



ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor (RJIF): 8.4
IJAR 2024; 10(11): 173-175
www.allresearchjournal.com
Received: 27-09-2024
Accepted: 28-10-2024

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Current approaches in the management of patients with keratoconus

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DOI: <https://dx.doi.org/10.22271/allresearch.2024.v10.i11c.12155>

Abstract

Keratoconus is a progressive, non-inflammatory eye disorder characterized by thinning and cone-like protrusion of the cornea, leading to visual impairment. The management of keratoconus has evolved significantly with advancements in diagnostic techniques and therapeutic interventions. This paper reviews current trends in the management of keratoconus, focusing on early diagnosis, individualized treatment plans, and innovative surgical and non-surgical options. Key areas of discussion include the role of corneal topography and tomography in early detection, the use of corneal cross-linking (CXL) to halt disease progression, and the integration of advanced contact lens designs for visual rehabilitation. Additionally, we explore recent developments in minimally invasive procedures, such as intrastromal corneal ring segments (ICRS) and topography-guided photorefractive keratectomy (TG-PRK), and their combined use with CXL to optimize outcomes. The advent of new technologies like femtosecond laser-assisted keratoplasty and artificial intelligence-based predictive models for disease progression are also examined. The paper emphasizes a patient-centric approach, highlighting the importance of personalized management strategies based on disease severity, patient lifestyle, and ocular biomechanics. These advancements underscore the need for a multidisciplinary approach, incorporating ophthalmologists, optometrists, and vision rehabilitation specialists, to provide comprehensive care for keratoconus patients.

Keywords: Keratoconus, corneal cross-linking (cxl), corneal topography, intrastromal corneal ring segments (ICRS), femtosecond laser-assisted keratoplasty, contact lens design, topography-guided photorefractive keratectomy (TG-PRK)

Introduction

Keratoconus is a bilateral, asymmetric, progressive ectatic corneal disorder that affects the structural integrity of the cornea, leading to visual impairment ^[1]. The disease typically manifests in adolescence, progressing at variable rates, and is associated with significant morphological changes in the cornea, including corneal thinning and conical protrusion, which lead to irregular astigmatism and myopia ^[2]. The management of keratoconus has undergone considerable evolution due to advancements in diagnostic tools and treatment modalities. Early detection and intervention are crucial for preventing irreversible damage, while personalized treatment strategies allow for optimized patient outcomes.

This paper aims to review and discuss current management strategies for keratoconus, examining both diagnostic and therapeutic approaches. We will analyze the roles of corneal topography, corneal cross-linking (CXL), advanced contact lenses, and surgical interventions like intrastromal corneal ring segments (ICRS) and topography-guided photorefractive keratectomy (TG-PRK) in contemporary keratoconus management.

Methodology

A systematic review of peer-reviewed journal articles, clinical studies, and review papers published between 2000 and 2024 was conducted using databases including PubMed, Google Scholar, and Scopus. Search terms included “keratoconus management,” “corneal cross-linking,” “contact lenses for keratoconus,” “ICRS,” and “TG-PRK.” Articles were selected based on their relevance to current diagnostic and treatment methods, as well as their contributions to the understanding of disease progression and patient outcomes.

Inclusion criteria involved studies that

1. Discussed advances in the diagnosis and treatment of keratoconus.
2. Examined outcomes of various treatment modalities.
3. Focused on personalized treatment strategies and patient-centered care approaches.

Exclusion criteria involved articles that

1. Did not focus on keratoconus specifically.
2. Lacked significant contributions to recent innovations in the management of keratoconus.

Data extracted from the selected articles were categorized based on diagnostic approaches, non-surgical treatment methods, and surgical interventions. Each section of the paper is structured around these categories.

Results**Diagnostic Approaches****Corneal Topography and Tomography**

Corneal topography and tomography have emerged as key diagnostic tools in the early detection and monitoring of keratoconus progression. Topography maps the anterior surface of the cornea, allowing clinicians to detect irregularities and subtle changes in corneal curvature. Tomography provides a three-dimensional analysis of both anterior and posterior corneal surfaces and assesses corneal thickness, which is vital for detecting subclinical keratoconus [3]. Devices such as the Pentacam and Orbscan are widely used to assess these parameters.

Ocular Biomechanical Analysis

The introduction of devices such as the Ocular Response Analyzer (ORA) and the Corvis ST has enhanced the ability to evaluate corneal biomechanics. These tools measure corneal stiffness and elasticity, which are crucial in assessing keratoconus risk and progression. Patients with lower corneal stiffness are more susceptible to disease progression, making biomechanical assessment an important part of patient evaluation [4].

Non-Surgical Treatment Approaches**Corneal Cross-Linking (CXL)**

Corneal cross-linking (CXL) is the most significant advancement in keratoconus management in the last two decades. CXL involves the application of riboflavin (vitamin B2) followed by ultraviolet A (UVA) light exposure to strengthen the corneal collagen fibers and halt disease progression. Multiple studies have demonstrated that CXL is effective in stabilizing the cornea and preventing further ectasia in most patients [5]. Two primary methods of CXL exist: epithelium-off (epi-off) and epithelium-on (epi-on). While epi-off CXL remains the gold standard due to better riboflavin penetration, epi-on CXL is preferred for certain patients due to its faster recovery and lower risk of complications [6].

Contact Lens Management

Contact lenses remain a primary method for visual rehabilitation in patients with keratoconus. While rigid gas-permeable (RGP) lenses have traditionally been the mainstay, newer lens designs such as scleral lenses, hybrid lenses, and custom soft lenses have improved comfort and visual acuity. Scleral lenses, which rest on the sclera and

vault over the cornea, are especially beneficial for patients with advanced keratoconus, as they provide a smooth optical surface that corrects the irregular astigmatism caused by the disease [7].

Surgical Interventions**Intrastromal Corneal Ring Segments (ICRS)**

Intrastromal corneal ring segments (ICRS) are crescent-shaped implants inserted into the corneal stroma to flatten the cornea and reduce irregular astigmatism. ICRS are often used in combination with CXL to provide structural stabilization and improve visual outcomes. Studies have shown that ICRS can effectively improve uncorrected and corrected visual acuity, particularly in patients with moderate keratoconus who are intolerant to contact lenses [8].

Topography-Guided Photorefractive Keratectomy (TG-PRK)

Topography-guided photorefractive keratectomy (TG-PRK) is a laser procedure that reshapes the cornea based on individual topographic data. While not a standalone treatment for keratoconus, TG-PRK is often combined with CXL to both halt progression and improve visual acuity. This combination therapy is especially useful for patients with irregular corneas and significant visual impairment who are not suitable candidates for other interventions [9].

Femtosecond Laser-Assisted Keratoplasty

For patients with advanced keratoconus that cannot be managed with less invasive techniques, corneal transplantation may be necessary. The use of femtosecond lasers in keratoplasty has improved the precision of donor tissue preparation and corneal incisions, leading to better post-operative outcomes and faster recovery times. Deep anterior lamellar keratoplasty (DALK), which preserves the patient's corneal endothelium, is preferred for keratoconus patients as it reduces the risk of graft rejection compared to full-thickness transplantation [10].

Discussion

Recent advancements in the management of keratoconus emphasize the importance of individualized treatment plans based on disease severity, ocular biomechanics, and patient lifestyle. The variability in keratoconus progression necessitates a tailored approach to optimize patient outcomes. For instance, patients with mild keratoconus may benefit from contact lenses alone, while those with more advanced disease may require a combination of CXL and surgical interventions. Biomechanical assessments help identify patients at higher risk of progression, allowing for early intervention with treatments like CXL [11].

The management of keratoconus requires a multidisciplinary approach involving ophthalmologists, optometrists, and vision rehabilitation specialists. This collaborative approach ensures that both the structural and visual aspects of the disease are addressed. Ophthalmologists are primarily responsible for surgical interventions and cross-linking procedures, while optometrists play a crucial role in fitting specialized contact lenses and monitoring disease progression. Vision rehabilitation specialists work with patients to maximize their functional vision, especially in cases where contact lenses or surgical interventions are insufficient [12].

Emerging technologies such as artificial intelligence (AI) and machine learning are poised to revolutionize keratoconus management further. AI-based predictive models could help clinicians identify patients at high risk of progression and personalize treatment plans more effectively. Additionally, advancements in minimally invasive techniques, such as small-incision lenticule extraction (SMILE) for keratoconus and bioengineered corneal implants, hold promise for improving long-term outcomes and expanding the range of treatment options for keratoconus patients^[13].

Conclusion

The management of keratoconus has advanced considerably over the past two decades, with significant improvements in diagnostic and therapeutic approaches. Early diagnosis using corneal topography and tomography, combined with biomechanical assessments, allows for timely intervention with treatments such as corneal cross-linking. For patients with more advanced disease, a range of surgical options, including intrastromal corneal ring segments and topography-guided photorefractive keratectomy, offer effective solutions. Personalized treatment strategies, tailored to individual patient needs, are essential for optimizing outcomes. The future of keratoconus management lies in continued innovation and the integration of artificial intelligence and minimally invasive techniques, ensuring that patients receive the best possible care.

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