FEMTOSECOND-ASSISTED DEEP ANTERIOR LAMELLAR KERATOPLASTY FOR KERATOCONUS: CONTEMPORARY CLINICAL PERSPECTIVES AND OUTCOME ANALYSIS

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Abstract. *Femtosecond-assisted deep anterior lamellar keratoplasty (femto-DALK) represents a contemporary surgical approach for corneal pathologies that preserves the recipient's endothelium. Despite increasing clinical adoption, comprehensive analysis of femto-DALK advantages over conventional techniques requires further investigation. We conducted a retrospective analysis of 12 patients aged 18-42 years with stage III keratoconus who underwent femto-DALK between 2023-2024. Primary outcome measures included visual acuity, refractive outcomes, keratotopographic parameters, and healing characteristics. Best-corrected visual acuity of 0.6 or better was achieved in 66.67% of patients at 12 months post-operatively, with mean postoperative astigmatism of 2.1±0.9 D. Tissue interface precision was characterized by predictable residual stromal thickness of 15.6±5.3 μm. Big-bubble formation was successful in 91.7% of cases, with conversion to penetrating keratoplasty required in only 8.3% of procedures. Postoperative complications were minimal, with complete anatomical apposition of Descemet's membrane confirmed by OCT in all cases. Femto-DALK demonstrates significant advantages in tissue interface precision and accelerated wound healing compared to conventional keratoplasty techniques, confirming high efficacy in achieving stable visual and refractive outcomes with enhanced surgical predictability.*

Keywords: *corneal transplantation, keratoconus, deep anterior lamellar keratoplasty, femtosecond laser, femto-DALK, tissue interface precision.*

Introduction. Deep anterior lamellar keratoplasty has emerged as the preferred surgical modality for corneal pathologies that spare the endothelial layer, particularly in the management of advanced keratoconus [1]. The fundamental advantages of DALK include preservation of the recipient's native endothelium, which significantly reduces immunological rejection risk and eliminates the necessity for lifelong immunosuppressive therapy. Additionally, DALK maintains superior biomechanical stability compared to penetrating keratoplasty, reducing the risk of traumatic wound dehiscence and providing enhanced long-term graft survival [2]. Traditional DALK technique employs mechanical or pneumatic stromal dissection using Anwar's big bubble methodology, however, this approach is associated with considerable technical challenges. Primary limitations include elevated risk of Descemet's membrane perforation, reported variably between 10-40% across different studies, and unpredictable dissection depth control. These technical difficulties have historically limited the widespread adoption of DALK despite its theoretical advantages over penetrating keratoplasty [3].

The integration of femtosecond laser technology in ophthalmic surgery has revolutionized the precision and safety profile of DALK procedures. Femtosecond laser-assisted DALK enables predictable and safe procedures with improved reproducibility compared to manual techniques. The technology facilitates precise incision formation with controlled resection depth, theoretically enhancing tissue apposition accuracy and promoting superior healing responses [4]. Contemporary studies demonstrate that femtosecond-assisted DALK shows comparable visual and refractive outcomes to manual techniques but exhibits more evident corneal wound healing patterns, suggesting potential advantages in post-operative recovery.

Keratoconus remains the predominant indication for keratoplasty, particularly in advanced disease stages characterized by significant corneal thinning and optical irregularities. In stage III keratoconus, conventional conservative management approaches including rigid contact lens fitting and corneal collagen cross-linking demonstrate limited efficacy, necessitating surgical intervention for visual rehabilitation. Recent advances in femtosecond laser technology have introduced innovative configurations, including mushroom-shaped profiles that enhance graft-host junction stability and optical outcomes through improved mechanical interlocking [5, 6].

Despite the progressive clinical implementation of femto-DALK, systematic evaluation of its advantages requires comprehensive analysis, particularly regarding tissue interface precision as a critical determinant of corneal optical surface quality and long-term graft stability [7].

The present study aims to conduct comprehensive analysis of femto-DALK clinical aspects in keratoconus management, with emphasis on tissue interface precision evaluation and functional outcomes assessment.

Materials and methods. This retrospective study was conducted at the "Saif-Optima" Ophthalmology Clinic, analyzing 12 patients who underwent femtosecond-assisted DALK between January 2023 and December 2024. Patient selection was based on strict inclusion criteria including age 18-42 years, confirmed diagnosis of stage III keratoconus (KC III), central corneal thickness less than 400 μm, absence of endothelial opacification, and no evidence of acute corneal hydrops. Exclusion criteria encompassed previous corneal surgical procedures, concurrent ocular pathology affecting visual potential, systemic connective tissue disorders, active ocular inflammation or infection, pregnancy or lactation, and insufficient follow-up compliance. Comprehensive preoperative evaluation included visual function assessment using standardized LogMAR charts for uncorrected (UCVA) and best-corrected visual acuity (BCVA) measurements. Refractive analysis was performed through automated refractometry determining spherical equivalent (SE) and cylindrical (cyl) components. Anterior segment evaluation involved detailed slit-lamp biomicroscopy with photographic documentation, while intraocular pressure was measured using iCare tonometry. Posterior segment assessment included B-scan ultrasonography. Corneal imaging utilized the CASIA II system for comprehensive analysis including anterior segment optical coherence tomography, Scheimpflug-based corneal tomography, pachymetric mapping, and keratotopographic analysis. Endothelial assessment was performed through specular microscopy for endothelial cell density quantification, while electrophysiological testing included visual evoked potentials and electroretinography when clinically indicated.

Surgical planning utilized comprehensive keratopachymetric mapping to determine optimal laser resection depth, with parameters configured to maintain residual corneal thickness of 100 μm at the thinnest point, ensuring adequate safety margin for subsequent manual dissection. The femtosecond laser procedures were performed using the Femto LDV Z8 system with CALLISTO intraoperative guidance, utilizing lamellar cut diameters of 7.5-8.5 mm individualized based on corneal diameter, with 90-degree side cut angles and optimized energy settings for corneal tissue. The surgical procedure commenced with standard sterile preparation and draping under topical anesthesia supplemented with intracameral lidocaine. Femtosecond laser application created precise lamellar cuts with predetermined depth and mushroom-shaped side cut configuration, followed by manual trephination using diamond keratotomic blade positioned 1.0 mm central to the peripheral laser incision edge. Stromal dissection involved formation of dissection plane using blunt-tipped microsurgical spatula from periphery to center in deep stromal layers. The big bubble technique employed pneumatic separation of Descemet's membrane through controlled air injection, creating characteristic air bubble configuration that facilitated safe stromal removal. Donor corneal preparation incorporated corresponding femtosecond laser profile for optimal fit, with precise donor-recipient alignment achieved through initial placement of four cardinal sutures, completed with 12-16 additional interrupted sutures using 10-0 nylon for optimal wound apposition.

Postoperative management followed standardized protocols including topical antibiotics four times daily for two weeks, topical corticosteroids with gradual tapering over 6-12 months, preservative-free artificial tears for ocular surface optimization, and appropriate protective eyewear with activity restrictions. Comprehensive evaluations were conducted at one week, one month, three months, six months, and twelve months post-operatively, assessing primary outcome measures including BCVA improvement, refractive astigmatism reduction, graft clarity and interface healing, and complication rates.

Statistical analysis was performed using SPSS version 25.0, with paired t-tests utilized for comparing pre- and postoperative parameters and statistical significance defined as $p<0.05$.

Results and discussions. The study cohort consisted of 12 patients with mean age 28.5±6.2 years, demonstrating the typical demographic profile of advanced KC patients requiring surgical intervention. All patients presented with advanced KC III characterized by significant visual impairment and contact lens intolerance, reflecting the appropriate patient selection for this advanced surgical procedure. Baseline visual function demonstrated severe impairment with UCVA of 0.02±0.01 LogMAR and BCVA of 0.12±0.08 LogMAR, indicating the profound impact of corneal irregularities on visual performance in KC III.

Preoperative refractive status revealed high myopia with SE of -6.84±0.62 D and significant cyl of -6.09±0.13 D, consistent with the typical refractive profile of KC III. These findings underscore the severity of optical aberrations present in advanced disease stages and justify the need for surgical intervention when conservative management fails to provide adequate visual rehabilitation. Maximum keratometry readings of 58.4±4.2 D confirmed the presence of significant corneal steepening characteristic of progressive KC.

Corneal parameters demonstrated advanced disease with minimum corneal thickness of 312±24 μm and central corneal thickness (CCT) of 385±31 μm, indicating substantial corneal thinning that precludes conservative treatment options such as additional corneal cross-linking procedures. The corneal volume of 45.2±3.1 mm^3 reflected the overall structural compromise present in these cases. Importantly, endothelial assessment revealed preserved endothelial function with mean cell density of 2208.3±180 cells/mm^2, coefficient of variation of 28.4±3.2%, and hexagonal cell percentage of 64.2±5.8%, confirming the appropriateness of endothelium-sparing DALK procedures rather than full-thickness corneal transplantation.

Intraoperative results demonstrated significant advantages of the femtosecond-assisted approach, with successful big-bubble formation achieved in 91.7% of cases. This success rate substantially exceeds the 68% rate reported in recent studies of femtosecond-assisted procedures and significantly surpasses historical rates of 60-70% associated with manual DALK techniques. The enhanced success rate can be attributed to the precise depth control provided by femtosecond laser pre-cutting, which standardizes dissection depth and reduces variability inherent in manual techniques. The improved visualization through consistent tissue plane creation and reduced mechanical trauma during stromal separation contribute to the higher success rate observed in our series.

Conversion to penetrating keratoplasty was required in only one case, representing an 8.3% conversion rate that compares favorably with historical rates of 15-25% reported in conventional DALK series. The single conversion case was attributed to extensive central scarring with inability to achieve adequate stromal separation, demonstrating that even with advanced technology, certain anatomical variations may preclude successful lamellar dissection.

A critical advantage of femtosecond laser technology demonstrated in our study was the ability to create predictable tissue interfaces with micron-level precision. Analysis revealed residual stromal thickness of 15.6±5.3 μm with interface regularity exceeding 95% smooth interface formation in successful cases. OCT findings confirmed complete anatomical apposition in all successful procedures, indicating optimal tissue healing and integration. This precision represents a significant

advancement over manual techniques, where interface irregularities can compromise optical quality and potentially influence long-term outcomes through induced higher-order aberrations.

Early postoperative visual rehabilitation was evident within the first week, with UCVA to 0.2±0.1 LogMAR and BCVA reaching 0.25±0.15 LogMAR. This rapid visual improvement reflects the precision of tissue apposition and minimal induced inflammation associated with femtosecond procedures. The early visual gains demonstrate the immediate benefits of precise surgical technique and suggest reduced postoperative morbidity compared to conventional approaches. The rapid visual recovery also indicates optimal wound healing characteristics and minimal disruption of corneal architecture during the surgical procedure. Intermediate follow-up at six months demonstrated continued improvement with UCVA of 0.35±0.05 and BCVA of 0.55±0.15; mean cyl reduction to 2.5±1.5D represented significant improvement from preoperative values, while CCT of 465±25 μm indicated appropriate graft thickness and successful anatomical reconstruction. These intermediate results suggest stable wound healing and appropriate refractive rehabilitation, with continued visual improvement throughout the early postoperative period.

Final outcomes at twelve months demonstrated clinically significant visual rehabilitation, with BCVA of 0.6 or better achieved in 8 patients, representing a 66.67% success rate for functionally significant visual improvement. This outcome compares favorably with published series of both manual and femto-DALK procedures, confirming the efficacy of the femto-assisted approach in achieving meaningful visual rehabilitation. The mean cyl of 2.1±0.9 D at final follow-up represented substantial improvement from preoperative values and demonstrated no progressive changes, indicating refractive stability and successful corneal reconstruction. The absence of progressive astigmatic changes throughout the follow-up period suggests stable wound healing and appropriate graft-host integration. Recent studies demonstrate that precisely controlled femto-laser side cuts achieve significantly better visual outcomes, with BCVA of 0.08 ± 0.07 at one year in some series, which aligns with our findings and validates the importance of surgical precision in achieving optimal outcomes. The refractive stability observed in our series indicates successful restoration of corneal architecture and appropriate optical rehabilitation. Graft clarity was maintained in 100% of cases throughout the follow-up period, with no evidence of immunological rejection episodes. This finding reflects the advantages of endothelium-sparing surgery in reducing rejection risk and supports the theoretical benefits of DALK over PK. The absence of rejection episodes eliminates the need for intensive immunosuppressive therapy and reduces long-term complications associated with chronic medication use.

Studies indicate that femtosecond-assisted and manual DALK show comparable visual and refractive outcomes, but femtosecond-assisted procedures exhibit more evident corneal wound healing patterns, supporting our observations of enhanced healing characteristics. The advantages of femto-DALK identified in our study include enhanced precision through consistent tissue interface formation with minimal variability, reduced complications with lower conversion rates and fewer intraoperative challenges, predictable outcomes through standardized surgical approach with reproducible results, accelerated healing with improved wound healing patterns as evidenced by OCT analysis, and refractive stability with consistent astigmatic outcomes without progressive changes. The enhanced surgical precision observed in our series can be attributed to the ability of femtosecond laser technology to create predictable incision depths and configurations, reducing surgeon-dependent variability and improving procedural standardization. The reduced complication rate reflects both the precision of laser-assisted incisions and the improved visualization provided by consistent tissue plane creation.

Conclusions. Femto-DALK represents a significant advancement in the surgical management of KC III, demonstrating several key advantages over conventional techniques. Enhanced surgical precision through improved tissue interface formation with predictable residual stromal thickness control addresses one of the primary limitations of manual DALK procedures.

Accelerated recovery patterns with enhanced wound healing characteristics compared to conventional techniques suggest reduced postoperative morbidity and improved patient experience. The refractive stability demonstrated through consistent long-term outcomes with minimal progressive changes indicates successful restoration of corneal architecture and appropriate optical rehabilitation.

The precision afforded by computer-controlled laser delivery reduces surgeon-dependent variability and improves procedural standardization, potentially shortening the learning curve associated with DALK surgery. As surgical experience continues to evolve and technology advances, femto-DALK is positioned to become the standard approach for anterior corneal pathologies requiring transplantation.

REFERENCES

1. Anwar M, Teichmann KD. Deep lamellar keratoplasty: surgical techniques for anterior lamellar keratoplasty with and without baring of Descemet's membrane. Cornea. 2002;21(4):374-383.

2. Buzzonetti L, Laborante A, Petrocelli G. Standardized big-bubble technique in deep anterior lamellar keratoplasty assisted by femtosecond laser. J Refract Surg. 2010;26(3):219-224.

3. Cleary C, Li YJ, Bourges JL. Keratoplasty: the use of the femtosecond laser. Curr Opin Ophthalmol. 2013;24(4):310-316.

4. Chamberlain W, Lin CC, Austin A, et al. Descemet endothelial thickness comparison trial: a randomized comparison between Descemet stripping automated endothelial keratoplasty and Descemet membrane endothelial keratoplasty. Ophthalmology. 2019;126(1):19-26.

5. Henein C, Nanavaty MA. Systematic review comparing penetrating keratoplasty and deep anterior lamellar keratoplasty for management of keratoconus. Cont Lens Anterior Eye. 2017;40(1):3-14.

6. Huang T, Zhang X, Wang Y, Zhang H. Outcomes of femtosecond laser-assisted mushroom-configuration keratoplasty in advanced keratoconus. Eye (Lond). 2016;30(4):569-575.

7. Sarnicola V, Toro P, Gentile D. Descemetic DALK and predescemetic DALK: outcomes in 236 cases of keratoconus. Cornea. 2010;29(1):53-59.