EDITORIAL

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Intracorneal Ring Segments for the Treatment of Keratoconus: Where are We Going?

Introduction

For nearly a quarter-century, Intracorneal Ring Segments (ICRS) have been a pivotal intervention in treating keratoconus (KC), post-LASIK ectasia, and pellucid marginal degeneration. These ICRS have consistently demonstrated their efficacy in reducing myopia, both regular and irregular astigmatism, and ameliorating high-order aberrations. Notably, they have significantly enhanced both uncorrected and best corrected visual acuity. The literature also boasts long-term safety profiles and comprehensive follow-up data.[1–4]

ICRS are primarily aimed at improving uncorrected distance visual acuity (UDVA) and best spectacle-corrected distance visual acuity (BSCDVA). While they induce some stabilization of KC and positively impact the cornea's biomechanical properties, their main purpose is to enhance vision.[2,5]

ICRS Combined with Other Treatments

Collagen corneal cross-linking (CXL) is specifically designed to stabilize KC and halt the progression of the disease. It strengthens the corneal structure by creating new cross-links within the collagen fibers. CXL has shown long-term effectiveness in halting disease progression, reducing myopia, astigmatism, and the K_{max}. However, the extent of improvement may vary among individuals, and the aim of the treatment, as explained to the patient, should be "to arrest the progression of the disease" and no more.[6–9]

A synergistic effect is achieved by combining ICRS and CXL.[10–13] In keratoconic eyes, phakic intraocular lenses (IOLs) are used to correct high refractive errors, and photorefractive keratectomy (PRK), especially when topography guided, can fine-tune the cornea's shape for improved vision.[14,15]

These treatment options, either used alone or in combination, either consequently or simultaneously offer a range of choices for managing KC, depending on the individual patient's condition, needs, and the desired visual outcomes.

New ICRS Designs

In our quest to enhance the predictability of ICRS in treating keratoconus, various adjustments to the nomograms have been introduced. These adaptations take into account factors such as refraction, the specific keratoconus phenotype, asphericity (Q value), posterior elevation location and high-order aberrations, with particular emphasis on the coma axis. These refinements aim to further augment treatment outcomes.[16,17]

In recent years, there have been several innovations in the design of intracorneal ring segments (ICRS), which are used in the treatment of KC and other ectatic corneal conditions. These innovations aim to provide more customized and effective options for patients. The classic INTACS design features hexagonal-shaped segments with a 7 mm diameter and a 150-degree arc length. In parallel with INTACS, the pyramidal-shaped Ferrara/Keraring segments were introduced, typically featuring 5 mm and 6 mm optical zones with a pyramidal shape, flat base, and a 160-degree arc length. Later, INTACS SK was developed with a 6 mm oval-shaped optical zone designed to fit advanced cases of KC (Figs 1 and 2).

ICRS segments have since evolved to include a range of arc lengths and designs, offering even more precise customization for corneal reshaping. We now have segments with variable arc lengths, ranging from 90 to 355 degrees, and, notably, progressive asymmetric thicknesses. These progressive thickness segments are tailored to address specific keratoconus phenotypes, such as the "duck" and "snowman" types, exhibiting a gradual increase in thickness from proximal to distal regions, yielding satisfactory outcomes. Another variation is similar to the previous but includes an additional increase in base width along with the progressive thickness.[18,19]

Remarkably positive results have been reported with a unique progressive ring segment design. In this design, thickness increases from the proximal end to the segment's center and then gradually decreases toward the distal part (Figs 3, 4A, 4B and 5). This segment was meticulously crafted by the author to address the specific KC phenotypes associated with the inferior, inferotemporal, and inferonasal types. The aim is to put the thicker part of the ICRS parallel to the steepest part of the cornea, less thickness where it is not required and less burden on the cornea and to customize the treatment aiming to achieve further improvement in visual acuity.

Two years follow-up were reported in July 2023 at the Aegean cornea and cataract meeting in Athens, Greece: Eleven out of seventeen eyes of patients suffering from KC grade 2–3 (Amsler Krumeich) achieving UCDVA between 20/40 and 20/20, which is a "functional" vision without glasses (Figs 6, 7 and 8).

These tailored options enable a high degree of treatment customization. The optimization of ICRS outcomes is facilitated through the utilization of finite element analysis and artificial neural networks.[20]

ICRS procedures are often chosen based on the patient's unique corneal characteristics and visual needs. The choice of ICRS design, size, and arc length depends on the individual case.

Corneal Allogenic Intrastromal Ring Segments (CAIRS)

Corneal allogenic segments are gaining favor among corneal surgeons for their soft tissue properties, which do not pose extrusion or melting risks as seen with traditional PMMA ICRS, albeit these complications are seen less and less since the introduction of femtosecond laser-assisted implantation of ICRS. However, challenges surrounding allogenic implants pertain to their availability, the intricacies of tissue handling, and the complexities of customizing thickness and shape (Figs 9A, 9B and 9C).[21–23]

The Future of ICRS

Biologically engineered tissues and materials in the field of ophthalmology have been a subject of interest for researchers and clinicians, offering the promise of improved outcomes and reduced risks in dealing with advanced KC.[24,25]

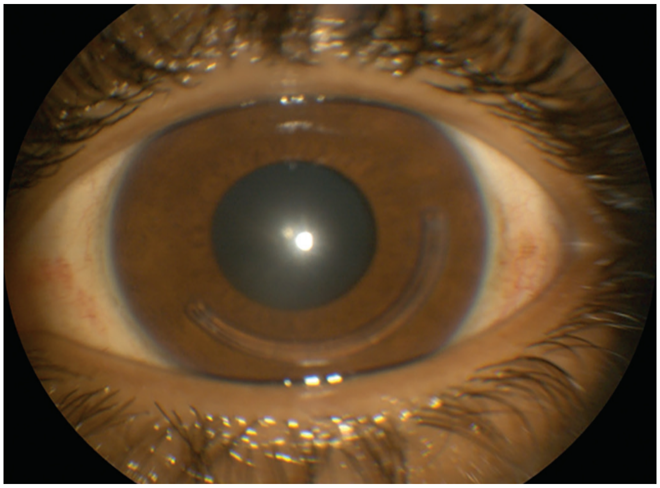


Fig. 1: Intac segment

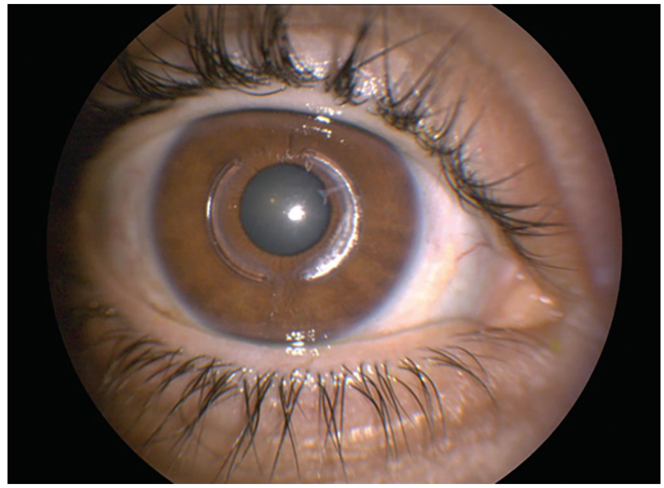
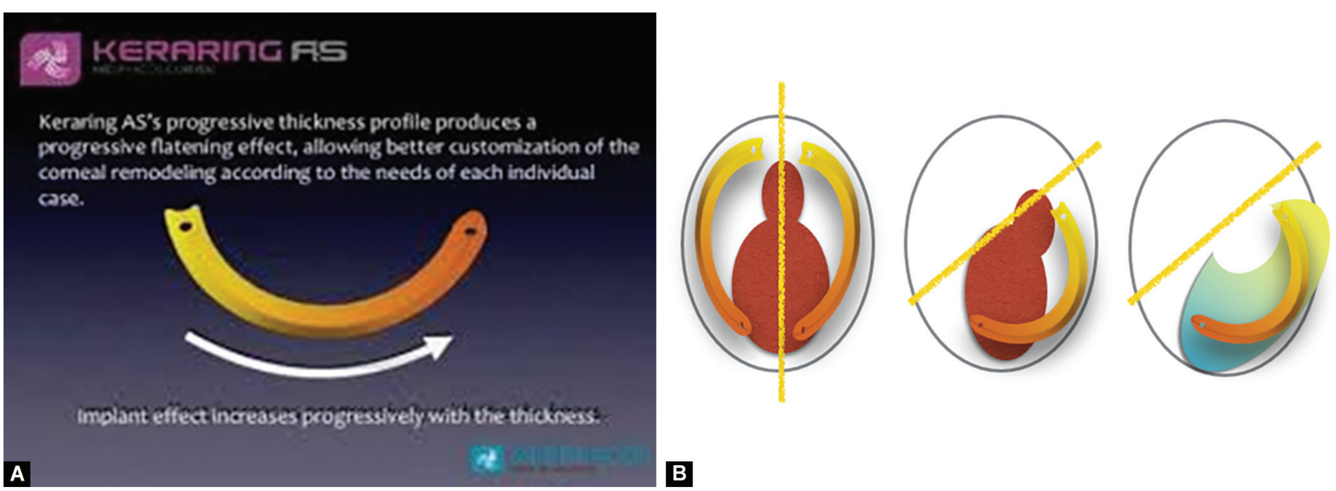


Fig. 2: Ferrara/Keraring 21 years after implantation. Notice : Precipitates in the tunnels, a common finding after many years of the implantation with no negative consequences. 5 mm optical zone

Fig. 3: Variable arc lengths ICRS. Arc length from 90 to 355 degrees



Figs 4A and B: Progressive thickness ICRS, thickness increases gradually from the proximal to the distal part, addressing certain phenotypes of KC, Duck, snowman and croissant phenotypes. Courtesy of Mediphacos Brazil

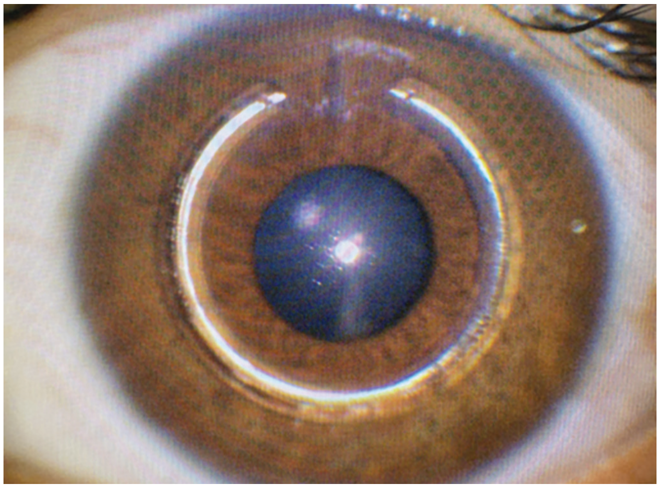


Fig. 5: A 6 mm optical zone Keraring 320 degrees

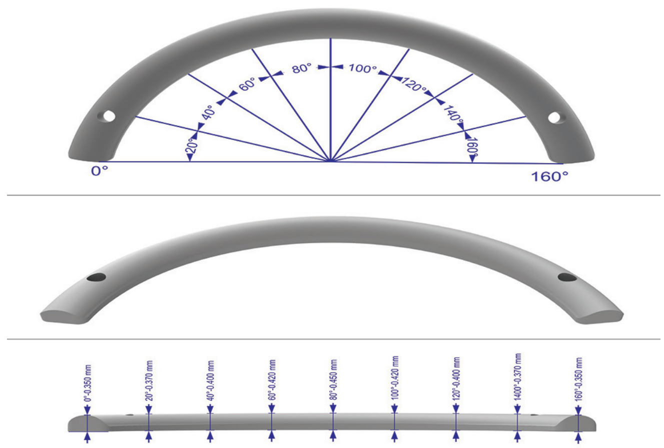


Fig. 6: ICRS designed by the author. Increases in thickness gradually from the proximal part to the center of the segment, then decreases gradually in thickness from the center toward the distal part

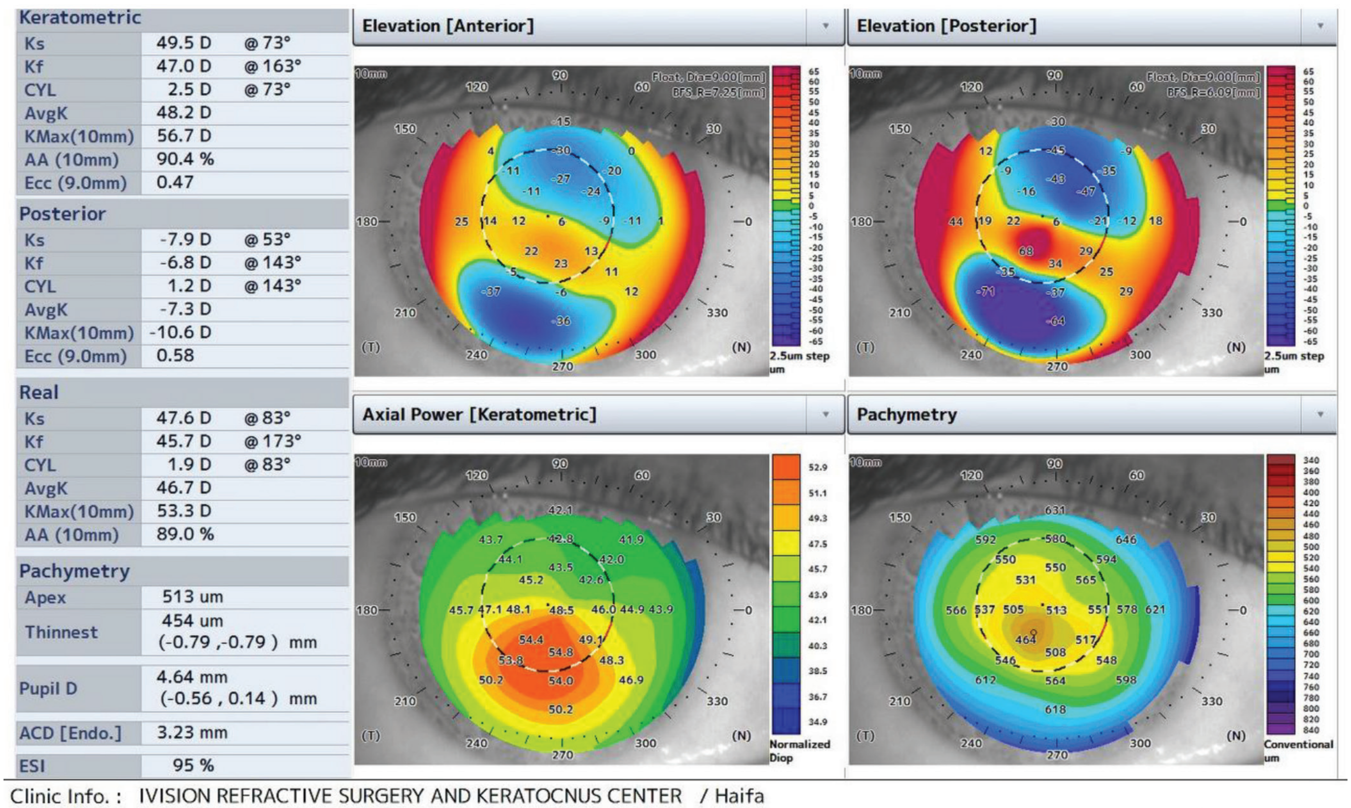


Fig. 7: Phenotype of KC for which the author's design is indicated (CASIA 2, Japan)

Exciting is the vision for the future of keratoconus treatment with the development of biologically engineered soft ICRS. The idea of creating segments with tailored shapes and parameters while maintaining their softness is intriguing and holds the potential to greatly benefit patients with KC. As advancements in regenerative medicine and bioengineering continue, we may indeed see in the near future new ICRS for the treatment of KC.

Conclusion

The primary objective in cases of KC is to avoid or delay the necessity for keratoplasty, and ICRS are a valuable option for those with unsatisfactory visual acuity with glasses and intolerance to contact lenses. Proper patient selection, thorough preoperative evaluation, and precise surgical techniques are pivotal factors for the success of ICRS procedures. Moreover, maintaining open and collaborative communication between the ophthalmologist and the patient is essential to meet the patient's individual needs and expectations, while aiming for the best possible visual outcome.

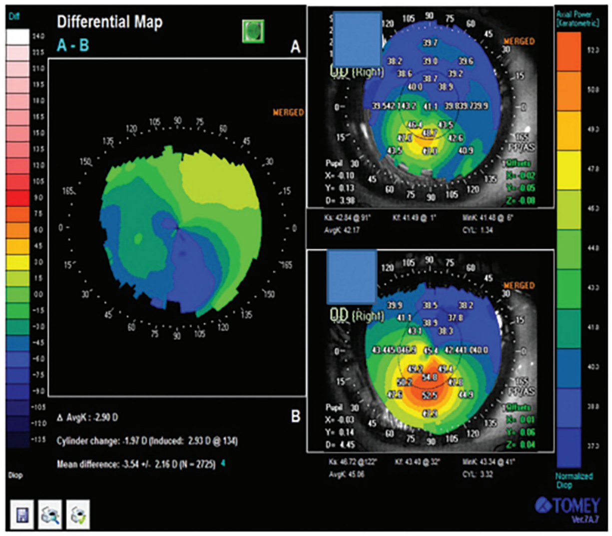
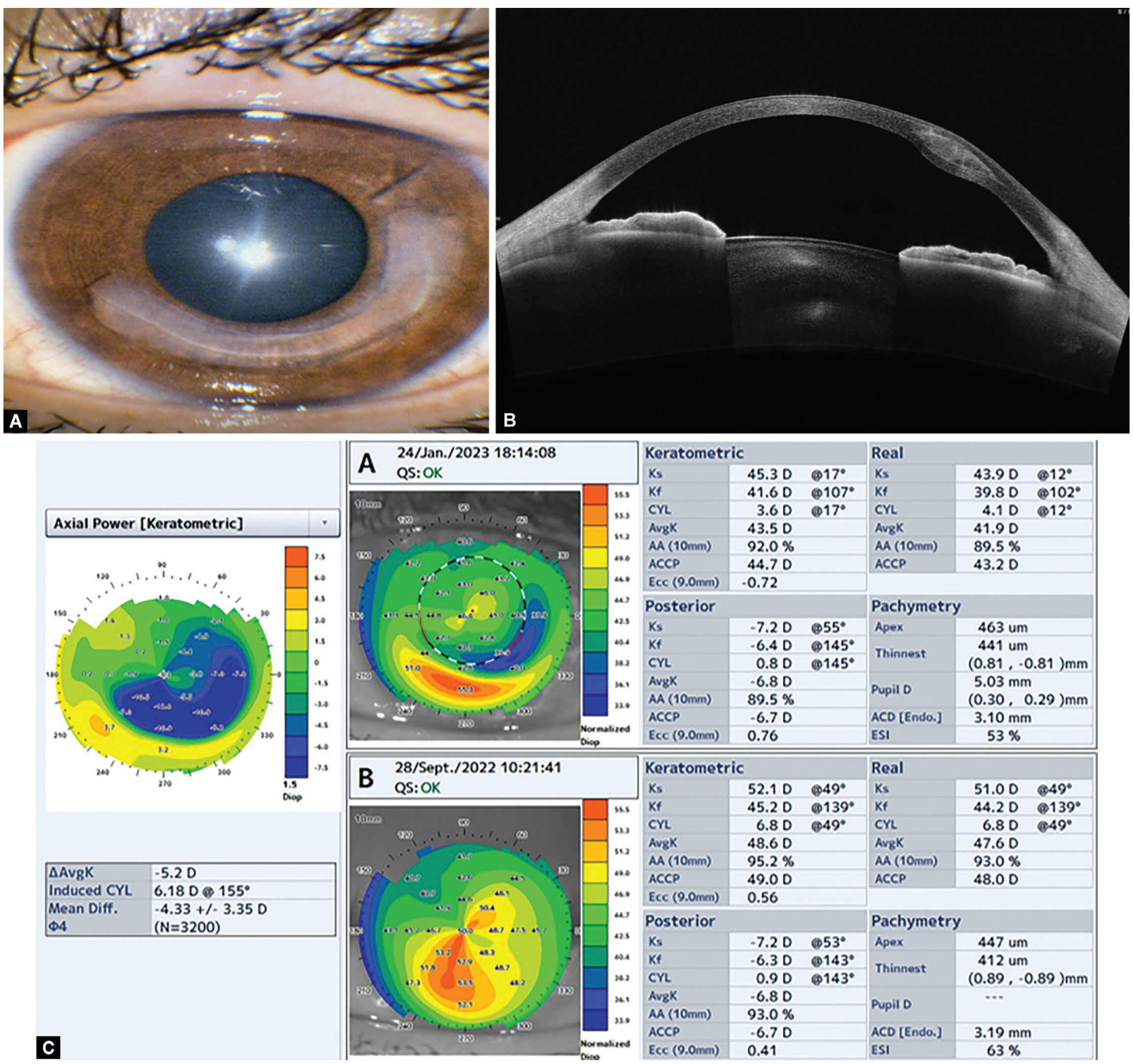


Fig. 8: Pre- and postoperative corneal tomography in an eye implanted with the author's designed ring with the difference map, showing the regularization and the flattening of the cornea (CASIA 2, Japan)



Figs 9A to C: Corneal allogenic intrastromal ring segment, photo of the cornea. OCT and pre- and postoperative tomography and difference map showing the flattening and the regularization of the cornea (CASIA2, Japan)

Recent advancements in the design of ICRS have further enhanced their effectiveness in treating KC. Newer ICRS models feature improved designs that allow for more precise customization to the patient's specific corneal shape and condition. This level of customization ensures that the reshaping effect is optimized, resulting in even better visual outcomes. Managing patient expectations is indeed critical in achieving surgical success, as it can greatly impact patient satisfaction and the overall outcome.

References

1. Alio JL, et al. Intrastromal corneal ring segments: how successful is the surgical treatment of keratoconus? Middle East Afr J Ophthalmol 2014;21:3–9.
2. Torquetti L, Fabri Berbel R, Ferrara P. Long-term follow-up of intrastromal corneal ring segments in keratoconus 2009;35(10):1768–73. doi:10.1016/j.jcrs.2009.05.036.
3. Vega-Estrada A, Alió JL, Plaza-Puche AB. Keratoconus progression after intrastromal corneal ring segment implantation in young patients: Five-year follow-up. J Cataract Refract Surg 2015;41:1145–52.
4. Barbara A, Barbara R. Long-term Follow-up of Ferrara Rings Segments for the Treatment of Keratoconus. Int J Kerat Ect Cor Dis 2013;2:34–39.
5. Kang M-J, Byun Y-S, Yoo Y-S, Whang W-J, Joo C-K. Long-term outcome of intrastromal corneal ring segments in keratoconus: Five-year follow up. doi:10.1038/s41598-018-36668-7.
6. Caporossi A, Mazzotta C, Baiocchi S, Caporossi T. Long-term results of riboflavin ultraviolet a corneal collagen cross-linking for keratoconus in Italy: the Siena eye cross study. Am J Ophthalmol. 2010;149:585–593.
7. Spoerl E, Mrochen M, Sliney D, Trokel S, Seiler T. Safety of UVA-riboflavin cross-linking of the cornea. Cornea 2007;26; 385–389.
8. Wollensak G, Spoerl E, Seiler T. Riboflavin/ultraviolet-A-induced collagen crosslinking for the treatment of keratoconus. Am J Ophthalmol 2003;135;620–627.
9. Ramez Barbara, Joseph Pikkel, Hanna Garzozi AB. Collagen cross-linking and keratoconus in pediatric patients. Int J Keratoconus Ectatic Corneal Dis. 2012;1:57–60.
10. Coskunseven E, Jankov MR 2nd, Hafezi F, Atun S, Arslan E, Kymionis GD. Effect of treatment sequence in combined intrastromal corneal rings and corneal collagen crosslinking for keratoconus. J Cataract Refract Surg. 2009;35:2084–2091.
11. El-Raggal TM. Sequential versus concurrent KERARINGS insertion and corneal collagen cross-linking for keratoconus. Br J Ophthalmol 2011;95:37–41.
12. Kamburoglu G, Ertan A. Intacs implantation with sequential collagen cross-linking treatment in postoperative LASIK ectasia. J Refract Surg 2008;24:726.
13. Chan CC, Sharma M, WB. Effect of inferior-segment Intacs with and without C3-R on keatoconus. J Cataract Refract Surg 2007;33:75–80.
14. Coskunseven E, et al. Four-stage procedure for keratoconus: ICRS implantation, corneal cross-linking, toric phakic intraocular lens implantation, and topography-guided photorefractive keratectomy. J Refract Surg 2017;33:683–689.
15. Ferreira iTB, Güell JL, Manero F. Combined intracorneal ring segments and iris-fixated phakic intraocular lens for keratoconus refractive and visual improvement. J Refract Surg. 2014;30:336–341.
16. Poulsen DM, Kang JJ. Recent advances in the treatment of corneal ectasia with intrastromal corneal ring segments. Current Opinion in Ophthalmology 2015;26.
17. Fernández-Vega Cueto L, Lisa C, Madrid-Costa D, Merayo-Lloves J, Alfonso JF. Long-term follow-up of intrastromal corneal ring segments in paracentral keratoconus with coincident corneal keratometric, comatic, and refractive axes: Stability of the procedure. J Ophthalmol 2017;4058026.
18. Prisant O, Pottier E, Guedj T, Xuan TH. Clinical outcomes of an asymmetric model of intrastromal corneal ring segments for the correction of keratoconus. Cornea 2020;39:155–160.
19. Cuiña Sardiña Ricardo, Arango A, Alfonso JF, Álvarez de Toledo J, Piñero DP. Clinical evaluation of the effectiveness of asymmetric intracorneal ring with variable thickness and width for the management of keratoconus. JCRS 2021;47:722–730.
20. Fariselli C, Vega-Estrada A, Arnalich-Montiel F, Alio JA. Artificial neural network to guide intracorneal ring segments implantation for keratoconus treatment: a pilot study. Eye and Vision 2020;7:20. doi: 10.1186/s40662-020-00184-5. eCollection 2020
21. Soosan Jacob, Shaila R Patel, Amar Agarwal, Arvind Ramalingam, Boptom AI Saijimol, John Michael Raj. Corneal allogenic intrastromal ring segments (CAIRS) combined with corneal cross-linking for keratoconus. JRS 2018;34:296–303.
22. Avetisov SÉ, Osipian GA, Mitichkina TS, Doguzov VA, Mamikonian VR, EG. Intralamellar bandage keratoplasty for the treatment of progressive keratoconus. Vestn Oftalmol. 2015;131:18–23. In Russian Language.
23. Osipyan GA, Sheludchenko VM, Youssef NY, KK. Bandage therapeutic-optical keratoplasty in keratoconus patients after intrastromal corneal segments implantation. Ophthalmol Russ. 2019;16:283–288. In Russian Language.
24. Rafat M, et al. Bioengineered corneal tissue for minimally invasive vision restoration in advanced keratoconus in two clinical cohorts. 2023;41(1): 70-81. doi:10.1038/s41587-022-01408-w.
25. Abby Wilson, Jones J, Marshall J. Biomechanical evaluation of decellularized and crosslinked corneal implants manufactured from porcine corneas as a treatment option for advanced keratoconus. Front Bioeng Biotechnol. 2022;10:862969. doi: 10.3389/fbioe.2022.862969. eCollection 2022.

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