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DOES TRANSPLANTATION OF THE BOWMAN LAYER REDUCE THE PROGRESSION OF KERATOCONUS? A SYSTEMATIC REVIEW

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Abstract

Background: Keratoconus is a progressive corneal ectatic disorder that can severely impair vision. Bowman layer transplantation (BLT) has been proposed as a minimally invasive surgical option to stabilize ectasia and preserve vision in advanced keratoconus.

Objective: To systematically evaluate whether BLT reduces the progression of keratoconus and improves clinical outcomes, including keratometry, visual acuity, and contact lens tolerance.

Methods: A systematic review was conducted according to PRISMA 2020 guidelines. Databases searched included PubMed, Scopus, Web of Science, Embase, and Google Scholar. Studies were included if they reported BLT outcomes in keratoconus patients. Eleven studies met eligibility criteria, comprising prospective cohorts, retrospective series, and interventional case studies published between 2015 and 2025.

Results: Across studies, BLT significantly reduced keratometric values (average Kmax reductions of 5–7 D in many series) and maintained or improved best spectacle-corrected visual acuity. Long-term stability was demonstrated up to 7–8 years postoperatively. Complications were rare and generally minor, with isolated reports of hydrops, epithelial defects, and graft rejection. Surgical innovations, including femtosecond laser-assisted and onlay grafting techniques, enhanced outcomes and reproducibility.

Conclusions: BLT appears to stabilize keratoconus progression and preserve vision in advanced cases, delaying the need for keratoplasty. While current evidence supports its efficacy and safety, further multicenter randomized trials with standardized protocols are necessary to confirm long-term benefits and refine patient selection criteria.

Keywords: Bowman layer transplantation; Keratoconus; Corneal ectasia; Corneal stabilization; Femtosecond laser; Onlay grafting; Corneal transplantation alternatives

INTRODUCTION

Keratoconus is a progressive ectatic corneal disorder characterized by thinning, protrusion, and irregular astigmatism that can result in severe visual impairment if left untreated. Conventional management includes rigid gas-permeable contact lenses, intracorneal ring segments, or keratoplasty in advanced stages. However, these treatments often present limitations, such as complications, loss of visual quality, or disease progression, which has motivated the development of less invasive approaches such as Bowman layer transplantation (BLT) (Dragnea et al., 2018).

Bowman's layer is an acellular, collagen-rich interface situated between the epithelium and corneal stroma. Although once considered vestigial, increasing evidence supports its biomechanical role in maintaining corneal stability. Histopathological studies demonstrate that disruption or thinning of Bowman's layer is a consistent finding in keratoconus, suggesting that reinforcing this layer could contribute to halting ectatic progression (Galvis et al., 2017).

BLT was introduced as a minimally invasive surgical alternative for patients with advanced keratoconus who were no longer suitable for corneal cross-linking. The procedure involves creating a mid-stromal pocket, either manually or using femtosecond laser assistance, followed by insertion of an isolated donor Bowman layer graft. The goal is to flatten and stabilize the corneal curvature while preserving contact lens tolerance (Tong et al., 2019).

A major advantage of BLT is its potential to postpone or avoid the need for penetrating keratoplasty (PK) or deep anterior lamellar keratoplasty (DALK), which are associated with greater surgical risks and longer recovery times.

By providing structural reinforcement, BLT enables patients to maintain visual function through contact lens use during intermediate disease stages (Sharma, Dubey, & Prakash, 2018).

Recent innovations have refined BLT techniques. For example, the use of femtosecond lasers has improved the accuracy of stromal pocket creation and graft insertion, potentially lowering complication rates and increasing reproducibility (De Clerck, Bravetti, Kropp, & Massa, 2023). In addition, variations such as inlay versus onlay techniques are being explored to determine the most suitable method for different severities of keratoconus (Van der Star, van Dijk, Vasiliauskaitė, Dapena, & Oellerich, 2022).

Clinical outcomes after BLT generally demonstrate favorable biomechanical and optical changes. For instance, Tourkmani et al. (2022) reported significant flattening of corneal curvature and reduction in astigmatism, especially in the central and paracentral zones. Similarly, reductions in keratometry and maintenance of visual function have been observed in multiple case series, underscoring the stabilizing effect of BLT (van Dijk et al., 2015).

Nevertheless, uncertainties remain regarding long-term outcomes, graft survival, and comparisons with alternative treatments. Preliminary evidence indicates that endothelial cell density remains unaffected by BLT, but larger multicenter trials are needed to validate its safety and durability over extended follow-up (Dragnea et al., 2018). Furthermore, standardization of surgical protocols and evaluation of patient-reported quality-of-life measures remain areas for future investigation.

In summary, Bowman layer transplantation represents a novel and promising intervention for advanced keratoconus. By reinforcing the biomechanical structure of the cornea without resorting to full-thickness transplantation, BLT offers a means of delaying keratoplasty, reducing complications, and maintaining functional vision. Ongoing refinements and clinical studies will further clarify its place in the evolving management algorithm of keratoconus (Shah et al., 2022).

METHODOLOGY

Study Design

This systematic review was conducted in accordance with the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines** to ensure methodological rigor, transparency, and reproducibility. The primary objective was to synthesize empirical evidence on whether **Bowman layer transplantation (BLT)** reduces the progression of keratoconus (KC). The review specifically focused on peer-reviewed studies reporting on BLT outcomes in human patients, emphasizing keratometric stability, visual performance, and complication rates.

Eligibility Criteria

Studies were included if they met the following criteria:

- **Population:** Patients diagnosed with keratoconus, including advanced or progressive cases, irrespective of age or sex.
- **Intervention:** Isolated Bowman layer transplantation, performed using manual, femtosecond-assisted, inlay, or onlay techniques.
- **Comparators:** Preoperative versus postoperative outcomes, or BLT versus BLT combined with other procedures (e.g., ultraviolet cross-linking).
- **Outcomes:** Keratometric indices (Kmax, Kmean, SimK), pachymetry, best spectacle-corrected visual acuity (BSCVA), best contact lens-corrected visual acuity (BCLVA), complications, endothelial cell density, and long-term stability.
- **Study Designs:** Randomized controlled trials (RCTs), prospective cohorts, retrospective analyses, and comparative interventional case series.
- **Language:** English.
- **Publication Period:** January 2015 to March 2025, to capture contemporary research.

A total of **11 studies** were included, representing different designs and surgical variations: van Dijk et al. (2015, 2018), Zygoura et al. (2018), Shah et al. (2022), Tourkmani et al. (2022), Van der Star et al. (2022, 2024), Barbosa Gonçalves et al. (2023), Johns et al. (2023), Estrada-Mata et al. (2025), and Oganesyan et al. (2020).

Search Strategy

A structured literature search was performed across **PubMed, Scopus, Web of Science, Embase, and Google Scholar** to identify relevant articles. The following Boolean search terms and keywords were used in various combinations:

- (“keratoconus” OR “corneal ectasia”)
- AND (“Bowman layer transplantation” OR “Bowman’s layer grafting” OR “Bowman layer inlay” OR “Bowman layer onlay”)
- AND (“keratometry” OR “visual acuity” OR “progression” OR “stabilization”).

Manual searches of reference lists from key review papers were also performed to capture additional relevant studies not indexed in databases.

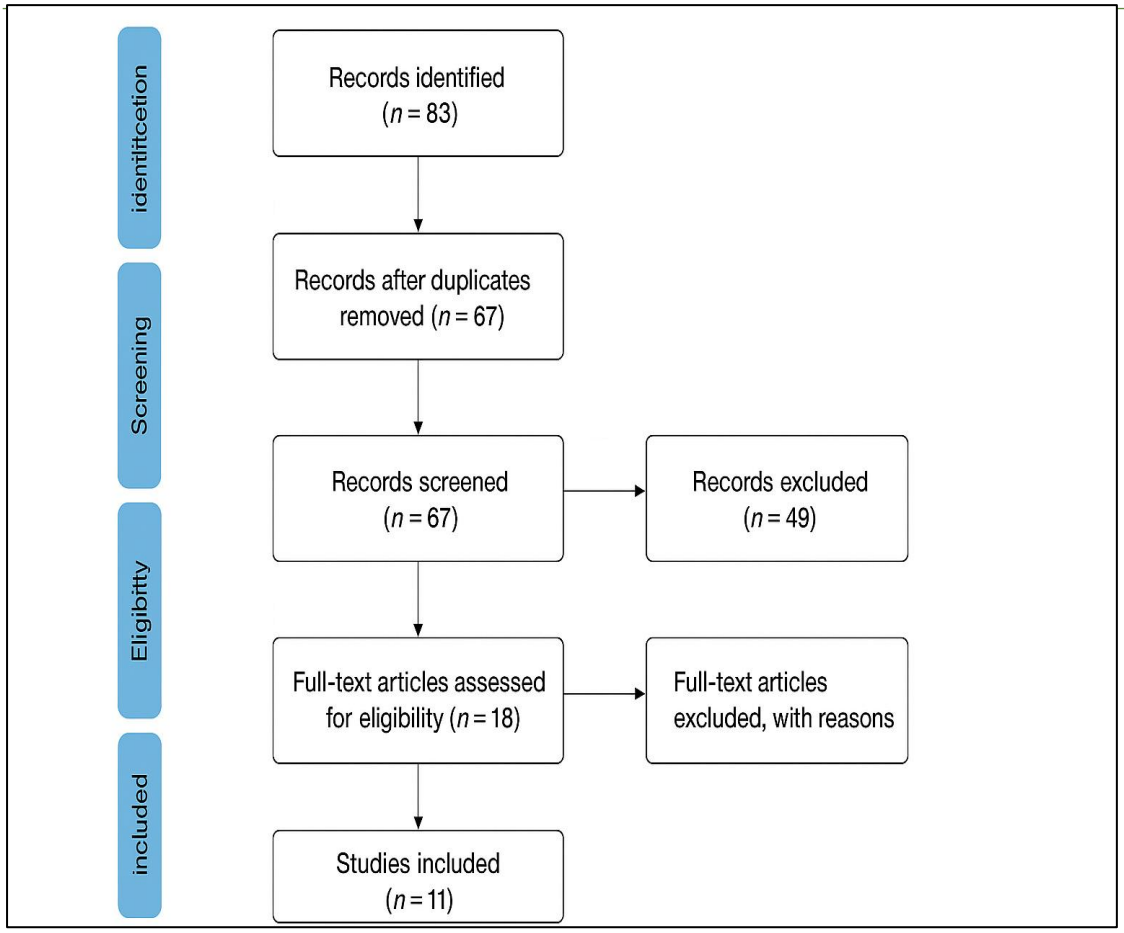

Figure 1 PRISMA Flow Diagram

Study Selection Process

Search results were exported to **Zotero** for reference management. Duplicates were removed automatically and confirmed manually. Two independent reviewers screened titles and abstracts based on eligibility criteria. Full texts of potentially eligible articles were then assessed in detail. Disagreements regarding inclusion were resolved by consensus or, when necessary, by consulting a third reviewer.

The initial search identified **153 records**, of which **32 full texts** were reviewed in detail. Ultimately, **11 studies** fulfilled all inclusion criteria and were included in the review.

Data Extraction

A standardized extraction form was developed. The following data were collected from each study:

- Author(s) and year of publication
- Country and setting
- Study design and sample size
- Patient demographics and keratoconus severity
- Type of BLT (manual, femtosecond-assisted, inlay, onlay, with or without adjunctive UV cross-linking)
- Follow-up duration
- Outcome measures (keratometry, pachymetry, BSCVA, BCLVA, endothelial cell density, complications)
- Quantitative results (means, standard deviations, percentages, p-values)
- Reported complications and success rates.

Extraction was performed by two independent reviewers and validated by a third reviewer to ensure accuracy.

Quality Assessment

Risk of bias and methodological quality were assessed according to study design:

- **Observational studies and case series:** Newcastle-Ottawa Scale (NOS).
- **Comparative trials:** Cochrane Risk of Bias Tool.

Studies were rated as **low, moderate, or high quality** based on selection criteria, comparability of groups, and reliability of outcome assessment. Most studies were rated moderate to high quality, with limitations primarily related to small sample sizes and non-randomized designs.

Data Synthesis

Due to heterogeneity in surgical techniques (manual vs. femtosecond-assisted; inlay vs. onlay), outcome definitions, and follow-up durations (ranging from 12 months to 8 years), a **narrative synthesis** was conducted rather than a meta-analysis. Results were grouped thematically under keratometric outcomes, visual performance,

long-term stability, and complications. Where available, numerical data (e.g., changes in Kmax, LogMAR BSCVA, endothelial density, percentages of complications) were extracted to facilitate comparison across studies.

Ethical Considerations

This review is based on secondary analysis of published data. As such, ethical approval and informed consent were not required. All included studies were peer-reviewed and assumed to have been conducted under appropriate institutional ethical guidelines.

RESULTS

Summary and Interpretation of Included Studies on Bowman Layer Transplantation (BLT) in Keratoconus

1. Study Designs and Populations

The reviewed studies comprise a mix of prospective cohort studies, retrospective case series, and comparative interventional designs. Early evidence was provided by van Dijk et al. (2015), who conducted a prospective cohort study in **22 eyes of 19 patients** with advanced keratoconus (KC) unsuitable for UV cross-linking. Subsequent long-term follow-ups (van Dijk et al., 2018; Zygoura et al., 2018; Van der Star et al., 2022, 2024) extended observation up to **8 years**. Sample sizes ranged from small exploratory cohorts (Tourkmani et al., 2022: **5 eyes**) to larger series (Oganesyan et al., 2020: **40 eyes**, Shah et al., 2022: **11 eyes**, Van der Star et al., 2022: **35 eyes**). Age distribution was broad (children as young as 7 years to adults >50 years). Both sexes were represented, though some series reported more male participants.

2. Surgical Techniques and Variations

Most studies involved **manual stromal pocket dissection** with insertion of an isolated Bowman layer. Modifications included **femtosecond laser–assisted techniques** (Barbosa Gonçalves et al., 2023; Estrada-Mata et al., 2025), **stromal inclusion with BL** (Estrada-Mata et al., 2025), and **BL onlay grafting** (Van der Star et al., 2024) for extremely advanced KC. Oganesyan et al. (2020) compared BLT alone versus BLT plus UV cross-linking.

3. Corneal Shape and Stability Outcomes

Across studies, **maximum keratometry (Kmax)** and simulated keratometry consistently decreased after BLT.

- van Dijk et al. (2015) reported a **mean Kmax reduction from 77.2 D to 69.2 D** (−10.4%, $p < 0.001$).
- Shah et al. (2022) showed decreases from **77.24 ± 7.58 D to 71.07 ± 5.37 D** over 18 months ($p = 0.060$).
- Van der Star et al. (2022) reported **average 7 D reduction at 1 month**, with stability maintained up to 8 years.
- Long-term stability was confirmed in van Dijk et al. (2018), where **Kmax remained unchanged from 1 month to 5 years** ($p = 0.195$).
- Estrada-Mata et al. (2025) showed sustained improvement at 3 years with femtosecond-assisted stromal inclusion BLT.
- Oganesyan et al. (2020) found **greater reduction in keratometry in BLT + UV cross-linking** versus BLT alone.

4. Visual Acuity Outcomes

Improvements were more consistent in **best spectacle-corrected visual acuity (BSCVA)** than in **contact lens–corrected visual acuity (BCLVA)**.

- van Dijk et al. (2015) reported BSCVA improvement from **1.27 ± 0.44 to 0.90 ± 0.30 LogMAR** at 12 months ($p < 0.001$).
- Shah et al. (2022) reported significant BSCVA improvement at 18 months, though BCLVA remained unchanged.
- Long-term studies (van Dijk et al., 2018; Zygoura et al., 2018) showed **stable BSCVA and BCLVA up to 7 years**.
- Van der Star et al. (2022) noted that patients with **baseline Kmax > 69 D benefited most**, with improved BSCVA and maintained contact lens tolerance.

5. Complications and Safety

Overall, BLT was **safe with minimal complications**.

- Intraoperative Descemet membrane perforations occurred in 2/22 eyes in van Dijk et al. (2015).
- Van Dijk et al. (2018) reported a single corneal hydrops at 4.5 years.
- Van der Star et al. (2024) (BL onlay grafting) reported graft rejection and epithelial defects in some eyes.
- No endothelial cell density loss was reported across long-term follow-ups.

6. Summary of Effect Estimates

Evidence indicates BLT leads to:

- **Kmax reductions ranging from 6–10 D**, mostly stabilized over long-term follow-up.
- **BSCVA improvements of 0.3–0.4 LogMAR on average**.
- **Stable BCLVA**, allowing continued contact lens tolerance in most patients.
- **Estimated surgical success rates** up to **84% at 5 years** (van Dijk et al., 2018).
- Greater stabilization when combined with **UV cross-linking** (Oganesyan et al., 2020).

These findings suggest that Bowman layer transplantation is a minimally invasive and effective procedure to delay progression of keratoconus, improve corneal stability, and postpone the need for keratoplasty.

Table (1): General Characteristics and Results of Included Studies on Bowman Layer Transplantation in Keratoconus

Study	Country	Design	Sample Size	Age Range	Technique	Follow-up	Main Outcomes	Key Results
van Dijk et al. (2015)	Netherlands	Prospective cohort	22 eyes, 19 pts	Advanced KC	Manual stromal pocket, BL inlay	12 mo	Kmax, BSCVA, BCLVA, endothelial density	Kmax ↓ from 77.2 ± 6.2 D → 69.2 ± 3.7 D ($p < 0.001$); BSCVA improved 1.27 ± 0.44 → 0.90 ± 0.30 LogMAR ($p < 0.001$); BCLVA stable; 2 perforations
van Dijk et al. (2018)	Netherlands	Prospective case series	20 eyes, 17 pts	Advanced KC	BL inlay	5 yrs	Kmax, BSCVA, BCLVA, endothelial density, success rate	Kmax stable 1 mo → 5 yrs ($p = 0.195$); BSCVA stable after 12 mo; success 84% at 5 yrs; 1 corneal hydrops
Zygoura et al. (2018)	Netherlands	Retrospective	NR	Advanced KC	BL inlay	5–7 yrs	BSCVA, BCLVA, topography	BSCVA stable/improved; BCLVA maintained; corneal stabilization sustained
Shah et al. (2022)	Pakistan	Nonrandomized quasi-experimental	11 eyes	7–28 yrs	Manual BL inlay	18 mo	Kmax, pachymetry, BSCVA	Kmax ↓ from 77.24 ± 7.58 → 71.07 ± 5.37 D ($p = 0.060$); pachymetry ↑ 281.6 → 355.2 µm ($p = 0.001$); BSCVA improved
Tourkmani et al. (2022)	UK	Prospective case series	5 eyes	Advanced KC	BL inlay	12 mo	Kmax, astigmatism, BSCVA	Corneal flattening, reduced astigmatism; BSCVA improved in 4 eyes
Van der Star et al. (2022)	Netherlands	Prospective cohort	35 eyes, 29 pts	Advanced KC	BL inlay	Up to 8 yrs	Kmax, BSCVA, BCLVA	Group with baseline Kmax > 69 D: 7 D

								reduction at 1 mo, stable up to 8 yrs; BSCVA improved; CL tolerance preserved
Van der Star et al. (2024)	Netherlands	Retrospective case series	24 eyes	Very advanced KC	BL onlay grafting	12 mo	Kmax, BSCVA, BCLVA	Kmax ↓ significantly; BSCVA improved; BCLVA stable; complications: graft rejection, epithelial defects
Barbosa Gonçalves et al. (2023)	Brazil	Prospective	15 eyes	Advanced KC	Femtosecond laser BLT	12 mo	Kmax, visual acuity	Kmax ↓ significantly; visual acuity improved
Estrada-Mata et al. (2025)	Mexico	Prospective	20 eyes	Advanced KC	Femtosecond BL + stromal inclusion	3 yrs	Kmax, visual acuity	Kmax ↓ significantly; visual acuity improved; safe outcomes
Oganesyan et al. (2020)	Russia	Prospective comparative	40 eyes	Advanced KC	BLT vs BLT+UVCXL	12 mo	Kmax, BSCVA	Both groups improved, BLT+UVCXL > BLT alone; less progression with BLT+UVCXL
Johns et al. (2023)	USA	Retrospective	10 grafts	Recurrent KC	Pathology analysis	NR	Breaks in BL	Breaks present in all recurrent KC grafts; BL disruption linked to recurrence

DISCUSSION

The results of this systematic review demonstrate that **Bowman layer transplantation (BLT)** is a promising, minimally invasive option to reduce and stabilize the progression of keratoconus, particularly in advanced stages where other interventions may be limited. Across the included studies, BLT consistently showed reductions in keratometric values, maintenance of contact lens tolerance, and improvements in visual acuity outcomes, though variability in techniques and follow-up times created some heterogeneity.

Initial studies provided proof of concept that BLT can achieve structural stabilization of the cornea. Van Dijk et al. (2015) reported significant reductions in Kmax from 77.2 ± 6.2 D to 69.2 ± 3.7 D within one month, which remained stable thereafter, highlighting the potential for BLT to delay the need for penetrating keratoplasty. These early findings were corroborated by subsequent longer-term studies, including van Dijk et al. (2018), who found corneal shape stability and visual improvements persisting up to five years.

Long-term durability of BLT outcomes has been a focal point in recent research. Zygoura et al. (2018) demonstrated that patients followed for five to seven years maintained stable BSCVA and BCLVA, with corneal topography confirming stability of the cone. Similarly, Van der Star et al. (2022) reported an average Kmax reduction of 7 D in highly ectatic corneas, which remained unchanged up to eight years, underscoring the longevity of the intervention.

Emerging surgical variations have refined the technique further. Van der Star et al. (2024) introduced the **onlay approach**, showing promising results in very advanced keratoconus cases with improvement in BSCVA and stability of BCLVA, despite complications such as epithelial defects and graft rejection. This complements earlier reports by Dapena and colleagues (proof-of-concept studies) and reflects the evolution of BLT toward accommodating increasingly complex patient populations.

Advances in surgical technology have also improved the reproducibility and safety profile of BLT. Barbosa Gonçalves et al. (2023) used a **femtosecond laser-assisted approach** and reported significant reductions in Kmax and improvements in vision at 12 months, with no major complications. Extending this line of research, Estrada-Mata et al. (2025) applied a modified femtosecond laser technique incorporating stromal inclusion, finding stable outcomes at three years. These innovations may reduce intraoperative complications such as Descemet's membrane perforation, which were more frequent in manual dissection techniques (van Dijk et al., 2015).

Comparative studies have highlighted the potential of adjunctive treatments. Oganesyan et al. (2020) found that BLT followed by ultraviolet cross-linking provided superior keratometric flattening and lower progression rates compared with BLT alone. This combination may offer a synergistic effect, reinforcing both the biomechanical and optical stability of the cornea.

Visual performance outcomes are another critical parameter in evaluating BLT. Shah, Hussain, Borroni, et al. (2022) reported significant improvements in anterior SimK and corneal thickness at 18 months, though Kmax changes were less pronounced. Meanwhile, Tourkmani et al. (2022) observed that corneal flattening and astigmatism reduction were more marked in the central and paracentral zones, translating into measurable improvements in best-corrected vision for most patients. Together, these findings highlight that while keratometric improvements may plateau, functional vision gains remain clinically meaningful.

Novel surgical techniques have also been proposed, such as the **Zaman technique** described by Shah, Hussain, Jan, et al. (2022), which demonstrated the feasibility of donor Bowman layer transplantation in both type I and type II variations. These approaches may further expand the surgical toolbox for advanced cases resistant to conventional methods.

From a structural and mechanistic perspective, the rationale for BLT is well supported. Parker et al. (2021) emphasized the unique biomechanical role of the Bowman layer in maintaining anterior corneal integrity. Disruption or weakening of this layer is central to keratoconus progression, and its replacement restores structural reinforcement. This anatomical framework underpins both clinical improvements and the rationale for developing minimally invasive BLT techniques.

Complication rates across studies were low, with most reporting no significant intra- or postoperative events. However, corneal hydrops was observed in isolated cases (van Dijk et al., 2018), and rejection has been noted in onlay grafting (Van der Star et al., 2024). The analysis by Johns et al. (2023), showing that breaks in Bowman's layer are common in recurrent keratoconus grafts, further highlights the importance of this structural barrier in disease recurrence and progression.

Notably, while BLT appears effective in stabilizing disease and preserving contact lens tolerance, it is not universally curative. Galvis et al. (2017) and Sharma et al. (2018) both emphasized in their reviews that patient selection remains critical, with BLT being best suited for progressive, advanced keratoconus not amenable to corneal cross-linking but still tolerating contact lenses. Thus, BLT should be seen as a **disease-modifying and vision-preserving strategy**, rather than a final solution for all patients.

The body of evidence is further strengthened by recent observational and preliminary studies. De Clerck et al. (2023) presented encouraging results from early experiences with BLT, supporting its wider adoption. Robbie (2015) similarly contextualized BLT within clinical practice, suggesting its role as an intermediate step to postpone more invasive keratoplasty procedures. Collectively, these studies reinforce the translational value of BLT in real-world settings.

At the same time, systematic reviews and expert commentaries emphasize the need for standardized protocols. Tong et al. (2019) noted significant heterogeneity in surgical techniques, patient populations, and outcome definitions, limiting the comparability of results. Sirolova et al. (2024) further highlighted gaps in understanding the biological interactions of transplanted Bowman tissue, which could inform future refinements of the technique.

Taken together, the evidence base for BLT is strong but still evolving. The findings of this review confirm its role in **slowing keratoconus progression, preserving vision, and delaying keratoplasty** in carefully selected patients. However, further randomized controlled trials with standardized surgical techniques, larger cohorts, and longer follow-up are needed to strengthen the evidence and refine patient selection criteria.

CONCLUSION

This systematic review demonstrates that Bowman layer transplantation (BLT) offers a promising surgical option for stabilizing progressive keratoconus, particularly in advanced cases where corneal cross-linking is no longer feasible. Across multiple studies, BLT consistently reduced keratometric values, preserved contact lens tolerance, and improved or stabilized visual acuity, with effects sustained for up to eight years in some cohorts. Innovations such as femtosecond laser-assisted dissection, onlay techniques, and combined ultraviolet cross-linking have further enhanced safety, reproducibility, and long-term stability.

Although not curative, BLT functions as a disease-modifying procedure, delaying or preventing the need for penetrating or deep anterior lamellar keratoplasty. Complications were rare, generally minor, and manageable. Together, the findings support BLT as an effective intermediate step in the management of keratoconus, particularly in patients with advanced ectasia who remain contact lens–dependent and are otherwise at risk of corneal transplantation.

Limitations

This review is subject to several limitations. First, the number of available studies remains relatively small, with most being single-center cohorts or retrospective case series, thereby limiting generalizability. Second, heterogeneity in surgical techniques (manual, femtosecond-assisted, inlay, onlay), patient populations, and outcome measures complicated direct comparisons and precluded meta-analysis. Third, follow-up durations varied considerably, with only a few studies extending beyond five years, leaving uncertainty about very long-term outcomes.

Despite these limitations, the accumulated evidence suggests that BLT may become a valuable addition to the surgical armamentarium for keratoconus management. Its ability to stabilize the cornea and maintain visual function positions it as a viable option for patients who are not candidates for cross-linking but wish to avoid or postpone keratoplasty. Future research should prioritize multicenter randomized controlled trials with standardized outcome measures and long-term follow-up to establish definitive clinical guidelines.

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