JOJ Ophthalmology
ISSN: 2473-5477

Review Article
Volume 10 Issue 5 - March 2024
DOI: 10.19080/JOJO.2024.10.555796

JOJ Ophthalmol

State of the Art of Corneal Transplantation

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Submission: March 06, 2024; **Published:** March 13, 2024

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Abstract

Corneal transplantation has undergone important advances in the last 20 years. Penetrant keratoplasty has been the dominant procedure for more than half a century and it successfully covers most causes of corneal blindness. The adoption of newer forms of lamellar transplantation surgery has been an essential change in recent years. Endothelial keratoplasty has resulted in more rapid and predictable visual outcomes. Deep anterior lamellar keratoplasty is replacing penetrant keratoplasty for diseases affecting the stromal corneal layers while avoiding the risk of endothelial rejection. Other emerging therapies like ocular surface reconstruction, femtosecond-laser assisted surgery, bioengineered corneas and medical treatment for endothelial disease are also likely to play a part in the future.

Keywords: Descemet Membrane Endothelial Keratoplasty (DMEK), Descemet Stripping Endothelial Keratoplasty (DSAEK), Deep Anterior Lamellar Keratoplasty (DALK), Penetrating Keratoplasty (PKP), Keratoconus

Abbreviations: PKP: Penetrant Keratoplasty; BCVA: Best Corrected Visual Acuity; ALK: Anterior Lamellar Keratoplasty; DALK: Deep Anterior Lamellar Keratoplasty; EK: Endothelial Keratoplasty; DSAEK: Descemet Stripping Automated Endothelial Keratoplasty; UT-DSAEK: Ultrathin-Descemet Stripping Automated Endothelial Keratoplasty; DMEK: Descemet Membrane Endothelial keratoplasty; IOCT: Intra-operative Optical Coherence Tomography

Introduction

Corneal blindness may be due to numerous dystrophic, degenerative, infectious, inflammatory or traumatic conditions [1,2]. Once corneal transparency is lost, transplantation is the current therapeutic intervention of choice with the aim of improving visual acuity. Corneal transplantation or keratoplasty is the most successful allogenic transplant worldwide and also the most frequently performed [3,4]. It has evolved from the replacement of full-thickness cornea to selective layers of it. This has been possible due to the improvement in understanding of corneal anatomy, advanced surgical techniques, instruments and microscopes.

Cornea: Structure and Function

The cornea is a transparent and avascular structure that provides protective and refractive functions. It forms, together with the sclera, the outer shell of the eyeball. It consists of six discernible layers. The anterior-most is epithelium consisting of four to six layers of stratified, non-keratizing squamous cells [5]. Its regeneration is enabled by limbal epithelial stem cells, a group of cells that accomplish three characteristics: lack of differentiation, slow-cycling and high proliferative activity [6]. These cells reside in the palisades of Vogt, a radially orientated fibrovascular ridge and when activated they proliferate, differentiate and migrate to the central cornea [7].

Beneath the corneal epithelium, the Bowman´s layer is acellular, and it does not regenerate. The third layer is the stroma, which constitutes a major part of the cornea and contains proteoglycans and keratocytes surrounding collagen lamellae. Posterior to the stroma, the Descemet membrane provides a base for endothelial cells whose main role is maintaining corneal transparency.

Evolution and Types of Corneal Transplantation

Eduard Zirm performed the first successful corneal transplant in 1905 [8]. However, penetrant keratoplasty was not established as the mainstay of corneal transplantation until mid-1950s, when surgical improvement was achieved, and topical steroids were introduced. In the last 20 years, the concept of selective lamellar keratoplasty has emerged, leading to fundamental changes in this procedure [3,4]. Keratoplasty can be performed for various aims and is classified as therapeutic, optical or tectonic. Therapeutic is done to remove the infective portion of the cornea. Optical restores vision and tectonic provides support and maintains the integrity of the globe. There are different clinical and anatomical parameters that need to be evaluated before planning the type of corneal transplantation. The selective replacement of the damaged part has many advantages compared to penetrating keratoplasty in terms of intraoperative complications and postoperative graft rejection.

Penetrant Keratoplasty (PKP)

Until recently, PKP was the most frequently performed corneal transplantation technique all around the world. Nowadays, PKP has limited its use in diseases where the benefit of replacing the whole cornea, compared with lamellar keratoplasty, will provide the best optical or therapeutic result [9]. It is mainly done in corneal decompensation with anterior stromal scarring, corneal dystrophies with endothelial involvement or in full thickness opacities due to healed keratitis or traumatic scars. Common indications also include tectonic grafts for acute ulcerating or infectious keratitis, previous graft failure or an advanced keratoconus not suitable for deep anterior lamellar keratoplasty [3]. PKP is an effective and successful treatment for improving visual function. Some studies have demonstrated a survival rate higher than 70% at 10 years follow-up [10-12] and others 90% at 5 years and 82% at 10 years [13]. Surgical indication plays a major role in influencing the graft survival rate, keratoconus patients achieving the best long-term results [14]. In developing countries, graft survival rate was lower than in many western countries. This is probably due to the higher percentage of patients with high-risk indications, lower quality of donor corneas and reduced access to medicines and expert care [15,16].

There have been several studies in order to evaluate the visual outcomes after PKP. Beckingsale et al described half of patients with a visual acuity better than 6/18 [17]. Paglen et al and Pramanik et al reported a best corrected visual acuity (BCVA) of more than 6/12 in 73% of patients at more than 10 years of follow up [14,18]. However, only 48% of patients achieved 6/12 at 5 years in a case-series by Rahman et al [19]. Brahma et al did a study on 18 patients with keratoconus to evaluate the visual outcome after PKP and found an improvement in visual acuity, contrast sensitivity and glare [20].

Graft rejection is the most common complication after PKP [21]. Rahman et al reported an incidence of 21% of graft rejection episodes, of which 7.4% could not be solved and went into graft failure [19]. Pramanik et al found early graft failure to be rare [14] and Olson et al reported allograft rejection in 31% of cases but none progressed to graft failure [22]. Even in the absence of rejection, donor corneal endothelial cell loss is progressive for 10 years post-PKP, which causes late failure of the graft [23]. In fact, the rate of endothelial cell loss was reported to be about 33% to 40% within the first 2 years [24-26].

The incidence of post-PKP glaucoma is estimated to be 21.5% [27]. It is caused by surgical changes of the anterior chamber angle and/or corticosteroid induced IOP elevation. Its treatment with topical drops and/or surgery is associated with graft failure as well [28]. Re-epithelization after PKP is altered due to the use of topical steroids and corneal denervation. Ocular surface complications constitute 18% of graft failure. Microbial keratitis after PKP is frequently caused by gram-positive organisms. The prolonged use of corticosteroids and the presence of loose sutures increased the risk of infection, and more than a half of the grafts affected progress to failure [29].

Anterior Lamellar Keratoplasty (ALK)

The lost technique of ALK was brought back in 1948 by Paufique et al [30] and microkeratome was introduced by Barraquer in 1964 [31]. Microkeratome was able to give a more regular cut and thus avoid the poor visual gain because of the irregular interface. Kaufman modified the technique and introduced epikeratophakia, which described the use of lamellar graft without the need to perform host corneal dissection [32]. ALK has come a long way from manual dissection to microkeratome assisted and now to femtosecond laser-assisted keratoplasty. There are a variety of techniques described for ALK depending upon the depth of corneal opacity.

Deep Anterior Lamellar Keratoplasty (DALK)

DALK has become a popular surgical technique to treat stromal diseases, reducing the risk of endothelial graft rejection. The most challenging step of this surgery remains the separation of corneal stroma from Descemet membrane. The most widely used technique is "Big Bubble", where air is injected into the deep stroma and cleaves Descemet membrane from the rest of the host tissue [33]. Finally, a donor corneal bottom with no Descemet membrane is then sutured to the host cornea. Keratoconus is the main indication for DALK. It also offers a treatment for infectious keratitis, corneal dystrophies and stromal scarring.

Long term follow-up data report a mean BCVA of 6/7.5 at 4 to 6 years follow-up after DALK procedure and 29% of patients with BCVA of 6/6 at 5 years [34,35]. The are several studies comparing DALK and PKP in terms of visual outcome. Recently, a systematic review by Henein and Navanaty demonstrated strong evidence of superior post-operative refractive astigmatism following DALK [36]. However, a recent meta-analysis by Song et al concluded that there was no significant difference in postoperative astigmatism and best corrected visual acuity in comparison to PKP, but spherical equivalents were greater in DALK [37].

As the host endothelial cells are preserved in DALK,

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endothelial immune rejection cannot occur, although stromal and epithelial rejections are still possible. In one study reported by Feizi et al [38], the rate of subepithelial and stromal rejections are 10.9% and 3.1 % respectively. The systematic review made by Keane et al [39] and the recent Song et al meta-analysis [37], conclude that graft rejection episodes were more likely to occur in PKP than in DALK. Moreover, comparative studies showed lower levels of endothelial cell loss after DALK compared to PKP at different times of post-surgery follow-up [40]. In contrast to PKP, endothelial cells seem to decrease in the immediate postoperative period after DALK but tended to stabilize at around 6 months to 1 year and remain stable for 10 years after DALK [35]. Then late corneal failure due to endothelial decay is less likely after DALK.

Glaucoma was observed to be less than 5% after DALK, much lower compared to PK because the distortion of the iridocorneal angle is diminished in DALK [41]. There is a group of complications unique to DALK. Intraoperative micro-perforations may occur when trying to split Descemet membrane (DM) from the stroma. Those of 1 mm or less can be managed intraoperatively and does not prevent the conversion to PKP [42]. In cases of macroperforations, conversion is usually required during surgery. This happens in approximately 60% of cases, according to a study performed in 2010 [43]. As the use of DALK gained popularity, the rate of complications reduced to 16.2 % to 20.7% [44-46].

Endothelial Keratoplasty (EK)

Descemet Stripping Automated Endothelial Keratoplasty (DSAEK)

Melles et al used a small, self-sealing 5-mm tunnel to perform a novel step which was called descemetorhexis, which is based in the replacement of pathological DM and endothelium from the recipient cornea by a "taco-folded" donor tissue with endothelium, DM and a layer of stroma adhered to the recipient cornea by air injection [47]. This technique was called Descemet stripping endothelial keratoplasty and evolved to DSAEK when Gorovoy started with the use of an automated microkeratome [48]. In DSAEK only the posterior lamella is replaced. Some authors observed that thinner grafts led to better BVCA due to less change in the relationship between anterior and posterior corneal curvatures of the recipient cornea and based on this principle Ultrathin-DSAEK (UT-DSAEK) was developed, which used grafts of half of the conventional graft thickness, of about 100 μm [49,50]. Then, this type of corneal transplantation gives the patient the benefit of faster and early visual recovery. Suture-related problems are also reduced.

DSAEK provides predictable and superior visual outcomes in comparison to PKP [51]. The average visual acuity is about 20/40 as described in different studies [52-54]. Van Rooij et al [55] found that BCVA of DSAEK patients was significantly better than those who had PK at 2-year follow-up and Woo et al reported 23.6% of the patients had BCVA 6/7.5 or better 3 years after DSAEK. Significantly less postoperative astigmatism was observed in DSAEK but spherical equivalent was not significantly different. As for the complications, graft failure has been reported to be approximately 10 per cent [56]. Most single centre studies showed a graft survival rate of 93% or above at 5 years after DSAEK [57,58]. A decrease of 36% in endothelial cell density after DSAEK has been observed by Terry et al [59], similar results to the ones documented by Price and Price [60]. The initial endothelial cell loss in DSAEK was reported to be higher than in PKP, followed by constant low-grade cell loss at a rate of 11.7% per year over 5 years [57]. The latest modification of this surgery, UT-DSAEK, demonstrated a survival rate of 94.5% at 5 years, comparable to conventional DSAEK [61].

Immunological graft rejection rates in DSAEK are much lower than PKP as the lesser amount of corneal tissue is transplanted as compared to the full thickness graft. Different authors have reported similar rejection rates. Price et al [54] published a 5-year graft rejection rate of 7.9% after DSAEK, Jordan et al [62] found a rate of 9 per cent in a study with almost 600 patients, while Madi et al [62] reported on 3.9% of rejection episode after UT-DSAEK.

Graft detachment is the most common complication after DSAEK, which requires rebubbling in the immediate to early postoperative period. While most of them are recognized by corneal oedema or direct visualization of a double anterior chamber on slit-lamp bio microscopy, the anterior segment coherence constitutes the most effective way of confirming detachments. Its rate of occurrence is between 0.7% and 14.8%, according to recent literature reports [52,60].

Descemet Membrane Endothelial Keratoplasty (DMEK)

After the introduction of DSAEK, Melles et al described a new endothelial graft of 10-15 μm of tissue consisting of only DM and endothelium obtained by descemetorhexis, called DMEK [63]. It provides faster visual rehabilitation, better visual outcomes and lower immune rejection rates than DSAEK [64,65]. One of the most difficult steps in this surgery is the orientation of the graft. Intra-operative optical coherence tomography (IOCT), stamping, staining or tearing the lenticule may help us for correct position. DMEK enhances visual outcome compared to DSAEK due to a reduced interface effect. Several studies have reported 32-85% of patients achieving BVCA of 6/7.5 or better at 6 months after DMEK and significantly better BCVA compared to PKP, DSAEK and even UT-DSAEK at 1 year [65]. 5-year survival rates are between 90 to 95% in eyes that underwent DMEK. It diminishes in the presence of glaucoma drainage device implant, prior trauma, or previous failed keratoplasty. Graft rejection rates are the best in corneal transplantation. They are about 0.7-1.5%.

Recent Advancements

Several techniques have helped to improve the outcomes of keratoplasty, being the intra-operative optical coherence tomography, the femtosecond laser and bioengineered corneas the most important ones.

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Intra-operative Optical Coherence Tomography (iOCT)

IOCT provides continuous details of the surgery, and it is very useful in lamellar keratoplasty such as DALK, DSAEK or DMEK. It measures the central corneal thickness of both the donor and the host cornea, an important parameter for deciding the blade size of the microkeratome for dissection. Moreover, it acts as a tool to minimize complications. In DALK procedure it guides every step of the surgery starting from depth of trephination to graft-host apposition [66]. In cases of DSAEK and DMEK, it helps in identifying the right orientation of graft and ensures the adequate apposition of host and donor cornea at the end of the surgery [67,68].

Femtosecond Laser-Assisted Lamellar Keratoplasty

Full thickness PKP as well as lamellar keratoplasty can be performed using femtosecond laser. It leads to better incision geometry, an accurate graft-host apposition and better wound healing, decreasing the risk for graft dehiscence. It is also associated with less endothelial cell loss at the margin of the graft [69,70].

Bioengineered Corneas

They are designed to replace the full or part of the diseased cornea and range from keratoprosthesis to the recent development of tissue-engineered hydrogels, which help in the regeneration of host tissues [71]. There are also lenticules that can be used to correct the refractive errors by their implantation into the cornea.

Discussion

Corneal transplantation remains the only available and effective therapy of corneal blindness worldwide and there has been no turning back since the first corneal transplantation surgery was performed in Europe in 1905 [8]. More than 95 per cent of corneal tissues were used for PKP over a period from 1980 to 2004 and the major indications were pseudophakic bullous keratopathy, keratoconus, Fuchs´ endothelial corneal dystrophy and failed grafts [72]. Even though the number of PKP remained the same, the number of DMEK and DSAEK increased significantly from 2008 to 2016. DMEK is well-established and was first reported in 2006 by Melles [73,74], providing several advantages over PK based on its minimal invasiveness, lower intraoperative risks and minimal refractive shift with fast visual recovery [75-77]. Many more patients with endothelial disorders have benefited from the high success of the DMEK in recent years, being treated with keratoplasties earlier than before. Corneas that had been considered not suitable for PKP are now qualified for DMEK. By contrast, Afshari et al reported in 2006 that eyes with Fuchs´ dystrophy and a visual acuity better than 0.5 were not still candidates for a keratoplasty [78].

In another sense, DMEK is a sophisticated surgery, presenting the challenges of stripping the donor graft and then manipulate it after injection into the anterior chamber to identify the endothelial layer for correct orientation. All these procedures have to be carried out without touching the Descemet membrane. Novel surgeons are sometimes reluctant to use the DMEK procedure because of the lack of donor corneas in some hospitals and the higher probability of graft preparation failure compared to DSAEK. However, experienced ophthalmologists tend to use almost always DMEK even in difficult surgical scenarios such as glaucoma drainage devices or previous failed keratoplasties due to DMEK better BCVA results comparing to DSAEK. As one important factor for the outcome of DMEK is the waiting time until surgery [79,80], pressure on eye banks to procure more suitable corneal grafts has been growing enormously in the last years. The knowledge and awareness of corneal donation through education is important to gain more corneal donors to help visually impaired patients in sufficient number with corneal transplantations.

Regarding anterior lamellar keratoplasties, the moderate introduction of DALK is probably due to its longer surgical time and higher technical challenge with the big bubble, the introduction of collagen crosslinking in patients with progressive keratoconus [81], a lower number of patients with the indication for DALK and, consequently, a slower and more difficult learning curve for the surgeon. There are no significant differences in BCVA comparing to PKP in recent studies [37] but graft rejection episodes are less likely to occur [37,39] so DALK should be the elective surgery in corneal anterior pathologies when the descemetic and endothelial layers are respected.

Conclusion

Nowadays, conventional PKP procedures are being replaced by selective lamellar keratoplasty, such as endothelial and deep anterior lamellar keratoplasty. The use of the iOCT and the femtosecond laser, together with the improvement in instrumentation and engineering devices help to reach better anatomical and functional results, reducing complications during surgery. Further developments in artificial cornea technology, endothelial therapies and stem-cell transplants are on the horizon in this fast-evolving ophthalmic field.

References

1. Mathews PM, Lindsley K, Aldave AJ, Akpek EK (2018) Etiology of global corneal blindness and current practices of corneal transplantation: a focused review. Cornea 37(6): 1198-1203.
2. Gain P, Julliene R, He Z, Mansour Aldossary, Sophie Acquart, et al. (2016) Global survey of corneal transplantation and eye banking. JAMA Ophthalmol 134(2): 167-173.
3. Liu S, Wong YL, Walkden A (2022) Current Perspectives on Corneal Transplantation. Clin Ophthalmol 16: 631-646.
4. Singh R, Gupta N, Vanathi M, Tandon R (2019) Corneal transplantation in the modern era. Indian J Med Res 150(1): 7-22.
5. DelMonte DW, Kim T (2011) Anatomy and physiology of the cornea. J Cataract Refract Surg 37(3): 588-598.
6. Tseng SC (1989) Concept and application of limbal stem cells. Eye (Lond) 3(2): 141-157.

How to cite this article: Guillermo Rodríguez I, Cristina Peris M. State of the Art of Corneal Transplantation. JOJ Ophthalmol. 2024; 10(5): 555796. DOI: 10.19080/JOJO.2024.09.555796

7. Townsend WM (1991) The limbal palisades of Vogt. Trans Am Ophthalmol Soc 89: 721-756.
8. Zirm EK (1989) Eine erfolgreiche totale Keratoplastik (A successful total keratoplasty). 1906. Refract Corn Surg 5(4): 258-261.
9. Zhang AQ, Rubenstein D, Price AJ, Elie Côté, Max Levitt, et al. (2013) Evolving surgical techniques of and indications for corneal transplantation in Ontario: 2000-2012. Can J Ophthalmol 48(3): 153-159.
10. Mannis MJ, Holland EJ, Gal RL, Mariya Dontchev, Craig Kollman, et al. (2013) The effect of donor age on penetrating keratoplasty for endothelial disease: graft survival after 10 years in the Cornea Donor Study. Opthalmology 120(12): 2419-2427.
11. Fukuoka S, Honda N, Ono K, Mimura T, Usui T, et al. (2010) Extended long-term results of penetrating keratoplasty for keratoconus. Cornea 29(5): 528-530.
12. Patel SV, Hodge DO, Bourne WM (2005) Corneal endothelium and postoperative outcomes 15 years after penetrating keratoplasty. Am J Ophthalmol 139(2): 311-319.
13. Thompson RW, Price MO, Bowers PJ, Price FW (2003) Long-graft survival after penetrating keratoplasty. Ophthalmology 110(7): 1396-1402.
14. Pramanik S, Musch DC, Sutphin JE, Farjo AA (2006) Extended long-term outcomes of penetrating keratoplasty for keratoconus. Ophthalmology 113(9): 1633-1638.
15. Arya SK, Raj A, Bamotra RK, Bhatti A, Deswal J, et al. (2018) Indications and graft survival analysis in optical penetrating keratoplasty in a tertiary care center in North India: a 5-year study. Int Ophthalmol 38(4): 1669-1679.
16. Joshi SA, Jagdale SS, More PD, Deshpande M (2012) Outcome of optical penetrating keratoplasties at a tertiary care eye institute in Western India. Indian J Ophthalmol 60(1): 15-21.
17. Beckingsale P, Mavrikakis I, Al-Yousuf N, Mavrikakis E, Daya SM (2006) Penetrating keratoplasty: Outcomes from a corneal unit compared to national data. Br J Ophthalmol 90(6): 728-731.
18. Paglen PG, Fine M, Abbott RL, Webster RG (1982) The prognosis for keratoplasty in keratoconus. Ophthalmology 89(6): 651-654.
19. Rahman I, Carley F, Hillarby C, Brahma A, Tullo AB (2009) Penetrant keratoplasty: Indications, outcomes, and complications. Eye (Lond) 23(6): 1288-1294.
20. Brahma A, Ennis F, Harper R, Ridway A, Tullo A (2000) Visual function after penetrating keratoplasty for keratoconus: A prospective longitudinal evaluation. Br Ophthalmol 84(1): 60-66.
21. Coster DJ, Williams KA (2005) The impact of corneal allograft rejection on the long-term outcome of corneal transplantation. Am J Ophthalmol 140(6): 1112-1122.
22. Olson RJ, Pingree M, Ridges R, Lundergan ML, Alldredge C, et al. (2000) Penetrating keratoplasty for keratoconus: A long-term review of results and complications. J Cataract Refract Surg 26(7): 987-991.
23. Claerhout I, Beele H, Kestelyn P (2008) Graft failure: I. endothelial cell loss. Int Opthalmol 28(3): 165-173.
24. Borderie VM, Boëlle PY, Touzeau O, Allouch C, Boutboul S, et al. (2009) Predicted long-term outcome of corneal transplantation. Ophthalmol 116(12): 2354-2360.
25. Jonathan H Lass, Robin L Gal, Mariya Dontchev, Roy W Beck, Craig Kollman, et al. (2008) Donor age and corneal endothelial cell loss 5 years after successful corneal transplantation: specular microscopy ancillary study results. Ophthalmology 115(4): 627-632.
26. Kubaloglu A, Koytac A, Sari ES, Akyol S, Kurnaz E, et al. (2012) Corneal endothelium after deep anterior lamellar keratoplasty and penetrating keratoplasty for keratoconus: a four-year comparative study. Indian J Ophthalmol 60(1): 35-40.
27. Wu S, Xu J (2017) Incidence and risk factors for post-penetrating keratoplasty glaucoma: a systematic review and meta-analysis. PLoS One 12(4): e0176261.
28. Dada T, Aggarwal A, Minudath K, M Vanathi, Sunil Choudhary, et al. (2008) Post penetrating keratoplasty glaucoma. Indian J Ophthalmol 56(4): 269-277.
29. Wright TM, Afshari NA (2006) Microbial keratitis following corneal transplantation. Am J Ophthalmol 142(6): 1061-1062.
30. Paufique L, Sourdille GP, Offret G (1948) Les Greffes de la corne´e. Paris: Masson, p.159.
31. Barraquer JI (1964) Queratomileusis para la corrección de la myopia. Arch Soc Am Oftalmol Optom 5: 27-48.
32. Kaufman HE (1980) The correction of aphakia. XXXVI Edward Jackson memorial lecture. Am J Ophthalmol 89(1): 1-10.
33. Anwar M, Teichmann KD (2002) Big-bubble technique to bare Descemet´s membrane in anterior lamellar keratoplasty. J Cataract Refract Surg 28(3): 398-403.
34. Romano V, Iovieno A, Parente G, Soldani AM, Fontana L (2015) Long-term clinical outcomes of deep anterior lamellar keratoplasty in patients with keratoconus. Am J Ophthalmol 159(3): 505-511.
35. Sarnicola V, Toro P, Sarnicola C, Sarnicola E, Ruggiero A (2012) Long-term graft survival in deep anterior lamellar keratoplasty. Cornea 31(6): 621-626.
36. Henein C, Navanaty MA (2017) Systematic review comparing penetrant keratoplasty and deep anterior lamellar keratoplasty for management of keratoconus. Cont Lens Anterior Eye 40(1): 3-14.
37. Song Y, Zhang J, Pan Z (2020) Systematic review and meta-analysis of clinical outcomes of penetrating keratoplasty versus deep anterior lamellar keratoplasty for keratoconus. Exp Clin Transplant 18(4): 417-428.
38. Feizi S, Javadi MA, Jamali H, Mirbabaee F (2010) Deep anterior lamellar keratoplasty in patients with keratoconus: big-bubble technique. Cornea 29(2): 177-182.
39. Keane M, Coster D, Zlaei M, Williams K (2014) Deep anterior lamellar keratoplasty versus penetrating keratoplasty for treating keratoconus. Cochrane Database Syst Rev 2014(7): CD009700.
40. Sogutlu Sari E, Kubaloglu A, Unal M, David Pinero, Nurullah Bulut, et al. (2012) Deep anterior lamellar keratoplasty versus penetrating keratoplasty for macular corneal dystrophy: a randomized clinical trial. Am J Ophthalmol 156(2): 267-274.
41. Huang OS, Mehta JS, Htoon HM, Tan DT, Wong TT (2016) Incidence and risk factors of elevated intraocular pressure following deep anterior lamellar keratoplasty. Am J Ophthalmol 170: 153-160.
42. Den S, Shimmura S, Tsubota K, Shimazaki J (2007) Impact of the Descemet membrane perforation on surgical outcomes after deep lamellar keratoplasty. Am J Ophthalmol 143(5): 750-754.
43. Unal M, Bilgin B, Yucel I, Akar Y, Apaydin C (2010) Conversion to Deep anterior lamellar keratoplasty (DALK): learning curve with big-bubble technique. Ophthalmic Surg Lasers Imaging 41(6): 642-650.
44. Myerscough J, Friehmann A, Bovone C, Mimouni M, Busin M (2020) Evaluation of the risk factors associated with conversion of intended deep anterior lamellar keratoplasty to penetrating keratoplasty. Br J Ophthalmol 104(6): 764-767.

How to cite this article: Guillermo Rodríguez I, Cristina Peris M. State of the Art of Corneal Transplantation. JOJ Ophthalmol. 2024; 10(5): 555796. DOI: 10.19080/JOJO.2024.09.555796

45. Schaub F, Heindl LM, Enders P, Roters S, Bachman BO, et al. (2017) Tiefe anteriore lamelläre keratoplastik. Ophthalmologe 114 (11): 1019-1026.

46. Gadhvi KA, Romano V, Cueto LFV, Aiello F, Day AC, et al. (2019) Deep anterior lamellar keratoplasty for keratoconus: multisurgeon results. Am J Ophthalmol 201: 54-62.

47. Melles GRJ, Wijdh RHJ, Nieuwendaal CP (2004) A technique to excise the Descemet membrane from a recipient cornea (descemetorhexis). Cornea 23(3): 286-288.

48. Gorovoy MS (2006) Descemet-stripping automated endothelial keratoplasty. Cornea 25(8): 886-889.

49. Feizi S, Javadi MA (2019) Effect of donor graft thickness on clinical outcomes after Descemet stripping automated endothelial keratoplasty. J Ophthalmic Vis Res 14(1): 18-26.

50. Neff KD, Biber JM, Holland EJ (2011) Comparison of central corneal graft thickness to visual acuity outcomes in endothelial keratoplasty. Cornea 30(4): 388-391.

51. Woo JH, Ang M, Htoon HM, Tan D (2019) Descemet membrane endothelial keratoplasty versus Descemet stripping automated endothelial keratoplasty and penetrating keratoplasty. Am J Ophthalmol 207: 288-303.

52. Shah AK, Terry MA, Shamie N, Chen ES, Phillips PM, et al. (2010) Complications and clinical outcomes of Descemet stripping automated endothelial keratoplasty with intraocular lens exchange. Am J Ophthalmol 149(3): 390-397.

53. Price MO, Price FW (2006) Descemet´s stripping with endothelial keratoplasty: Comparative outcomes with microkeratome-dissected and manually dissected donor tissue. Ophthalmology 113(11): 1936-1942.

54. Macsai MS, Kara-Jose AC (2007) Suture technique for Descemet stripping and endothelial keratoplasty. Cornea 26(9): 1123-1126.

55. Van Rooij J, Lucas EH, Geerards AJ, Remeijer L, Wubbels R (2018) Corneal transplantation for Fuchs' endothelial dystrophy: a comparison of three surgical techniques concerning 10 years graft survival and visual function. PLoS One 13(10): e0203993.

56. Thompson RW, Price MO, Bowers PJ, Price FW (2003) Long-term graft survival after penetrating keratoplasty. Ophthalmology 110(7): 1396-1402.

57. Fajgenbaum MAP, Hollick EJ (2017) Modeling endothelial cell loss after Descemet membrane endothelial keratoplasty: data from 5 years of follow-up. Cornea 36(5): 553-560.

58. Price DA, Kelley M, Price FW, Price MO (2018) Five-year graft survival of Descemet membrane endothelial keratoplasty (EK) versus Descemet stripping EK and the effect of donor sex matching. Ophthalmology 125(10): 1508-1514.

59. Terry MA, Shamie N, Chen ES, Hoar KL, Phillips PM, et al. (2008) Endothelial keratoplasty: The influence of preoperative donor endothelial cell densities on dislocation, primary graft failure, and 1-year cell counts. Cornea 27(10): 1131-1137.

60. Price MO, Price FW (2008) Endothelial cell loss after Descemet stripping with endothelial keratoplasty influencing factors and 2-year trend. Ophthalmology 115(5): 1700-1709.

61. Madi S, Leon P, Nahum Y, Giannaccare G, Beltz J, et al. (2019) Five-year outcomes of ultrathin Descemet stripping automated endothelial keratoplasty. Cornea 38(9): 1192-1197.

62. Jordan CS, Price MO, Trespalacios R, Price FW Jr (2009) Graft rejection episodes after Descemet stripping with endothelial keratoplasty: Part one: Clinical signs and symptoms BR J Ophthalmol 93: 387-390.

63. Melles GRJ, Ong TS, Ververs B, van der Wees J (2008) Preliminary clinical results of Descemet membrane endothelial keratoplasty. Am J Ophthalmol 145(2): 222-227.

64. Anshu A, Price MO, Price FW (2012) Risk of corneal transplant rejection significantly reduced with Descemet´s membrane endothelial keratoplasty. Ophthalmology 119(3): 536-540.

65. Deng SX, Lee WB, Hammersmith KM, Anthony N Kuo, Jennifer Y Li, et al. (2018) Descemet endothelial keratoplasty: safety and outcomes: a report by the American Academy of Ophthalmology. Ophthalmology 125(2): 295-310.

66. Steven P, Le Blanc C, Lankenau E, Marc Krug, Stefan Oelckers, et al. (2014) Optimising deep anterior lamellar keratoplasty (DALK) using intraoperative online optical coherence tomography (iOCT). Br J Ophthalmol 98(7): 900-904.

67. Pasricha ND, Shieh C, Carrasco-Zevallos OM, Brenton Keller, Joseph A. Izatt, et al. (2015) Real-time microscope-integrated OCT to improve visualization in DSAEK for advanced bullous keratopathy. Cornea 34(12): 1606-1610.

68. Juthani VV, Goshe JM, Srivastava SK, Justis P Ehlers (2014) Association between transient interface fluid on intraoperative OCT and textural interface opacity after DSAEK surgery in the PIONEER study. Cornea 33: 887-892.

69. Shousha MA, Yoo SH, Kymionis GD, Ide T, Takeshi Ide, William Feuer, et al. (2011) Long-term results of femtosecond laser-assisted sutureless anterior lamellar keratoplasty. Ophthalmology 118: 315-323.

70. Yoo SH, Kymionis GD, Koreishi A, Takeshi Ide, David Goldman, et al. (2008) Femtosecond laser–assisted suture less anterior lamellar keratoplasty. Ophthalmology 115: 1303-1307.

71. Griffith M, Jackson WB, Lagali N, Merrett K, Li F, et al. (2009) Artificial corneas: A regenerative medicine approach. Eye (Lond) 23: 1985-1989.

72. Darlington JK, Adrean SD, Schwab IR (2006) Trends of penetrating keratoplasty in the United States from 1980 to 2004. Ophthalmology 113: 2171-2175.

73. Melles GR (2006) Posterior Lamellar keratoplasty: DLEK to DSEK to DMEK. Cornea 25: 879-981.

74. Melles GR, Ong TS, Ververs B, Jacqueline van der Wees (2006) Descemet membrane endothelial keratoplasty (DMEK). Cornea 25: 987-990.

75. Fasolo A, Frigo AC, Böhm E, Claudio Genisi, Paolo Rama, et al. (2006) The CORTES study: Corneal transplant indications and graft survival in an Italian cohort of patients. Cornea 25: 507-515.

76. Cursiefen C, Küchle M, Naumann GO (1998) Changing indications of penetrating keratoplasty: Histopathology of 1,250 corneal buttons. Cornea 17: 468-470.

77. Terry MA, Ousley PJ (2005) Deep lamellar endothelial visual acuity, astigmatism and endothelial survival in a large prospective series. Ophthalmology 112: 1541-1548.

78. Afshari NA, Pittard AB, Siddiqui A, Gordon K Klintworth (2006) Clinical study of Fuchs corneal endothelial dystrophy leading to penetrant keratoplasty: A 30-year experience. Arch Ophthalmol 124: 777-780.

79. Maier AK, Gundlach E, Schroeter J, Matthias K J Klamann, Johannes Gonnermann, et al. (2015) Influence of the difficulty of graft unfolding and attachment on the outcome in Descemet endothelial keratoplasty. Graefes Arch Clin Exp Ophthalmol 253: 895-900.

How to cite this article: Guillermo Rodríguez I, Cristina Peris M. State of the Art of Corneal Transplantation. JOJ Ophthalmol. 2024; 10(5): 555796. DOI: 10.19080/JOJO.2024.09.555796

80. Röck T, Bramkamp M, Bartz-Schmidt KU, D Röck, E Yörük (2015) Causes that influence the detachment rate after Descemet membrane endothelial keratoplasty. Graefes Arch Clin Exp Ophthalmol 253: 2217-2222.

81. Raiskup-Wolf F, Hoyer A, Spoerl E, Lutz E Pillunat (2008) Collagen crosslinking with riboflavin and ultraviolet-A lightin keratoconus: long-term results. J Cataract Refract Surg 34: 796-801.