved by injecting sterile air into the stroma followed by lamellar dissection, which may have to be repeated several times.[27] Anwar and Teichmann modified this technique and described the big-bubble DALK (BB-DALK), which is currently the gold standard.[28]

Big-bubble deep anterior lamellar keratoplasty

The technique involves injecting air into the corneal stroma at 60%–80% corneal depth through a groove created by partial trephination of the recipient cornea. The air creates a separation between the deep stromal layer and the DM pushing the DM behind. This can be recognized as a ring, which is visible in the corneal periphery under the

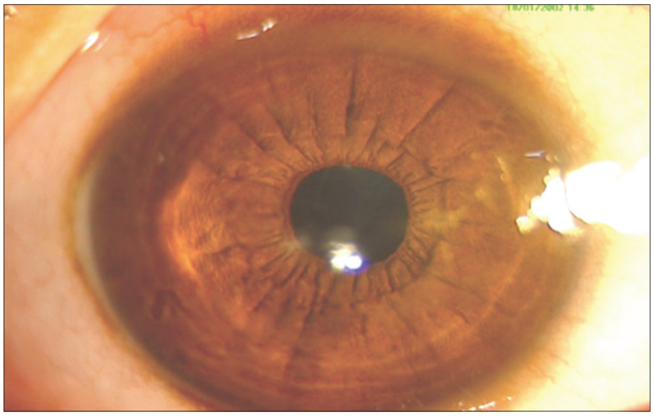

Figure 1: A case of keratoconus with sub-epithelial scar

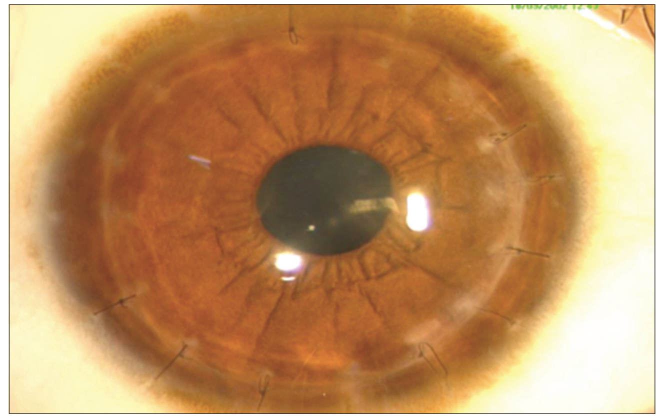

Figure 2: Case of keratoconus (same as Figure-1) after ALTK

microscope. After the plane of separation is achieved, the superficial stromal tissue is excised leaving a bare Descemet membrane.[28] The best part of this surgery is that the visual function achieved is comparable to PK. The disadvantages are a steep learning curve and its poor repeatability in inexperienced hands. In fact, the perforation rate ranges between 10% and 20% in experienced hands.[28]

Jhanji *et al*. described the "double-bubble" technique for easy identification of big-bubble formation.[29] In this technique, an air bubble is injected in the anterior chamber before injection of air in the corneal stroma. The shifting of the air bubbles to the periphery identifies successful separation of DM.

Recently, Dua *et al*.[30] hypothesized the existence of a sixth layer of cornea called pre-Descemet's layer ranging between 6 μ and 14 μ. In an experimental study, the authors described three types of bubble formation during big-bubble DALK. The type 1 bubble is characterized by a central, well-circumscribed, dome-shaped elevation of around 8.5 mm in diameter which the author hypothesized is due to the plane of separation anterior to the pre-Descemet layer rather than DM. On the contrary, a large (maximum 10 mm) bubble which extends till the periphery is due to separation above DM. Although an interesting concept, the existence of the sixth layer of cornea needs further validation.

Viscoelastic-assisted deep anterior lamellar keratoplasty

Melles technique is useful in the eyes with keratoconus with healed hydrops, traumatic cornea opacities, or healed keratitis with residual scars extending up to the DM.[31-36] In this technique, "air-to-endothelium" interface is utilized as a guide for depth of stromal dissection. An initial stromal pocket is created with the help of lamellar dissection followed by injection of viscoelastic into this pocket to achieve a dissection level as close as DM. It has the limitations similar to that of manual DALK due to the residual stroma.[22,29] A recent RCT reported similar outcomes between BB-DALK and Melles techniques except for poor contrast sensitivity in Melles technique.[37]

In addition to Melles technique, various modifications of visco-assisted DALK include deep lamellar keratoplasty using viscoelastic dissection,[38,39] full-bed DALK using hooking-detaching technique[40] and air-visco bubble technique.[41]

Hydrodelamination

In this technique, described by Sugita, saline solution is injected into the cornea, which enhances the identification and removal of the deep stromal fibers.[42]

Femtosecond-assisted lamellar keratoplasty

FSL provides a precise, accurate, and reproducible plane of dissection at desired depth in the corneal stroma.[43] Therefore, it can be extremely useful in creating the initial cutoff BB-DALK to inject air at appropriate depth for successful formation of big bubble. The other advantage is to create customized corneal edges for both donor and recipient corneas for mushroom- or zigzag-shaped DALK.[43,44]

Diamond knife-assisted deep anterior lamellar keratoplasty

This is another modification of DALK described by Vajpayee *et al*.[45] which is extremely useful in cases of corneal scar due to healed hydrops, healed keratitis, advanced corneal ectasia, and severe corneal thinning. Dia-DALK involves use of a diamond knife set at a depth of 30 μ less than the pachymetry reading, to create an initial 2.0-mm cut (from 11 to 12 o'clock) which is extended circumferentially as well as centripetally to remove the anterior stroma. The authors reported visual outcomes comparable to BB-DALK.[45] However, residual stromal haze may compromise the visual function as in the case of manual DALK.

Deep anterior lamellar keratoplasty in special situations

DALK with cataract surgery has been described by Muraine *et al*., wherein a closed-chamber phacoemulsification was performed after a deep lamellar dissection of diseased corneal stroma with the help of viscoelastic substance.[46] This helps to avoid complications associated with optical triple procedures such as incomplete capsulorrhexis, aspiration of the cortex, uncertain placement of the intraocular lens, posterior capsule rupture, choroidal effusion, and even expulsive hemorrhage. DALK combined with autologous limbal stem cell transplantation has been described for ocular surface reconstruction and visual rehabilitation in patients with unilateral severe chemical injury. This helps to restore a healthy ocular surface with replenishment of limbal stem cells and providing a clear cornea with good visual outcome.[47] DALK in children has been performed for various stromal pathologies such as keratoconus, microbial keratitis, corneal scar, corneal keloid, chemical injury with limbal stem cell deficiency, and dermoid.[48] Major advantages include lower risk of graft rejection and reduced risk of complications related to open-sky procedures with a similar visual outcome as PKP. DALK has been described for medically nonresponsive infective keratitis with complete removal of diseased stroma.[49] Anatomical success rate was similar to PK without any increased risk of recurrence of infection. This has been reported to be beneficial in cases of fungal, bacterial, and acanthamoeba keratitis. Advantages include less risk of graft rejection, failure and endophthalmitis with preservation of host endothelium.[21]

"Tuck in" lamellar keratoplasty

"Tuck in" lamellar keratoplasty is a special technique of LK described for the management of cases with extreme corneal ectasia, keratoglobus, and pellucid marginal degeneration.[50,51] The surgical technique involves transplantation of a large corneal graft (about 8.5 mm diameter) with a 2 mm peripheral flange, which is tucked into a previously created circumferential pocket at the edge of the host bed. A large tucked-in graft provides tectonic support to the corneal periphery avoiding any damage to the limbal stem cells. The disadvantages of this technique include a long operating time, steep learning curve, and interface haze.[51]

Complications

Descemet membrane perforation: The most important intra-operative complication of DALK is DM perforation.[21,52] Its incidence ranges between 4% and 20%, and this can occur at any step of surgery. The risk factors for DM perforation includes inexperienced surgeon, healed hydrops, healed keratitis, advanced corneal ectasia, and corneal thickness <250 µm.[21,53] A small perforation can be managed by intracameral injection of air and careful stromal dissection while a large perforation requires conversion to PK.

Pseudoanterior chamber

Pseudoanterior chamber, also referred as double anterior chamber or interface fluid, can be due to retention of fluid as a consequence of DM perforation or retention of viscoelastic.[54,55] The reported incidence is <1%.[21] Although a shallow pseudochamber can be observed, a large pseudochamber requires surgical intervention in the form of drainage of fluid and intracameral injection of air or gas.[54,55]

Urrets-Zavalia syndrome: This syndrome was first described by by Urrets-Zavalia[56] and is characterized by a fixed dilated pupil with or without associated iris atrophy. Other associated features includes, posterior synechiae, ectropion uvea, pigment dispersion, and anterior subcapsular cataract. Although the exact pathogenesis is not known, the proposed mechanisms include iris ischemia and pupillary block.[21]

Interface wrinkling: Mismatch between the donor and the recipient bed size leads to folds in the DM. This is common in cases with advanced ectasia.[57] These folds are usually temporary and disappear with time without any effect on the final visual acuity.

Epithelial/stromal rejection: The incidence of this visually nonsignificant complication ranges between 3% and 15%.[21,58] Such episodes respond rapidly to topical steroids, however, very rarely stromal vascularization leading to poor vision can occur in such cases if inadequately treated.[21,58]

Interface keratitis: This is one of the major sight threatening complications of DALK. *Candida* is the most common species identified in such cases. Conservative treatment is usually unsuccessful and most cases need a therapeutic PK.[59]

Outcomes

Visual acuity: In general, the visual outcomes are comparable between PK and DALK. Visual outcome depends on the residual stromal bed thickness and interface irregularity.[34]

Refractive outcomes: Reports of postoperative myopia ranges from 3.0 to 13.0 D.[21] Comparable outcomes between PK and DALK have been reported in various studies.

Endothelial cell loss: The major advantage of DALK over PK is a lower rate of endothelial cell loss. The endothelial cell loss in PK can be as high as 34.6%, whereas in DALK, it has been reported to be around 13.9%.[21,60]

Although, conventionally DALK is considered to have better endothelial cell loss and graft survival compared to PK, recently a large study published by Australian Graft Registry reported graft survival and visual outcomes significantly better in penetrating grafts.[61] Even though, the study suffers from several limitation such as retrospective study design, lack of data on surgeon's experience, reporting bias, and nonuniformity of the technique used the findings may offer a more practical data on comparison between DALK and PK in daily clinical practice that cannot be ignored.

Endothelium-DM complex

Endothelial keratoplasty (EK) has recently emerged as the procedure of choice for patients with endothelial diseases, including Fuchs' endothelial corneal dystrophy, PBK, and corneal graft failure. In EK, a healthy donor tissue replaces only a diseased posterior layer of the cornea. It has several advantages over full-thickness PK that includes early visual rehabilitation, a less invasive procedure, no need of long-term corneal sutures, predictable refractive outcomes, preservation of corneal innervation, fewer ocular surface complications, better tectonic/structural integrity, and reduced chances of endothelial graft rejection.[1,21] Currently, the popular techniques of EK includes Descemet stripping automated endothelial keratoplasty (DSAEK) and DM endothelial keratoplasty (DMEK).

Descemet stripping automated endothelial keratoplasty/Descemet-stripping endothelial keratoplasty

DSAEK has become the gold standard of EK in recent years due its efficacy, safety, and reproducibilty in achieving optimal visual outcomes.[62,63] The procedure is fairly reliable with a low rate of complications. Over the past few years, there has been a constant attempt to reduce the graft thickness (GT) without increasing the risk of tissue loss while donor preparation since a thinner graft is associated with a better visual outcome.

Donor preparation: Various methods have been discovered such as manual lamellar dissection, single- and double-pass automated microkeratome, and recently, FSL.[64-66] Previously, donor lenticule used to be prepared just before the surgery, now in most of the centers, it is prepared in advance by an eye bank technician and is delivered to the surgeon.[67]

In the standard single-pass technique that uses microkeratome head of size 350 μm, the average thickness of harvested endothelial grafts may be 150–250 μm.[62] In recent times, following two techniques that can harvest thinner donor lenticules are being successfully used:

i. Double-pass microkeratome technique: This technique, first described by Busin *et al*., aims to achieve an ultrathin graft (GT < 100 μm) by passing the microkeratome twice.[65] In this technique, a specially designed artificial anterior chamber with a rotatable guide ring allows the second pass to be initiated 180 degrees away from the initial entry point of the first pass. This modification allows entry at a thicker area of the cornea which decreases the chance of perforation and creates more planar grafts. Busin *et al*. reported the visual outcomes of "ultrathin DSAEK" (UT DSAEK) that are comparable with those published for DMEK and better than the standard DSAEK in terms of both speed of visual recovery and percentage of patients with 20/20 final visual acuity. However, unlike DMEK, in UT DSAEK, preparation and delivery of the donor tissue is easier and less-time consuming. Complications of UT DSAEK are same as recorded with standard DSAEK but are much less frequent than those reported after DMEK[65]
ii. Single-pass microkeratome technique: Although the reported results are encouraging with UT DSAEK but the donor tissue needs to be cut twice resulting in a potential risk of donor corneal perforation. In addition, like DMEK, after a double pass, thin lenticule is more difficult to maneuver. Finally, it involves longer duration of raised intraocular pressure as well as the risk of obtaining a smaller diameter cut after the second pass[68]
   To overcome these problems, Vajpayee *et al*. used a 400-μm microkeratome head and slowed the speed of the pass to achieve a thinner donor lenticule without any complications during the donor preparation.[64] A single, slow pass of 400 μm microkeratome yielded thin donor lenticules in all the cases, and the mean GT achieved at the end of 6 months was 111 ± 17.62 μm (range: 70–134 μm). Excellent visual outcomes were obtained in majority of the patients [Figs. 3 and 4]. Moreover, this technique has no learning curve for the surgeons who are already using an artificial anterior chamber for the preparation of a DSAEK donor lenticule and is more economical as compared with the double-pass technique and without the possible complications associated with the double-pass technique.
iii. Microkeratome and excimer laser-assisted endothelial keratoplasty (MELEK): A modified form of the UT DSAEK is the MELEK.[69] In this technique, a corneal graft is prepared by a single cut of a microkeratome followed by a stromal excimer-laser thinning and smoothening
iv. Femtosecond and excimer laser-assisted endothelial keratoplasty (FELEK): Femtosecond laser-assisted endothelial keratoplasty is another addition to the existing techniques of EK donor lenticule preparation.[69,70] However, the problem with this technique was greater surface irregularity with the laser-assisted EK.[70] A new technique, FELEK, has been described to overcome these issues. In this technique, the donor cornea undergoes a lamellar cut with the FSL at a desired depth, followed by excimer laser photoablation of the stromal tissue. While FSL yields a thin and reproducible graft with a high level of safety and accuracy, excimer laser provides a smooth and a high-quality interface.[69,70]

Host bed preparation: The standard technique involves scoring of the DM either through a clear corneal incision or through a corneoscleral tunnel.[62,63] The area of DM scored should be greater than the donor tissue. The size of the donor is usually decided by the host corneal diameter (we prefer 3 mm less than the white-to-white measurement). Few authors recommend no stripping of the DM other than cases where DM is wrinkled or scarred which may affect the final visual outcome.[63] In cases with failed graft DM scoring are usually avoided, and the graft size is usually kept less than the previous graft size due to high risk of graft detachment postoperatively which occurs due to irregularity at the posterior graft host junction.[71]

Donor insertion: Advancements have also been made in the delivery of donor lenticule inside the eye. Earlier, forceps were used most commonly. However, due to a significant endothelial cell loss noted by the crushing effect of the forceps, development of safer insertion devices became a necessity. All the newer available inserters have been designed to protect the graft from folding and to reduce the incision compression pressure. The currently available insertion devices may be categorized into two groups based on the injection technique such as pull through designs (glides) and push in designs (injectors).[62,72-74] Most of these devices require an incision size of 2.5–5 mm to inject a lamellar allograft with a diameter of around 7–9 mm and thickness of 100–250 μm.[62,72-74] The commonly used glides are EndoGlide and Busin glide. The different inserters are Endoserter, Endoshield/Endoinjector, and Neusidl injector.[72-74]

Descemet's membrane endothelial keratoplasty

Ophthalmic surgeons have constantly endeavored to reduce the thickness of the DSAEK donor lenticule, aiming to improve visual outcomes, and reduce the magnitude for potential hyperopic shift after the surgery [Table 3]. The concept of eliminating corneal stroma from the donor lenticule was realized in the surgical technique of DMEK, whereby only the DM with endothelial cells is transplanted into the host.[75] This ensured a rapid visual recovery and a higher chance of achieving 20/20 visual acuity postoperatively. However, the major challenges

Table 3: Comparison of descemet stripping automated endothelial keratoplasty and descemet membrane endothelial keratoplasty

Features	DSAEK	DMEK
Learning curve	Easy	Difficult
Need of microkeratome	Yes	No
Graft manipulation	Easy	Difficult
Wastage of tissue	Less	More
Graft dislocation	Less	More
Stromal interface	Present	None
Speed of visual recovery	Slow	Rapid
Hyperopic shift	Present	Nil
PAS	More	Less
% of cases with 20/20 vision	Less	More
Endothelial rejection	More (12%)	Less (1%)

DM: Descemet's membrane, DSAEK: Descemet stripping automated endothelial keratoplasty, DMEK: DM endothelial keratoplasty are the preparation as well as insertion of the donor lenticule inside the anterior chamber of the recipient eye. In addition, this technique has a greater graft repositioning rate, thereby leading to a higher risk of wastage of graft. Due to these difficulties, this technique is less popular among the corneal surgeons compared to Descemet-stripping endothelial keratoplasty/DSAEK.[74-77]

In DMEK, the donor DM is stripped and injected into the anterior segment of the recipient that has been stripped of its own DM [Fig. 5], through a 3-mm clear corneal incision.[74-77] The membrane is unrolled using pneumatic and fluidics manipulations and apposed to the recipient posterior stroma using air-bubble technique similar to DSAEK.

Donor preparation: The donor preparation for DMEK involves harvesting the donor DM scroll [Fig. 6]. Various techniques described for donor preparation are as follows:

Yoeruek and Bartz-Schmidt introduced two new untoothed curvilinear forceps for improved dissection of DM and compared it with the 1-point forceps technique.[78] Curvilinear forceps technique was associated with low-level tissue wastage and a shorter preparation time.

Busin *et al*. developed a technique of pneumatic dissection of donor DMEK scroll. Donor corneas are mounted on an artificial anterior chamber, and the anterior stroma is removed with a 300 μm microkeratome head.[79] Air is then injected into the residual donor tissue with a 30-gauge needle from the endothelial side to detach DM. The bubble is expanded as far as possible into the periphery. Complete detachment of DM was reported in 19 of 20 (95%) of the cases with an average graft size of 8.11 ± 2.0 mm.[79]

Muraine *et al*. devised a "Muraine Punch," which is a circular trephine with a blade, and opened in two places with a guard at a depth of 300 μm. The blade was pressed against the endothelial surface to separate DM and a part of the stroma. The preparation of the graft was then continued on an artificial anterior chamber using a 27-gauge cannula.[80]

Brissette *et al*., in an *ex vivo* study, reported no significant difference in the median time to prepare grafts between Muraine punch, and the standard submerged cornea using backgrounds away (SCUBA) peeling technique.[81] However, there was a significantly higher number of graft tears in the Muraine punch group (5/20) compared to no graft tears in the SCUBA technique. In addition, specialized equipment is required in Muraine technique. Thus, the SCUBA technique may be superior for the preparation of endothelial donor grafts for DMEK.[81]

Hemi-Descemet's membrane endothelial keratoplasty: The concept of using two endothelial grafts from one donor cornea was evaluated by Lie *et al*.[82] This technique takes into consideration the substantial shortage of donor tissues for endothelial keratoplasty worldwide and evaluated the concept of using two endothelial grafts from one donor cornea, which may potentially increase the pool of suitable donor tissues for DMEK.[82] In an experimental study including 10 human corneas, the authors could successfully obtain two DMEK grafts with a different (semi-circular) shape (hemi-DMEK), but similar surface area as a "conventional" 8–9 mm circular transplant from a single donor cornea. They concluded that preparation of two hemi-DMEK grafts from one single human donor cornea is technically feasible, and the grafts can be stored in organ-culture medium similar to the standard circular DMEK grafts. Thus, hemi-DMEK may have the potential to double the availability of donor endothelial tissue.

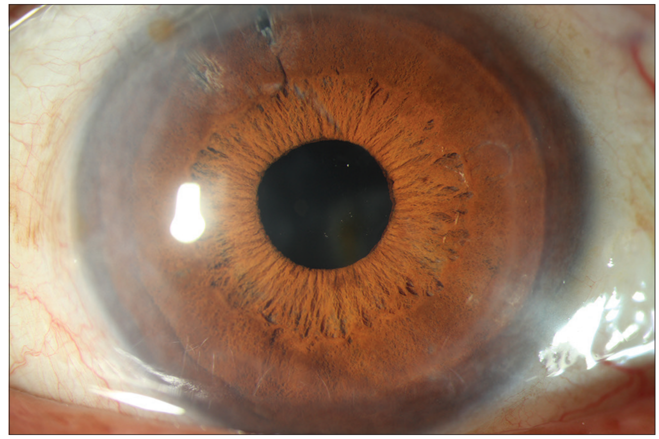

Figure 3: Diffuse slit-lamp image showing a case of operated DSAEK with clear cornea

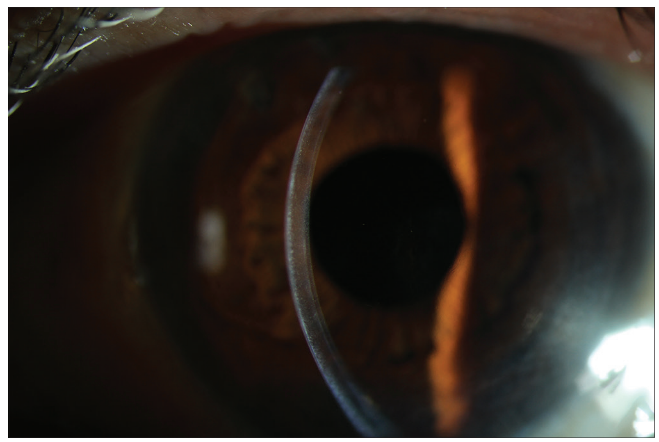

Figure 4: Focal slit-lamp image (of figure-3 case) showing a well attached DSAEK lenticule

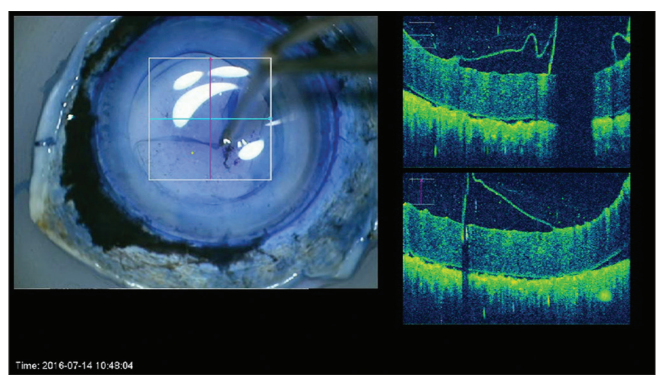

Figure 5: iOCT assisted DM peeling from host cornea

Donor insertion: Various methods have been described for donor insertion in DMEK.

i. Bimanual technique: Güell *et al*. introduced a new bimanual technique for insertion and positioning

Table 4; Outcomes of DMEK

Author	Type of study	No. of eyes	Surgical technique	Graft survival	Graft failure	Intraoperative complication	Comments
Parekh *et al*.[91]	Randomized , comparative	18; (9 in each group)	DMEK in DMEK out	-	-	-	Donor lenticule can be tri-folded (endo-in) with no significantly less cell loss as compared to endo-out
Szurman *et al*.[92]	Retrospective	86	DMEK (Novel liquid bubble dissection technique for DM preparation)	98.84%	1.16 %,	8% of preparations were complicated; the total success rate was 99 %. One graft could not be used for transplantation because of a central tear	Novel liquid bubble technique is easy, can be learned and performed rapidly, with no touch
Arnalich *et al*.[4]	Retrospective	30 15 in group 1(no premarking and air tamponade) and 15 in group 2 (premarking and SF6 tamponade)	DMEK	60% vs 100%	40% vs 0%)	Need of rebubbling due to complete or partial graft detachment (40% vs 6%)	Premarking the graft to assess orientation and using a SF6 gas tamponade dramatically reduces the risk of primary graft failure
Tourtas *et al*.[5]	Retrospective	26 in group 1 22 in group 2	DMEK	-	-	-	A larger descemetorhexis in DMEK resulting in a peripheral small zone of denuded stroma does not increase the incidence of peripheral corneal edema
Maier *et al*.[96]	Prospective	53	Temporal DMEK Superior DMEK	-	-	Rebubbling for graft detachment 39.1% vs 26.7%	The temporal approach induces significantly less SIA and corneal aberration
Melles *et al*.[7]	Interventional	10	Hemi DMEK	90%	10%	4 eyes required rebubbling for visually significant graft detachment.	Hemi -DMEK have the potential to double the availability of donor tissue
Busin *et al*.[42]	Retrospective	42	DMEK Contact Lens-Assisted Pull-Through Technique for Delivery of Tri-Folded (Endothelium in)	100%	0%	Graft detachment in 23.8%	Trifolded with the endothelium inward, reduces surgical trauma to donor cells and facilitates spontaneous unfolding, thus minimizing surgical time

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Table 4: Contd...

Author	Type of study	No. of eyes	Surgical technique	Graft survival	Graft failure	Intraoperative complication	Comments
Guell *et al.*[96]	Retrospective	42 in Group 1 (SF6) 39 in Group 2(air)	DMEK	100%	0%	Intracameral air reinjection was needed in 1 patient in group 1 (2.38%) and in 5 patients in group 2 (12.8%)	Tamponade with 20% SF6 yielded a significantly lower incidence of graft detachments
Jacob *et al.*[85]	-	-	E-DMEK	-	-	-	Enhanced intraoperative visualization of the graft in corneal decompensation
Agarwal *et al.*[87]	Case series	5	PDEK	100%	0%	-	PDEK can be a viable option in endothelial keratoplasty with some potential advantages
Studeny *et al.*[89]	Retrospective case series	20	DMEK-S/Hybrid technique	90%	10%	Partial graft detachment (60%). The loss of donor corneas during preparation decreased from approximately 10 to 5% as more experience was acquired with the procedure	DMEK-S is entirely manual, and no special surgical equipment is needed
McCauley *et al.*[88]	-	-	DMAEK (Hybrid technique)	-	-	-	It combines the superior vision potential of Descemet membrane endothelial keratoplasty with the easier insertion and manipulation of DSAEK
Pereira *et al.*[90]	Retrospective	6	DMEK (4) DMAEK (2)	83.33%	16.66%	4 DMEK eyes had peripheral graft detachment	DMEK or DMAEK can be considered to treat failed PKs
Yoeruek *et al.*[78]	Case series	10	DMEK	100%	0%	-	Simultaneous digital pressure with corneal tapping is a helpful maneuver to unfold the DM inside the anterior chamber

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Table 4: Contd...

Author	Type of study	No. of eyes	Surgical technique	Graft survival	Graft failure	Intraoperative complication	Comments
Muraine *et al*.[80]	Retrospective case series	50	DMEK	96%	4%	-	Use of a 27 gauge cannula to detach the Descemet membrane (DM) is a reliable and efficient technique
Güell *et al*.[83]	Prospective, noncomparative, consecutive interventional case series	15	DMEK (Bimanual infusion technique)	100%	0%	Partial peripheral graft detachment (6.6%)	Insertion and positioning of EDM grafts in DMEK was successfully achieved using this bimanual infusion technique
Salvalaio *et al*.[97]	Retrospective	30	Submerged hydro-separation (SubHyS) technique) DMEK	-	-	Complete detachment (100%) of Descemet's membrane and stroma was achieved in all 30 cases.	Standardised , pre-validated (quality assured), pre-separated, no-touch technique
Terry *et al*.[98]	-	80	DMEK (Novel glass injector)	92.5%	7.5%	6% rebubble rate	Upside-down grafts may be eliminated by the use of donor tissue premarked by the an S orientation stamp
Veldman *et al*.[99]	Retrospective	Group 1 (Stamped)-133 Group 2(Unstamped) -32	DMEK Stromal -sided S-stamp preparation technique	-	-	Upside -down graft implantations 0 vs 3 Rebubble rate- 17 vs 1	Stromal -sided S-stamp eliminates iatrogenic primary graft failure
Ciechanowski *et al*.[100]	Retrospective	400	DMEK no touch technique	-	-	Resurgery rate -5%	Standardized no-touch DMEK technique achieves a rapid and nearly complete visual rehabilitation
Dsaek							
Busin *et al*.[65]	Prospective	285	UT-DSAEK (double pass)	97.2%	Primary failure in 1.4%; and secondary failure in 1.4%.	Microkeratome failure to achieve perfect dissection in 7.2% donor tissues with 2.1% being discarded; total graft detachment in 3.9%	-
Vajpayee *et al*.[64]	Interventional case series	15	Thin lenticuleDSAEK (single slow pass technique)	100%	0	-	Single pass technique is safe

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Table 4: Contd...

Author	Type of study	No. of eyes	Surgical technique	Graft survival	Graft failure	Intraoperative complication	Comments
Ang *et al.*[102]	Retrospective comparative case series	EndoGlide group (100 eyes) Sheets glide group (119 eyes)	DSAEK TAN EndoGlide/Sheets glide	97.9% vs 86.5%	2.1% vs 13.5%	-	Graft survival was greater in the EndoGlide.
Foster*et al.*[101]	interventional, nonrandomized, consecutive case series	175 (105 small incision forcep, 70 with injector)	DSAEK (small incision)	98.6%- injector 93.5%- forcep	1.4%- injector 6.5%- forcep	Graft detachment; 5.7%- injector 27.6%- forcep	Injector device has several advantages over the trifold forceps technique
Titiyal *et al.*[103]	Prospective case series	27	Sutureless clear corneal DSAEK	100%	0%	-	Sutureless clear corneal DSAEK is simple and effective
Thannhäuser *et al.*[69]	Prospective case series	18	MELEK	-	-	-	It is safe technique
Rosa *et al.*[104]	-	25	Femtosecond laser and microkeratome-assisted DSAEK	-	-	-	It yielded very thin grafts (<100 μm), excellent visual results
Terry *et al.*[74]	Prospective, randomized, masked clinical trial	100 Gp1 Forceps- 50 Gp2 Neusidl Inserter -50	DSAEK	99	Late failure=1 (Neusidl group)	1 dislocation occurred in the Neusidl group	Neusidl Corneal Inserter yielded a low immediate complication rate

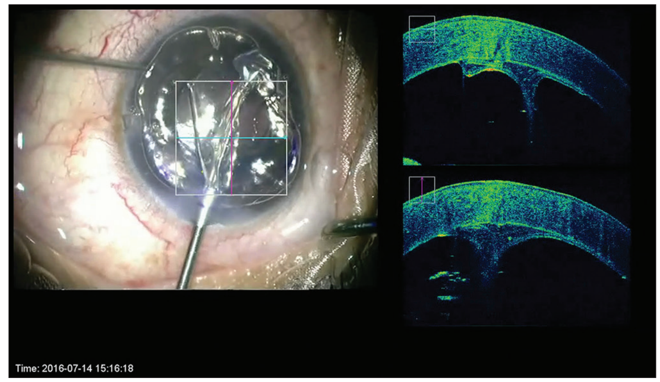

Figure 6: iOCT assisted Peeling of Donor in DMEK

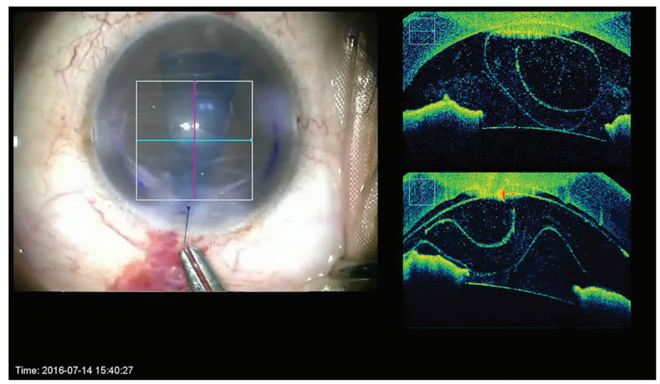

Figure 7: DM roll in anterior chamber during DMEK as seen in iOCT

of endothelium-DM (EDM) grafts in DMEK.[83] This technique involves the injection of EDM after lowering the pressure of the irrigation fluid, and withdrawing the infusion cannula just before the injector is retracted from the main incision to prevent the EDM roll sweeping through the main incision. A Gills cannula connected to an automated irrigation aspiration system is introduced to unfold and position the graft. Insertion and positioning of EDM grafts in DMEK was successfully achieved in 15 pseudophakic eyes using this technique, and air reinjection was needed in only one case for a partial peripheral graft detachment[83]

ii. Contact Lens-Assisted Pull-Through Technique for Delivery of Tri-Folded (Endothelium in) DMEK Grafts: Busin *et al.* described a unique technique in which donor lenticule is harvested to a diameter of 8.25 mm and then trifolded with the endothelium in.[84] A sterile soft contact lens is used as a scaffold; the tissue is loaded in this configuration into a disposable cartridge and delivered into the anterior chamber under continuous irrigation using a bimanual pull-through technique to ensure proper unfolding. Delivering donor lenticule trifolded with the endothelium inward, reduces surgical trauma to donor cells, and facilitates spontaneous unfolding, thus minimizing surgical time

iii. Endoillumination-assisted DMEK (E-DMEK): Compromised visibility is problematic in DMEK, especially in the presence of corneal edema. The visualization can be improved using an oblique light from the endoilluminator.[85] Jacob *et al.* reported better graft visibility in 12 eyes of 12 patients with

E-DMEK.[85] In all patients, despite the lack of adequate media clarity, the graft could be easily visualized with the endoilluminator probe during all the steps. In addition, graft position, orientation, and folds were better visualized with endoillumination. The final graft location after the bubble was injected could also be confirmed with the endoilluminator.

One of the major challenges after donor tissue insertion is to identify the orientation of the graft [Fig. 7]. To avoid the complication of an inverted graft, various donor tissue-marking techniques have been described like the F stamp and S stamp.[86]

Outcomes and complications

Outcomes and complications are described in Table 4.[75-104]

Pre-Descemet's endothelial keratoplasty: Agarwal *et al*. described a technique in which the pre-Descemet's layer along with DM and endothelium is transplanted.[87] The technique was performed in five eyes of five patients, with the successful attachment of the graft and good postoperative visual recovery in all cases. Postoperative optical coherence tomography showed graft attachment without any interface abnormalities with a mean GT of 28 ± 5.6 μm.[87]

Hybrid technique: The literature suggests that endothelial cell loss is similar in DMEK and DSAEK. However, DMEK has better outcomes in terms of BCVA, whereas DSAEK has the advantage of easier graft manipulation. Trying to merge the superior visual results of DMEK with the easier manipulation of the DSAEK grafts, McCauley *et al*. described a hybrid DSAEK/DMEK technique, using big-bubble dissection at the central part of the donor cornea, to leave a bare central Descemet's membrane with a peripheral rim of stroma.[88] Subsequently, different authors have proposed various hybrid techniques including DMEK with a stromal rim by Studeny *et al*.,[89] DMAEK (DM automated endothelial keratoplasty) by Pereira *et al*.[90] and "sickle" DMEK by Busin *et al*.[79] However, in exchange for the ease of intraoperative placement, these techniques are difficult to learn and tissue preparation may not be consistently successful.

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Conflicts of interest

There are no conflicts of interest.

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