Review Article

Paradigm Shifts in Corneal Transplantation

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Abstract

Conventional corneal transplantation, in the form of penetrating keratoplasty (PK), involves full-thickness replacement of the cornea, and is a highly successful procedure. However, the cornea is anatomically a multi-layered structure. Pathology may only affect individual layers of the cornea, hence selective lamellar surgical replacement of only the diseased corneal layers whilst retaining unaffected layers represents a new paradigm shift in the field. Recent advancements in surgical techniques and instrumentation have resulted in several forms of manual, microkeratome and femto-second laser-assisted lamellar transplantation procedures. Anterior lamellar keratoplasty (ALK) aims at replacing only diseased or scarred corneal stroma, whilst retaining the unaffected corneal endothelial layer, thus obviating the risk of endothelial allograft rejection. Posterior lamellar keratoplasty/endothelial keratoplasty (PLK/EK) involves the replacement of the dysfunctional endothelial cell layer only. Whilst significant technical and surgical challenges are involved in performing lamellar micro-dissection of a tissue which is only 0.5 mm thick, the benefits of a more controlled surgical procedure and improved graft survival rates have resulted in a shift away from conventional PK. This review details the current advances in emerging lamellar corneal surgical procedures and highlights the main advantages and disadvantages of these new lamellar corneal procedures.

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Introduction

The major advances in corneal transplantation over the last 50 years, have been due to the development of the microsurgical microscope, improvements in microsurgical techniques, better understanding of the fundamental basis of immunological allograft rejection and the role of the corneal endothelium in graft clarity and corneal graft rejection. All these factors have resulted in the success of penetrating keratoplasty (PK) as the predominant form of corneal transplantation, with at least 1 million transplants performed since 1961 (www.restoresight.org). Penetrating keratoplasty is full-thickness replacement of the cornea. Prior to PK surgery, in the middle of the last century, the most commonly performed corneal transplantation procedure was anterior lamellar keratoplasty (ALK). This involved only exchanging the corneal stromal and epithelial layers and avoided replacement of the deepest layer of the cornea (the endothelial layer). Avoiding the replacement of the endothelial layer circumvented the risk of endothelial immunological graft rejection, which was the most common reason for PK failure prior to our understanding of transplantation immunology and the role of the donor endothelial layer as the major cause of graft failure from allograft rejection. Subsequent development of topical steroid eye-drops (to prevent and treat corneal graft rejection) led to greatly enhanced PK graft survival rates. Hence, PK surgery became the dominant form of modern corneal transplantation in the second half of the last century, and is still the most common form of corneal transplant surgery performed worldwide today. This shift from ALK to PK occurred because the surgical technique used for ALK resulted in an irregular interface with sub-optimal visual results.

In the last decade, however, there has been a gradual resurgence of ALK surgery. This has occurred due to publications of long-term PK survival studies which have

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shown poor long-term graft survival rates. This has been primarily due to the continual loss of donor endothelial cells eventually leading to graft failure. Bourne et al have shown that endothelial cell attrition follows a bi-exponential decay.[1] This earlier observation was confirmed more recently by Bertelmann et al and the Cornea Donor study group with both studies showing a 70% endothelial cell loss in the 5 years following PK.[2,3] The Australian Corneal Graft Registry (ACGR) has shown that the 1-year graft survival rate following PK, for all indications, was 90% and this dropped to 59% at 10 years.[4] In a similar study by Dandona et al from India, the long-term graft survival rates were 79% at 1 year and 46% at 5 years (it should be noted that this study excluded poorer prognosis grafts for therapeutic indications such as infectious keratitis).[5] In addition, the development of new surgical techniques of manual, semi-automated microkeratome-assisted and femtosecond laser-assisted corneal lamellar surgery has revitalised ALK surgery (see below).

The introduction of microkeratome devices evolving from their use in laser-assisted in-situ keratomilieusis (LASIK), has now led to the development of new forms of posterior lamellar replacement, in the form of endothelial keratoplasty (EK), and new EK procedures such as Descemets Stripping Automated Endothelial Keratoplasty (DSAEK). These newer surgical procedures are now being adopted by corneal surgeons as a viable alternative to conventional PK surgery for endothelial forms of corneal blindness.

Asian Studies on Corneal Transplantation – The Singapore Corneal Transplant Study (SCTS)

Although there are several large-scale longitudinal studies on the success and risk factors for corneal transplantation, there are very few studies evaluating the success of corneal transplantation in Asian eyes.[5-7] The Singapore Corneal Transplant Study (SCTS) is the largest published study on corneal transplant survival in Asian eyes, and is an on-going prospective cohort study on all corneal grafts performed at the Singapore National Eye Centre (SNEC). The data collected by the study include information on preoperative clinical data, donor tissue data, and operative data prior to, and at the time of surgery, as well as postoperative information for all patients attending SNEC on a yearly open-ended basis. The SCTS data collection forms consist of 65 preoperative fields, 45 donor fields, 37 operative fields and 85 postoperative fields. The SCTS database currently has data on over 2700 transplants, performed between January 1991 and December 2007, and includes corneal grafts for all indications e.g. optical – for visual improvement, therapeutic – to eradicate infection or neoplasia; and tectonic – to restore globe integrity in perforated corneas. It includes all forms of corneal transplantation, including PK and the newer forms of lamellar corneal transplantation.

We recently published the success rate and risk factors for graft survival in 901 consecutive cases of PK surgery within the SCTS cohort.[6] Our PK study confirmed that graft survival rates gradually reduce over a 10-year period, similar to other studies in Caucasian populations, e.g. the ACGR.[4] Our PK survival rates were 91%, 77%, 67% and 56% at 1, 3, 5 and 10 years, respectively, very similar to those rates reported in ACGR, but considerably better than the only other longitudinal study of PK survival in Asian eyes by Dandona et al.[5]

Targeted Lamellar Replacement in Corneal Transplantation Surgery (Fig. 1)

Due to the poor long-term survival of PK surgery, many authors have been exploring other forms of corneal transplantation. These have mainly focused on lamellar replacement of just the diseased corneal layers. The concept of targeted or selective lamellar corneal replacement is surmised around the fact that a significant proportion of corneal diseases tends to involve either just the anterior corneal layers or the endothelial cell layer. ALK is the procedure of choice for the replacement of just the anterior corneal layers, since it avoids unnecessary replacement of the endothelial cell layer, and EK is the procedure of choice to replace a diseased endothelial cell layer, since it avoids unnecessary surgery on a healthy anterior stromal surface.

A major reason for late graft failure is the continual attrition of endothelial cells following PK surgery. Our SCTS study showed that over 60% of PK graft failures were related to either an acute episode of endothelial graft rejection or to late endothelial decompensation from gradual endothelial cell loss.[6] In a multivariate analysis of risk factors for graft failure, preoperative vascularisation/ inflammation and low donor endothelial cell counts were all significant predictors of graft failure. Hence, avoiding unnecessary endothelial replacement would provide a significant improvement in graft survival. In conditions such as anterior stromal scarring following infectious keratitis, corneal stromal dystrophies and corneal ectasias such as keratoconus, the corneal endothelium is unaffected and essentially healthy. In these situations, instead of performing PK, one should consider performing ALK. Since the mid-90s, SNEC surgeons have been gradually switching to ALK surgery, and 34% of all grafts performed in SNEC in 2007 were ALK procedures (Fig. 2). The indications for ALK included keratoconus (8.3%) and anterior stromal dystrophies (9.5%), non-perforated infections unresponsive to medical treatment (7.3%), and other forms of corneal scarring or thinning (12.9%).

In the last 8 years, various surgical procedures aimed at targeting posterior lamellar replacement, whilst retaining the healthy anterior corneal stroma have arisen. Since the first description of posterior lamellar keratoplasty (PLK), this procedure has now evolved into a variety of EK procedures, and most recently, are essentially sutureless, small incision (keyhole) forms of surgery. The most recent form, DSAEK, is quickly becoming the preferred alternative to conventional PK for pathology affecting the corneal endothelium e.g. Fuchs' endothelial dystrophy, post-surgical endothelial decompensation.

Both ALK and EK procedures minimise the unnecessary replacement of unaffected, healthy corneal layers and EK additionally result in tectonically stronger eyes.

New Forms of Anterior Lamellar Keratoplasty Surgery

A variety of new ALK procedures are now emerging, catering to a wide range of corneal stromal disorders. The various ALK procedures today include:

1. Conventional manual ALK surgery (Predescemetic ALK) – Improved manual surgical dissection techniques now enable removal of stroma down to the deeper most layers of the corneal stroma, but usually with retention of up to 10% of remaining posterior stroma, without fully reaching Descemets membrane (DM). The disadvantages of manual ALK are interface haze causing a reduction in best corrected visual acuity compared to PK and the risk of inadvertent rupture of DM.

2. Deep Anterior Lamellar Keratoplasty (DALK) (Descemetic ALK) with total corneal stromal replacement – Total stromal removal down to DM may be achieved using a variety of techniques. Forceful intrastromal air injection to split DM away from the posterior stroma was described by Anwar (Anwar's big bubble technique). Other surgeons have described the use of viscoelastic or balanced salt solution (BSS). All these techniques involve forceful injection of a substance to enter the potential space between the posterior stroma and descemet's membrane resulting in a clean separation. DALK with total stromal removal represents a significant advancement over conventional manual ALK in terms of visual acuity outcomes. However, its widespread acceptance has been limited by a steep surgical learning curve and a high risk of inadvertent perforation of DM.

3. Microkeratome-assisted ALK [Automated Lamellar Therapeutic Keratoplasty (ALTK)] – The invention of semi-automated surgical microkeratomes to perform a superficial corneal flap in laser-assisted in-situ keratomileusis (LASIK) surgery has led to the use of these microkeratomes in corneal transplant surgery. The ALTK (Moria, Antony, France) system involves combining a LASIK type microkeratome with an artificial chamber to perform automated lamellar dissection of the donor cornea, and also of the recipient cornea. Variable depths or thicknesses of lamellar dissection of both the donor and recipient can be selected. However this is limited to the available head sizes because current head sizes can dissect the cornea from 100 microns to about 400 microns. The automated nature of the lamellar dissection results in smoother and enhanced lamellar dissection quality as compared to manual dissection, and greater ease and reproducibility of surgery. The ALTK device in recent years has gained great prominence in its ability to perform posterior lenticule dissection in donor corneas for EK (see below).

4. Femtosecond laser-assisted ALK – Mirroring LASIK advances, in which femtosecond lasers are now used to create the lamellar flap in LASIK surgery, femtosecond lasers are beginning to be used to perform various forms of penetrating and lamellar keratoplasty procedures. Clinical trials to use femtosecond lasers to perform deeper lamellar ablations in both ALK and EK surgery are now on-going, and may ultimately provide more accurate depths and precision of lamellar dissection than that of microkeratome devices.

The major advantage of ALK is the avoidance of unnecessary replacement of healthy endothelium, thus obviating the problems of endothelial rejection and hence subsequent endothelial graft failure. In addition, being essentially a non-penetrating extraocular procedure, complications such as expulsive haemorrhage, glaucoma, cataract and endophthalmitis are greatly reduced. One of the other inherent disadvantages of PK is that minor trauma even years after surgery may result in wound dehiscence with catastrophic loss of the eye. The major disadvantages of ALK include a steep learning curve and the possibility of sub-optimal visual outcomes due to interface related problems. In our centre, we have been able to show that long-term outcomes of ALK are better than PK. Data from SCTS confirm that graft survival at 1 (PK, 88.6%; ALK, 93.7%), 3 (PK, 69.2%; ALK, 79.0%), and 5 years (PK, 59.2%; ALK, 67.8%; $P = 0.001$) were significantly better in the ALK group. Although the risk of graft rejection is minimal following an ALK procedure, graft failure can occur from various other causes including infective keratitis and ocular surface problems.

Traditional manual ALK procedures involve surgical dissection of the stromal layers with the use of various lamellar knives or dissectors. This may not give a consistently smooth stromal bed and the visual outcomes tend to be suboptimal because of interface haze and residual scarring. Several recent techniques have been described to aid in lamellar separation with greater safety and consistency and may involve the use of air,[8-10] BSS,[11,12] or viscoelastic.[13-15] Recently published series indicate that visual outcomes following DALK down to DM are comparable if not

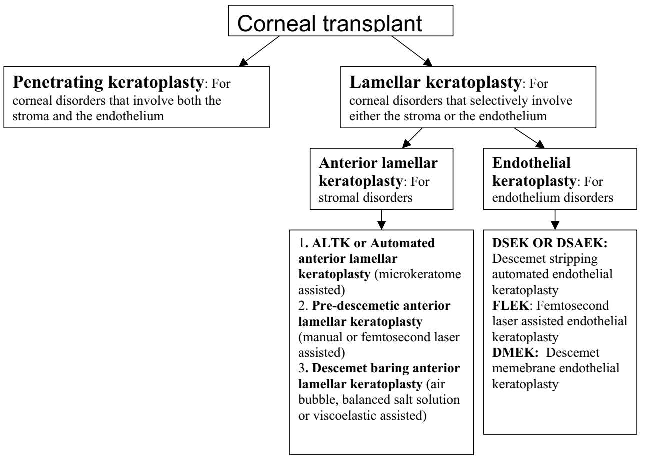

Fig. 1. Schematic diagram depicting the various forms of lamellar keratoplasty procedures and the indications.

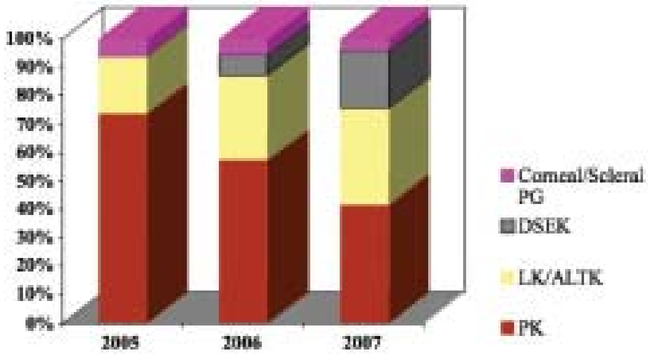

Fig. 2. Bar chart depicting shifting trends in corneal grafting procedures at SNEC over the past 3 years. In 2005, penetrating keratoplasty (PK) was the most commonly performed grafting procedure while in 2007, lamellar keratoplasty in the form of anterior lamellar keratoplasty (LK and ALTK) and descemet stripping endothelial keratoplasty (DSEK) was the most common procedure.

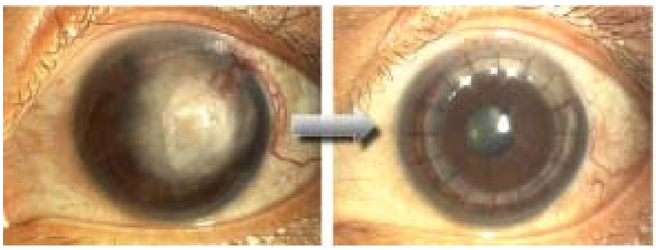

Fig. 3. Photo showing a patient with a vascularised stromal scar secondary to interstitial keratitis with counting fingers vision. The patient underwent deep anterior lamellar keratoplasty with total stromal removal and achieved a best-corrected visual acuity of 6/9.

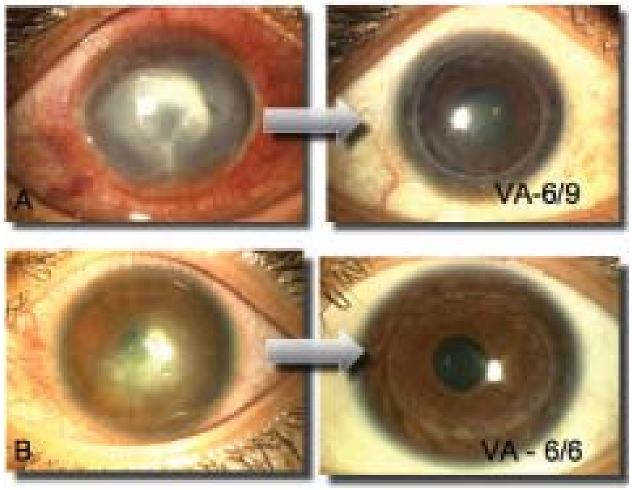

Fig. 4. Photo A showing a patient with advanced pseudomonas keratitis who underwent deep anterior lamellar keratoplasty (DALK) using the modified big bubble technique and achieved a visual acuity of 6/9 postoperatively. Photo B of another patient with progressive fusarium keratitis who underwent DALK and attained a visual acuity of 6/6.

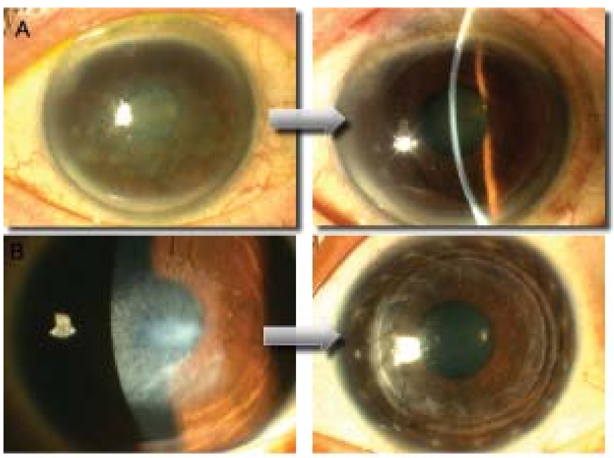

Fig. 5. Photo A showing a patient with Thiel Beinke dystrophy with preoperative visual acuity of 6/24 who underwent automated lamellar therapeutic keratoplasty (ALTK) and attained a best-corrected visual acuity of 6/12. Photo B showing another patient with scarring and thinning after PRK (photo refractive keratectomy) who required ALTK and achieved 6/7.5 vision postoperatively.

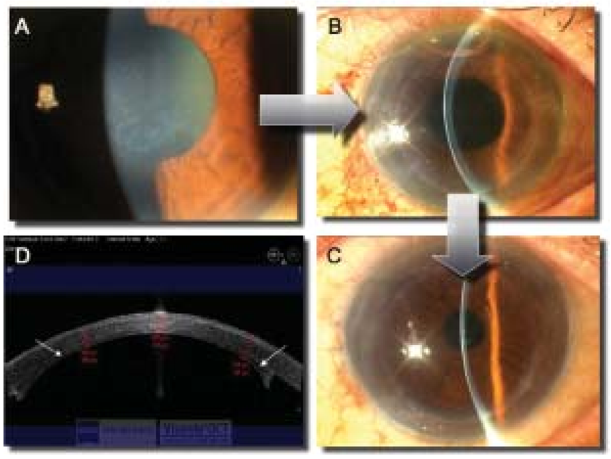

Fig. 6. Preoperative (A), early (B) and late (C) postoperative photos of a patient with Fuchs endothelial corneal dystrophy whose visual acuity improved from 6/30 to 6/9 (4 weeks postoperatively) following descemet stripping automated endothelial keratoplasty (DSAEK) using the glide technique. Anterior segment optical coherence tomography (ASOCT) of the same patient (D) showing a fully attached posterior donor lenticule (white arrow).

superior to PK[16-21] and with lesser endothelial cell loss.[17,18,22]

We have quickly adopted and modified the technique of total stromal replacement as described by Anwar and Teichmann[8] to achieve air-assisted separation of the DM from the overlying stroma with greater precision. This involves first removing the anterior half of the stroma by manual dissection, after partial trephination of the recipient cornea, thus enabling deeper and more consistent insertion of the needle to inject stromal air.[23] With our modified technique, we are now able to achieve a big bubble in >93% of cases with a relatively low risk of perforation (7%) (unpublished data).

DALK for Optical Indications (Fig. 3)

Our visual results using this technique for optical indications have shown significantly better visual outcomes when compared to manual pre-descemetic ALK and PK (unpublished data). Postoperative best-corrected visual acuity of 20/20 was achieved in 19.4% of PK, 21.6% of ALK cases using the manual technique and 38.5% of DALK cases using the modified Anwar big bubble technique ($P = 0.029$).

DALK for therapeutic indications (Fig. 4)

Severe corneal infections (usually bacterial or fungal) that do not respond to medical therapy with topical and systemic broad-spectrum antibiotics require an emergency corneal graft to prevent perforation and intraocular spread of infection (endophthalmitis) that may lead to loss of the eye. Conventional PK for therapeutic indications may result in intraocular spread of infectious organisms during removal of the cornea as intraocular contents are exposed during surgery, and may accelerate the development of endophthalmitis. In addition, therapeutic PKs are also considered high risk grafts as they are associated with severe inflammation and vascularisation which accompanies infectious keratitis. This leads to a higher rate of subsequent endothelial graft rejection. ALK surgery in cases of infectious keratitis where no perforation or spread beyond DM has occurred, has a major advantage over PK, as the procedure is extraocular (thus obviating risks of intraocular entry of organisms), and the endothelium is not replaced, thus reducing the risk of subsequent graft failure from endothelial failure. With the advent of descemetic DALK procedures, such as the big bubble procedure, where total stromal removal can be achieved, higher chances of eradicating infection can be expected, and in our recently published series,[24] no recurrence of infection was seen in eyes that had the modified big bubble technique of DALK. With ALK surgery there is a reduced risk of secondary endophthalmitis and this was demonstrated in our series where none of the eyes in the DALK group developed postoperative endophthalmitis, while 50% of eyes with recurrent infection in the PK group developed endophthalmitis necessitating eye removal. With respect to graft rejection, none of our cases in the DALK cohort developed allograft rejection compared to 15 eyes (15%) in the PK group.

ALTK for refractive accuracy (Fig. 5)

As ALTK uses essentially LASIK technologies, ALTK can provide greater surgical precision and accuracy, resulting in better visual and refractive outcomes than manual ALK. It is therefore apt, and ironic, that ALTK can be used to treat complications which may arise rarely following LASIK and other forms of corneal refractive surgery e.g. post-LASIK infectious keratitis, PRK related thinning, damaged LASIK flaps, or keratectasia (abnormal thinning and distortion of the cornea after refractive surgery). We have achieved good visual and refractive results in our series of 15 eyes that underwent ALK for various refractive surgery-induced complications.[25-28] Automated lamellar dissection results in optimally smooth lamellar dissection but is contra-indicated in cases of topographical irregularity or differential corneal thinning. This is because any irregular surface is replicated in the microkeratome cut. The ATLK instrument (Moria, Antony, France) is one such automated microkeratome that is being utilised for both anterior and posterior lamellar surgery.

For ALK, the ALTK procedure involves the use of microkeratome to dissect the recipient cornea. With the aid of an artificial chamber maintainer, the same microkeratome is then used to dissect the donor to a predetermined thickness. The current indications for the use of ALTK assisted ALK are anterior stromal dystrophies, moderate central keratoconus with uniform corneal thinning and post-PRK scar that is regular and uniformly thin. In keratoconus, the aim of surgery is to augment the thin and steep cornea, and this can be achieved by using a thick lamellar donor, thus tectonically strengthening the cornea and reducing corneal steepness and high myopia. Similarly, in cases with post-PRK thinning, ALTK is used to remove the stromal scar, augment the thickness of the recipient cornea by using a thicker donor lamella which also subsequently allows for LASIK to correct any residual refractive error.

One of the disadvantages of ALTK surgery is its inability to achieve a precise trephination margin. This may lead to a mismatch of the donor and host cornea, which can delay epithelial healing and increases the risk of epithelial ingrowth between the lamellar interfaces. To overcome this problem, we have modified the procedure by combining the use of ALTK with a conventional vacuum trephine system such as Hanna (Moria, France).[29] This allows a more precise fit of the donor and host cornea due to the vertical edges from the vacuum trephine.

Posterior Lamellar Keratoplasty or Endothelial Keratoplasty

Endothelial keratoplasty is a rapidly emerging lamellar grafting procedure that involves targeted replacement of the diseased endothelium with donor tissue while retaining the corneal stroma. Essentially it is a small incision (4 mm to 5mm), sutureless, closed eye surgery. EK appears to be rapidly replacing PK surgery in the United States (US), although outside the US, its acceptance has been less rapid. US corneal transplant statistics show that in 2006, only 18% of all grafts were EK surgery, but in 2007, EK surgery rates had risen to 37%.[30]

The pursuit of endothelial replacement has taken two approaches. Busin et al[31] performed this procedure through an anterior approach. This involved the creation of a large LASIK-like flap, full thickness trephination of the recipient cornea and replacement by donor cornea that comprised of stroma and endothelium. This was followed by the replacement of the LASIK flap and suturing. This was essentially an open sky technique like PK and is technically difficult to perform.

In 1998, Melles et al[32] first described the surgical technique of posterior lamellar keratoplasty or PLK. This procedure was adopted by Terry et al[33] who renamed the procedure as DLEK (deep lamellar endothelial keratoplasty) and described their first series of US patients in 2001.[34-37] Subsequently, several other authors reported good visual outcomes with this procedure compared to conventional PK.[38,39]

Melles et al further revolutionised the field of PLK by introducing the technique of descemet's membrane stripping of the recipient cornea. They renamed the procedure DSEK (Descemets stripping endothelial keratoplasty).[40] DSEK surgery involves stripping away unhealthy DM and endothelium from the recipient, through a peripheral incision, and replacing this with a thin (150 um) manually dissected posterior donor lamella lenticule which consists of posterior stroma, DM and the endothelium. The donor is inserted into the recipient eye through the peripheral incision, and attached to the recipient posterior corneal surface using an air bubble in the anterior chamber. Price et al reported on a large series of eyes undergoing DSEK surgery with visual outcomes comparable to PK.[41] DSEK has now been further modified in which the posterior donor lamella is obtained using the ALTK unit hence the term DSAEK or descemet's stripping automated endothelial keratoplasty.[42,43] Using a microkeratome dissection reduces the risk of donor perforation and provides faster visual recovery after surgery.[42] Today, DSAEK is synonymous with EK and is currently the gold standard in posterior lamellar keratoplasty procedures.

A major advantage of EK over PK is that EK is performed as a closed eye procedure, greatly minimising the risk of the severe but rare complication of a suprachoroidal or expulsive haemorrhage. EK surgery is performed through a small incision and is essentially sutureless making it a tectonically stronger eye with faster postoperative visual rehabilitation. There is minimal disturbance of the ocular surface and hence patients largely retain their normal corneal sensation. The refractive changes are more predictable hence there is less likelihood of an astigmatic shift with this procedure. However, following EK, a hyperopic shift in refraction has been reported due to a reduction in the optical power of the cornea.[44,45]

It has been shown to be successful in previously failed grafts and is less invasive than repeat PK. Perhaps, but yet unproven, is a low likelihood of rejection since less tissue is transplanted. However, new complications have emerged with this procedure and these include donor dislocation and endothelial cell damage from donor insertion. The major challenge in DSAEK today is to reduce endothelial damage – primary/iatrogenic graft failure rates range from 1% to 45%.[41,46]

A major stage of the EK procedure involves inserting the lamellar donor through a small peripheral corneal or scleral incision. The "taco" folding technique[37] in which the donor is folded into a 60:40 fold, and inserted into the eye through incision, is currently the most common method used to insert the donor lamella, but grasping the donor tissue with forceps, and folding and unfolding the donor lamella in the AC, even in uneventful surgery, can cause significant loss of endothelial cells. This stage is believed to be the most traumatic, resulting in high endothelial cell damage resulting in higher primary/iatrogenic graft failure rates and low endothelial cell counts as compared with conventional PK surgery. Damage is more profound in the smaller Asian eye, which has shallower anterior chambers and higher vitreous pressure as compared to the Caucasian eye, leading to more difficult manipulations of the donor in the anterior chamber.

Donor dislocation may occur in up to 50%[47] of cases and attempts at re-attaching the donor with a repeat air injection further exacerbates endothelial cell loss.[48] EK also involves the adoption of new surgical skill sets and familiarity with the ALTK microkeratome to perform donor lamellar dissection, resulting in a steep learning curve. In the US, eye banks now perform this stage for most corneal surgeons without access to ALTK devices. EK may also be suitable only for relatively mild or early forms of endothelial decompensation because visual recovery can be compromised in the presence of pre-existing stromal scarring and interface haze which can occur with longstanding corneal decompensation.

The SNEC Dsaek Programme

EK surgery was first performed in Singapore at SNEC in 2006, and we have since considerably modified EK surgical techniques to provide safer and more effective methods leading to enhanced success in our series of 126 eyes, currently the largest in Asia (Fig. 6). We initially performed EK in 20 eyes using the conventional "taco" folding technique but quickly abandoned this method when we experienced an unacceptably high primary/iatrogenic graft failure rate of 25% (5 eyes), and a mean 6-month endothelial cell loss of 61.4%. A similar series of EK in Japanese eyes also using a "taco" technique showed virtually identical graft failure rates and endothelial cell loss rates of 22.2% and 60.5%, respectively (Asia Cornea Society meeting, 2008). We hence modified our EK technique to suit the Asian eye by inserting the donor with the use of an anterior chamber (AC) intraocular lens Sheets Glide, a clear plastic sheet which is normally used in the insertion of an AC IOL in cataract surgery.[49] The donor is placed endothelial surface down on the Glide, protected from the plastic surface with copious viscoelastic, and the anterior portion of the Glide is inserted through a 5-mm scleral wound. The donor is then pulled through into the AC with the help of specially designed Tan DSAEK forceps (ASICO, USA). We validated this technique in comparative laboratory studies using research-grade human corneal eye bank tissue and confirmed far less mean endothelial cell damage with our Sheets Glide technique (9.24%) as compared to the "taco" technique (38%) ($P = 0.00435$).[50] To date, in our consecutive series of 106 cases with this technique, we have only encountered 1 primary/iatrogenic graft failure, (which was our first attempt at this technique) (0.94%), and achieved a mean 6-month endothelial cell loss rate of only 29.8% (unpublished data). In comparison, published studies of the "taco" method report primary/iatrogenic graft failures of up to 45%,[46] and endothelial cell rates of 34% to 35%.[48,51] In addition, we have only encountered 2 graft dislocations (1.9%) as compared to reported rates in the region of 8% to 50%. We are currently devising a new disposable EK donor inserter which aims to further reduce endothelial cell loss and simplify donor insertion.

Future Advances

The immediate future of corneal transplantation lies in further refinement of new lamellar transplantation procedures and advances are likely in 2 main areas:

1. Development of Descemet Membrane Endothelial Keratoplasty (DMEK)

Whilst DSAEK surgery is currently the main surgical technique of EK surgery, new concepts in EK continue to evolve. Melles recently described the potential next evolution of EK surgery, DMEK, in which only DM with attached endothelium is replaced.[52,53] Surgical challenges with this procedure are considerable – DM with intact endothelium has to be carefully stripped away from the donor cornea. This immediately scrolls up tightly and after insertion into the recipient eye, has to be unscrolled and attached to the recipient cornea. Currently, the technique has a very high endothelial cell loss and dislocation rate. Further refinements in the technique are needed before it can begin to replace DSAEK.

2. Development of Femtosecond Laser-assisted Lamellar Transplantation

An alternative approach to ALK and EK surgical procedures is the use of femtosecond lasers to perform the surgery. The femtosecond laser is an infrared laser developed for LASIK that causes intracorneal plasma mediated corneal stromal dissection (photodisruption) and there are several platforms currently available: Intralase (intralase, Irvine, CA), FEMTEC (20/10 Perfect Vision, Heidelberg, Germany) and Visumax (Carl Zeiss Meditec, Germany). While superficial lamellar flap dissection with these lasers has been well-refined, deep lamellar dissection poses new challenges which are currently being tackled, and current results with femtosecond laser assisted ALK and femtosecond laser-assisted EK (FLEK) do not match non-laser surgical results. However, we have recently refined laser algorithms for deep lamellar corneal stromal dissection, and our published human eye bank studies[54,55] performed with the 20/10 Perfect Vision FEMTEC laser now confirm that we are able to produce consistent high quality stromal bed profiles matching ALTK profiles, and current research and trials in this area continues.

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