

Advances in Corneal Transplantation: Techniques, Surgical Improvements, Clinical Outcomes, and Future Prospects

¹Umar Tipu, ²Mansoor Musa, ³Dr Rehan Moinuddin Shaikh, ⁴Qamar Abbas, ⁵Isma Abbas, ⁶Faiza Maqsood

¹UHS, Lahore

²Service Hospital, Lahore

³Sharif Medical College, Lahore

⁴Mayo Hospital, Lahore

⁵PIMS, Islamabad

⁶Sir Gangaram Hospital, Lahore

Abstract

Background: Corneal transplant is the most prevalent solid tissue transplant performed worldwide, restoring vision to patients with corneal opacity, keratoconus, endothelial failure, and other corneal conditions. Surgical techniques have dramatically enhanced the success rate of graft survival and vision over the last two decades.

Objective: The present article gives an overview of various corneal transplant procedures, including penetrating keratoplasty (PK), lamellar keratoplasty (LK), endothelial keratoplasty (EK), and emerging bioengineered grafts, emphasizing their applications, outcomes, advantages, and disadvantages.

Methods: A detailed study of the literature and incorporation of recent clinical accounts were done to analyze surgical techniques, postoperative visual outcomes, graft survival, and complication rates in various transplantation procedures.

Results: Lamellar surgery, such as Descemet's stripping automated endothelial keratoplasty (DSAEK) and Descemet's membrane endothelial keratoplasty (DMEK), is associated with faster visual recovery and lower rejection rates compared with the standard PK. Advances in donor tissue processing, femtosecond lasers, and minimally invasive techniques optimized overall success.

Conclusion: Evolution from complete thickness to selective layer transplantation has revolutionized the science of corneal surgery. Patient-specific selection of technique and continuous innovation promise even superior visual rehabilitation and graft survival in the long term.

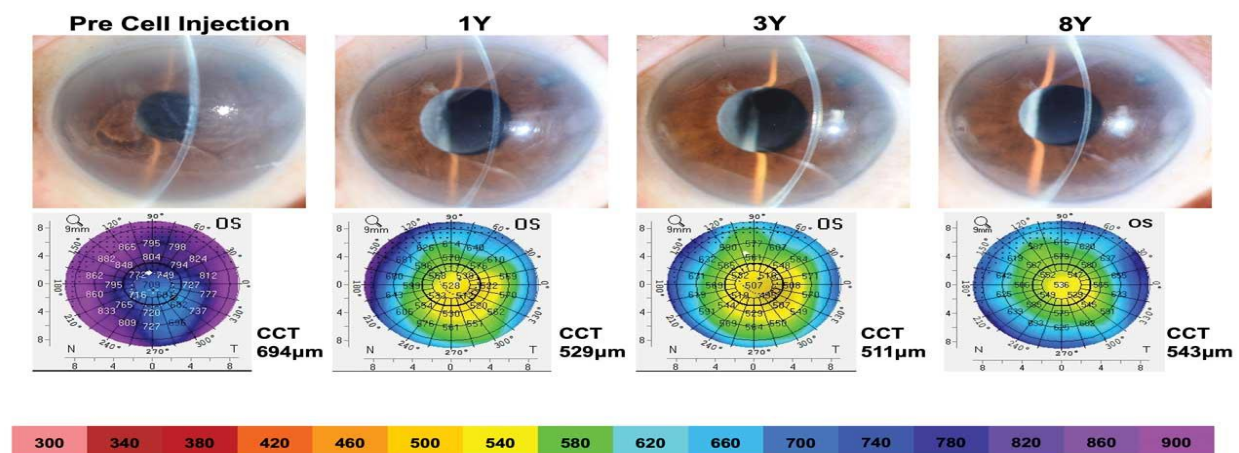
Keyword: Corneal transplantation, penetrating keratoplasty, lamellar keratoplasty, endothelial keratoplasty, DSAEK, DMEK, graft survival, visual outcomes, surgical innovations.

Introduction

Millions of people have corneal blindness throughout the world and it is one of the leading causes of blindness, especially where there is limited access to ophthalmic treatment [1]. Corneal transplant, or keratoplasty, continues to be the "gold standard" for vision restoration in patients with unrepairable injury of the cornea from trauma, infectious keratitis, keratoconus, corneal dystrophies, or endothelial disease [2]. It is the most frequent solid organ transplant with excellent results if under ideal circumstances [3].



Traditionally, penetrating keratoplasty (PK) a full-thickness corneal transplant was the dominant surgical technique [4]. While PK provides excellent long-term clarity, it carries risks such as irregular astigmatism, prolonged visual recovery, wound dehiscence, and immune-mediated graft rejection [5]. Over the past two decades, lamellar keratoplasty techniques have gained prominence by selectively replacing diseased corneal layers while preserving healthy tissue [6]. This shift represents a major advancement in the field. Anterior lamellar keratoplasty (ALK) is substitution of the anterior stroma with native endothelium of the patient intact, useful in conditions like keratoconus [7]. Endothelial keratoplasty (EK), including DSAEK and DMEK, is suited for diseases limited to posterior cornea, such as Fuchs' endothelial dystrophy or pseudophakic bullous keratopathy [8]. These techniques share the following advantages in common: more rapid visual rehabilitation, greater structural integrity, fewer rejections, and fewer complications due to sutures. Technological advancements have also maximized the outcome of surgery [9]. Femtosecond laser keratoplasty has increased accuracy in recipient and donor bed preparation, enabling customized wound architecture and more stable postoperative results [10]. In addition, advancements in eye banking, tissue preservation, and pre-cut donor tissue preparation have optimized procedures and accessible formats.



As these improvements have taken place, however, there are some associated disadvantages with them, including global donor shortages, postoperative morbidity such as graft loss or loss of endothelial cells

and use of long-term immunosuppression in certain cases [11]. Xenograft research, bioengineered cornea, and cell-based therapies promise to break through these limitations. Individual patient care requires understanding relative advantage and outcome of various strategies. This article is a study of current corneal transplant methods, indication, outcome, and disadvantages, and future developments that are shaping the future of corneal surgery.

Methodology

Systematic literature research on PubMed, Scopus, and Cochrane Library was conducted between 2005 and 2025. The search terms used were "corneal transplantation," "penetrating keratoplasty," "lamellar keratoplasty," "endothelial keratoplasty," "DSAEK," and "DMEK." Clinical guidelines by the American Academy of Ophthalmology (AAO) and the European Society of Cataract and Refractive Surgeons (ESCRS) were also studied. Inclusion criteria were randomized controlled trials, cohort studies, and meta-analyses of postoperative outcomes, graft survival, vision, rejection rate, and complication in adult recipients who underwent corneal transplant. Data on surgical procedure, indication, postoperative outcome, and complication rate were extracted. Future perspective articles on experimental bioengineered grafts were also considered. Information was synthesized in tabular and narrative forms to compare various techniques and emphasize key findings.

Results

Corneal transplantation remains the cornerstone for restoring vision in patients with advanced corneal diseases. Over time, surgical techniques have evolved from traditional full-thickness grafts to selective lamellar and endothelial replacements, aiming to improve outcomes and reduce complications.

Penetrating Keratoplasty (PK) involves replacement of the entire corneal thickness and remains the most widely practiced method, particularly for cases involving stromal opacities or severe scarring. However, its longer visual rehabilitation period and higher risk of astigmatism and graft rejection have prompted the development of more targeted procedures.

Table 1. Overview Comparison of Corneal Transplanting Procedures

Procedure	Indications	Vision Rehabilitation	Graft Survival (5 years)	Risk of Rejection	Key Strengths	Key Limitations
Penetrating Keratoplasty (PK)	Full-thickness corneal disease	Slower (6–12 months)	75–85%	Moderate to severe	Widely practiced, excellent visual clarity	High astigmatism, suture-related complications
Anterior Lamellar Keratoplasty (ALK/DALK)	Keratoconus, stromal scars	Moderate (3–6 months)	85–90%	Low	Preserves endothelium, reduced rejection risk	Technically demanding, possible interface haze
Endothelial Keratoplasty (DSAEK/DMEK)	Endothelial dysfunction	Quick (1–3 months)	90–95%	Very low	Minimal sutures, rapid recovery	Steep learning curve, delicate tissue handling

Table 2. Postoperative Results and Complications

Parameter	PK	ALK/DALK	DSAEK/DMEK
Best-Corrected Visual Acuity $\geq$ 20/40	70–80%	80–85%	85–90%
Endothelial Cell Loss (1 year)	25–30%	10–15%	20–25%
Graft Rejection Episodes	10–18%	2–5%	1–3%
Average Rehabilitation Time	8–12 months	4–6 months	1–3 months

Discussion

Corneal transplantation's evolution is an eye surgery paradigm shift, away from the traditional full-thickness to the selective layer replacement technique [12]. Penetrating keratoplasty, costly in the past though it may be, continues for all-layer corneal disease or when other techniques are contraindicated [13]. It is high-quality optics but beset with prolonged visual recovery, high postoperative astigmatism, and elevated rejection risk [14]. Lamellar keratoplasty surgeries are very popular as they can target diseased layers of the cornea selectively. Deep anterior lamellar keratoplasty (DALK) is free from endothelium replacement, with preservation of the endothelium by the host and less risk of rejection [15]. It is technically challenging but can create interface haze in case it is carefully done. Endothelial keratoplasty, and specifically DSAEK and DMEK, has transformed treatment of posterior corneal illness. DMEK, with near-anatomical substitution through replacing just Descemet's membrane and endothelium, provides better vision outcomes and low rejection [16]. Its principal disadvantages are tissue handling and surgical learning curves, which are being overcome with experience and standardization of training. Technical advances like femtosecond laser-assisted keratoplasty and preloaded donor tissue have made procedures faster, accuracy with wounds improved, and operating time reduced. Moreover, advances in eye banking and donor tissue preparation have improved the availability of grafts as well as consistency of results [17]. Complications continue. Endothelial cell loss affects long-term graft survival, and rejection does continue, but less frequently with lamellar surgery. Chronic immunosuppression, suture-related issues, and pathology of interface remain concerns. Patient selection, careful preoperative planning, and stringent postoperative management make success a reality [18]. New technologies like bioengineered cornea, xenograft, and regeneration through cell therapy have the potential to surpass donor scarcity globally and reduce complications. Clinical trials for the implants in corneal stroma and injecting endothelial cells are already in process, with a promise of transplanting in a more minimally invasive way in the future and being accessible universally.

Conclusion

Corneal transplant has come a long way, with newer technologies yielding improved results and rehabilitation period over the traditional methods. Selective lamellar and endothelial keratoplasty are becoming first line for all indications, reducing rejection and enhancing visual recovery. Enhanced surgery and technology have guaranteed optimal graft survival and made transplantation available all over the world. Future development of regenerative therapy and bioengineered tissue will further counteract existing drawbacks and provide even more predictable, less traumatic, and globally available means of addressing corneal blindness.

References

1. Ziemińska, D., Motolko, K., Burczyk, R., Duszyński, K., & Tokarczyk, E. (2024). Advancements in Corneal Transplantation: Addressing Rejection Risks, Innovations and Challenges. *Quality in Sport*, 35, 56443-56443.
2. Aggarwal, S., Kumari, M., & Bhatnagar, N. (2024). Advancements in keratoplasty: Exploring newer techniques and imaging modalities for enhanced surgical outcomes. *Saudi Journal of Ophthalmology*, 10-4103.
3. Nanavaty, M. A., & Khoramnia, R. Enhancing Patient Outcomes After Cataract, Corneal and Refractive Surgery: A Comprehensive Analysis of Contemporary Advances and Future Directions. *Frontiers in Medicine*, 12, 1697162.
4. Boroumand, S., Rahmani, M., Sigaroodi, F., Ganjoury, C., Parandakh, A., Bonakdar, A., ... & Soleimani, M. (2024). The Landscape of clinical trials in corneal regeneration: a systematic study of tissue Engineering approaches in corneal disease. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, 112(8), e35449.
5. Nascimento, H., Martins, T. M., Moreira, R., Barbieri, G., Pires, P., Carvalho, L. N., ... & Raia, S. (2025). Current Scenario and Future Perspectives of Porcine Corneal Xenotransplantation. *Cornea*, 44(3), 387-404.
6. Heger, K. A., Egger, D., Schmidinger, G., Skorpik, C., Waldstein, S. M., & Pircher, N. (2025). A historical view of the development of corneal transplantation: from penetrating keratoplasty to selective transplantation of the finest corneal layers. *Wiener Medizinische Wochenschrift*, 1-11.
7. Morales, P., & Durán, J. A. (2025). Advances in Intracorneal Ring Segment (ICRS) Implantation for Keratoconus: A Comprehensive Literature Study, Clinical Insights, and Future Prospects. *Journal of Clinical Medicine*, 14(13), 4454.
8. Javed, Z., & Daigavane, S. (2024). Harnessing Corneal Stromal Regeneration for Vision Restoration: A Comprehensive Study of the Emerging Treatment Techniques for Keratoconus. *Cureus*, 16(9).
9. Aldebasi, T., Gangadharan, S., Alshammari, Y. S., Alruhaimi, S. S., Alrashid, S. O., Ardah, H., ... & Alfardan, F. (2024). Comparison of clinical outcomes, complications and patient satisfaction following deep anterior lamellar keratoplasty and penetrating keratoplasty. *BMC ophthalmology*, 24(1), 501.
10. Mohammed, S. E. M., Ahmed, S. T. R. S., & Mohammed Elmetwaly, A. A. (2025). Impact of Educational Program on Post-operative Health Outcomes for Patients Undergoing Keratoplasty. *International Egyptian Journal of Nursing Sciences and Research*, 6(1), 189-207.
11. Suresh, S. (2024). Letter Regarding: Outcomes of Secondary Intraocular Lens Implantation and Descemet Stripping Endothelial Keratoplasty—Comparing Staged Versus Combined Surgical Approach. *Cornea*, 43(11), e44-e45.
12. Thacharodi, A., Singh, P., Meenatchi, R., Tawfeeq Ahmed, Z. H., Kumar, R. R., V, N., ... & Hassan, S. (2024). Revolutionizing healthcare and medicine: The impact of modern technologies for a healthier future—A comprehensive study. *Health Care Science*, 3(5), 329-349.
13. Krysik, K., Miklaszewski, P., Gadamer, A. M., Janiszewska-Bil, D., Lyssek-Boroń, A., Dobrowolski, D., ... & Wylęgała, E. (2024). Clinical Outcomes and Early Postoperative Complications in Boston Type I Keratoprosthesis Implantation: A Retrospective Study. *Journal of clinical medicine*, 13(22), 6710.
14. Rodríguez Fuentes, D. E., Flores Nucamendi, K., Valdez-García, J. E., Raquel, C. D. D., Isaac Alejandro, V. P., Cirian, O., & Zavala, J. (2024). Corneal tissue engineering: From research to

- industry, quality of life impact, and Latin American ophthalmologists' perspectives. *F1000Research*, 13, 608.
15. Kirgiz, A., Kemer Atik, B., Emul, M., & Taskapili, M. (2024). Clinical outcomes of femtosecond laser-assisted corneal allogenic intrastromal ring segment (CAIRS) in the treatment of keratoconus. *Clinical & Experimental Ophthalmology*, 52(7), 713-723.
 16. Ianchulev, T., Weinreb, R. N., Calvo, E. A., Lewis, J., Kamthan, G., Sheybani, A., ... & Ahmed, I. K. (2024). Bio-interventional cyclodialysis and allograft scleral reinforcement for uveoscleral outflow enhancement in open-angle glaucoma patients: one-year clinical outcomes. *Clinical Ophthalmology*, 3605-3614.
 17. France, A., De Silva, H., Tong, D., Mei, L., & Guan, G. (2025, May). From Tooth to Vision: A Decade of Breakthroughs in Osteo-Odonto-Keratoprosthesis (OOKP) and Modified OOKP—Global Insights into Surgical Techniques, Outcomes, and Pioneering Research. In *Seminars in ophthalmology* (pp. 1-12). Taylor & Francis.
 18. Coscarelli, S., de Oliveira Sieiro, R., Fernandes, V. M., Coscarelli, S. P., & Torquetti, L. (2024). Double intrastromal corneal ring segment implantation: a new approach for improved clinical outcomes in keratoconus patients. *International Journal of Ophthalmology*, 17(11), 2023.