Intracorneal Ring Segments: Types, Indications and Outcomes

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17.1 Introduction

Keratoconus is a progressive corneal ectatic disorder characterized by alterations in the morphology of the corneal stromal tissue that will negatively impact in the visual function and the optical quality of the patients by the generation of a progressive and severe irregular astigmatism that cannot be corrected with spectacles [1]. Nowadays, there are several therapeutic options in order to manage this pathological condition, such as thermokeratoplasty procedures (currently abandoned), corneal collagen crosslinking (CXL), intracorneal ring segment (ICRS) implantation, lamellar keratoplasty and penetrating keratoplasty [2–6]. Nevertheless, rigid gas permeable contact lenses are still the gold standard for the visual rehabilitation of these patients as this non-invasive option provides the best visual performance and they can be adjusted to further changes in the corneal shape of the patient. However, they have the inherent risks related to any contact lens wear such us infective or non-infective keratitis, and the challenge raises for those patients that become intolerant to the use of either rigid, hybrid or scleral lenses or when the cornea is too steep that the contact lens becomes unstable.

Intracorneal ring segments (ICRS) are small devices made of synthetic materials (PMMA) that are implanted within the corneal stroma in order to induce a change in the geometry and in the refractive power of the tissue. Prof. Joseph Colin proposed the use of such medical device for the treatment of keratoconus for first time in the year 2000 [4]. Nevertheless, the idea of implanting a corneal ring into the cornea was introduced by Reynolds in 1978, being the first design a complete full ring of 360° [7]. This design led to several postoperative complications like wound healing-related problems in the incision site, which was the main reason to abandon the full ring design and change it for the ring segments that we know today. During the 1980s and in the beginning of the 1990s, the ring segment design was extensively investigated as an alternative for the correction of refractive errors, specifically myopia. In spite of the success of ICRS for the correction of such refractive error, this technology was overcome by the good results and popularity of corneal excimer laser procedures.

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By this time, Colin and his co-workers observed that ICRS were able to flatten the central cornea and regularize the asymmetry of the tissue, thus leading to a reduction in the keratometric readings and improving the refraction and vision of keratoconus patients. Since then, several authors have reported the benefit of using ICRS in keratoconic eyes with the added value of delaying or avoiding more complex interventions like keratoplasty procedures.

17.2 Mechanism of Action of the ICRS

ICRS will act as spacer elements between the collagen fibres of the corneal tissue [8]. Thus, ICRS induce an arc shortening effect of the corneal geometry that in consequence flattens the central area of the corneal tissue. For the correction of astigmatism, the end point of each segment may produce a traction force on the surface, inducing an additional flattening on this reference axis. Some theoretical models based on finite element analysis have proven that the flattening observed after ICRS implantation is directly proportional to the thickness of the segment and inversely proportional to the corneal diameter where it is implanted. This means that the thicker and the smallest the diameter, the higher the flattening effect that will be induced by the segment [9]. Nevertheless, these theoretical analyses apply just to normal corneas where there is an orthogonal arrangement of the collagen fibres. As we know, in patients with keratoconus this special disposition of the fibres is lost, which leads to a more unpredictable outcome in this type of corneas [10]. Another theory that may explain the mechanism of action of the ICRS is the "thickness law" proposed by Barraquer which quote that when tissue is added to the periphery of the cornea or tissue is removed from the centre a flattening of the cornea will be achieved and vice versa [11]. However, there is not enough scientific data published in the literature that supports this theory.

17.3 Indications

Selecting the adequate patient for ICRS represents an important challenge for the clinician when are facing the therapeutic approach of a keratoconic patient. A full ophthalmic examination should be performed including the following: (1) *corrected and uncorrected visual acuity*; (2) *corneal topography including corneal aberrometry*: the majority of patients with keratoconus wear contact lenses, so discontinuing them must be advised for at least 1 week prior to the examination in those cases where soft contact lenses are used and 2 weeks in those cases wearing rigid contact lenses, in order to increase the reliability of the examination. Although a longer period of rigid contact lens discontinuation may be advisable, it is often unacceptable for the patient as many of them are functionally blind without them; (3) *corneal pachymetry*, preferably a corneal pachymetric map aiming to assess the appropriate thickness in the area where the ICRS would be implanted; (4) *corneal biomechanics*, either Ocular Response Analyser (ORA) or Corvis ST.

Before the implantation of any intracorneal segment, we must take into account a number of preoperative indications in order to increase the likelihood of attaining the best possible postoperative outcome for the patient [12]:

- Corrected distance visual acuity <0.9 in the decimal scale.
- Internal astigmatism <3 D.
- Alignment of refractive and keratometric axes. The flattest meridian of the cornea (K1) should be aligned with the refractive cylinder axis (expressed as a negative value). When the meridian and the axis form an angle of between 0 and 15° they are considered properly aligned.
- Corneal pachymetry >250/300 μm in the site of the corneal tunnel (depending on the thickness of ICRS to be implanted).
- Absence of central corneal scarring.

17.4 Types of Intracorneal Ring Segments

Nowadays, there are different types of ICRS that are commercially available, but the ones that are commonly used in the clinical practice are the *Keraring* (Mediphacos) (Fig. 17.1), the *Intacs* (Addition technologies) (Fig. 17.2) and the *Ferrara* segments (AJL Ophthalmic). Table 17.1 summarizes the main characteristics of these ICRS. Triangular designs generate a prismatic effect of the light coming through the implant, being reflected, thus reducing incidence of glare and halos. In addition, there are two other types of ICRS that because of their smaller diameter and different design have more flattening capabilities and are reserved for those keratoconic eyes that present high myopic refractive errors: the *Intacs SK* (Addition technologies), and the *Myoring* (Dioptex) (Fig. 17.3). The features of these two types of ICRS are shown in Table 17.2:

- *Intacs SK* (SK means severe keratoconus) are designed with rounded edges to potentially reduce the incidence of visual symptoms since SK segments are placed closer to patient's visual axis than the standard Intacs segments. They are indicated for the treatment of moderate to severe keratoconus (SK) with steep keratometric values >55.00 dioptres. Intacs SK segments seem to offer a compromise between the standard Intacs with 7 mm diameter and the Ferrara or Kerarings which are 5 mm in diameter, because diameter is inversely proportional to effectivity.
- *The Myoring* is the only one with a full ring (360°) design with published clinical data, and it is implanted within a corneal stromal pocket. They have a greater capacity to flatten and reduce the spherical equivalent than the segments, but do not usually significantly reduce astigmatism and therefore their use is limited to cases in which patients have a high spherical error and low astigmatism. Daxer et al. support that, while ICRS and incomplete rings are biomechanically neutral, MyoRing strengthens and stabilizes the cornea considerably and subsequently it is no longer necessary to combine it with CXL in progressive keratoconus [13]. This statement still requires long-term studies before its confirmation.

17.5 Surgical Procedure

In order to implant the ICRS into the deep cornea, we need to perform channels within the stroma where the rings will be implanted. For this purpose there are two different surgical options: mechanical and femtosecond laser-assisted technique.

In the mechanical or manual technique, the surgeon must mark the centre of the pupil in order to use it as a reference point during the procedure. Then a calibrated diamond knife is used to create an incision at a depth of 70 % of the cor-

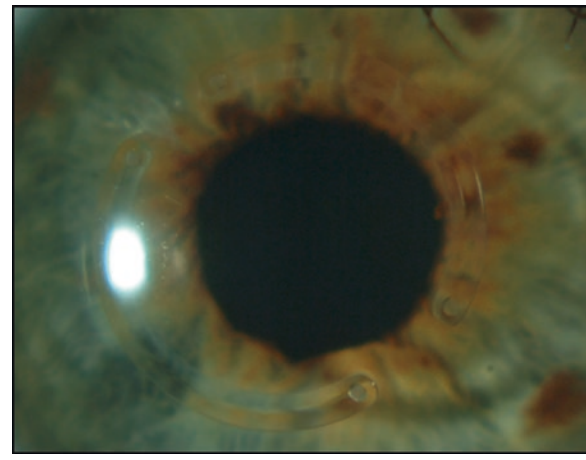

Fig. 17.1 Intracorneal ring segment Keraring (Mediphacos)

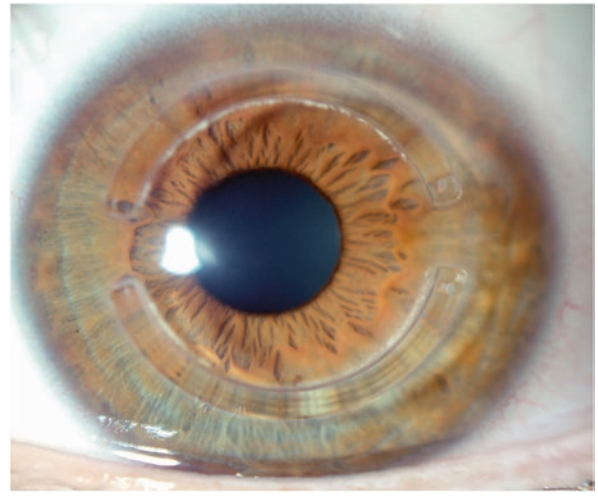

Fig. 17.2 Intracorneal ring segment Intacs (addition technologies)

Table 17.1 Main characteristics of the intracorneal ring segments most commonly used in the clinical practice

Design	Intacs	Kerarings	Ferrara
Arc length (degrees)	150°	90°–210°	90°–210°
Cross section	Hexagonal	Triangular	Triangular
Thickness (mm)	0.25–0.35	0.15–0.35	0.15–0.30
Inner diameter (mm)	6.77	6.00	4.8
Outer diameter (mm)	8.10	7.00	5.4

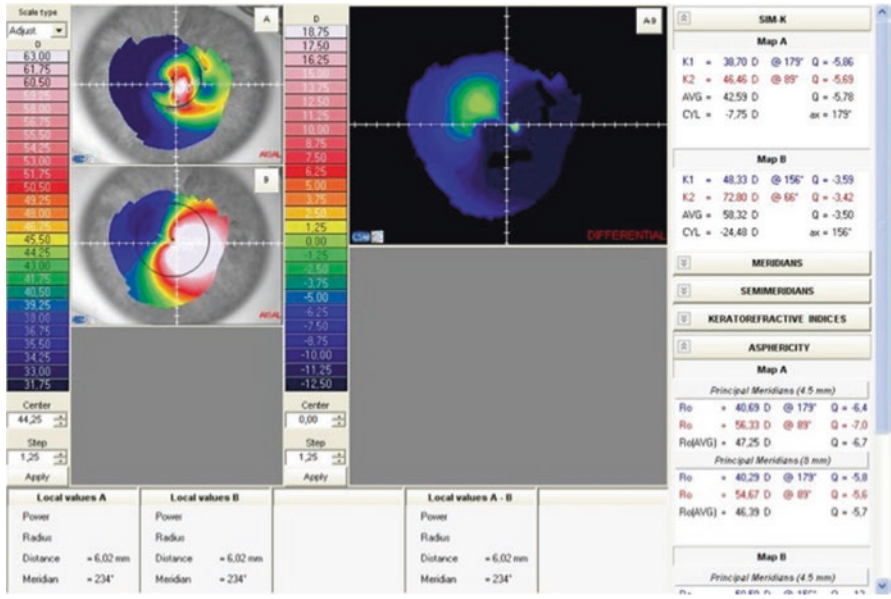

Fig. 17.3 Topography of a patient implanted with a Myoring (Dioptex) showing the significant flattening that is observed in the postoperative period. Map A: postoperative topography showing an average SimK of 42.59 D; Map B: preoperative topography showing an average SimK of 58.32 D

Table 17.2 Main characteristics of the intracorneal ring segments with higher flattening capabilities, reserved for those eyes with high myopic refractive errors

Design	Intacs SK	Myoring
Arc length (degrees)	150°	360°
Cross section	Oval	Triangular
Thickness (mm)	0.40–0.45	0.15–0.35
Inner diameter (mm)	6.00	5.00–8.00
Outer diameter (mm)	7.00	5.00–8.00

neal pachymetry at the incision point. A suction ring is placed around the corneal limbus in order to fixate the eye during the dissection of the corneal stroma. Then, two semi-circular dissectors are placed through the incision and advanced into the deep stroma in a clockwise and counterclockwise movement aiming to perform the tunnel.

With the femtosecond laser-assisted technique, a disposable suction ring is placed and centred. Afterwards, the cornea is flattened with a disposable aplannation cone, which allows a precise focus of the laser beam thus creating the dissection on the desire depth. Then the tunnel is created at approximately 70 or 80 % of the corneal pachymetry without direct manipulation of the eye. Finally, ICRS are inserted in the created tunnels.

Femtosecond laser produces a more precise and controlled stromal dissection than the manual technique. However, if we are talking about visual and refractive outcomes, most studies that have been conducted concur that both techniques produce similar results in cases of ICRS implantation for keratoconus. On the other hand, femtosecond laser makes the process faster, easier (especially for inexperienced surgeons) and more comfortable for the patient [14–17]. Apart from the safety and efficacy differences between both techniques, Alió and co-workers found that intrastromal segment implantation using femtosecond laser is a method that produces a greater reduction in corneal high order aberrations in eyes with coma aberration >3.0 μm [14, 15].

17.6 Implantation Nomograms

Regardless of the technique used to make the tunnels in the corneal stroma, the number, thickness, position and arc length of the segments are determined based on the manufacturer's nomograms. Likewise, rings are chosen from the nomogram taking into account the refractive error and the topographic map of the disease. It should also be noted that the incision guiding implantation of the segments in the tunnel is located on the axis of the steepest meridian of the corneal topography.

It is important to consider that although several authors have reported good results implanting ICRS in keratoconic eyes, the main limitations that nomograms have is that most of them are based in anecdotic clinical data, or variables that are very subjective in patients with keratoconus, such as sphero-cylindrical refraction and topographic pattern of the cone. For instance, it was found that based on the topographic pattern of the keratoconus the best choice was to implant one segment in those cases of inferior steepening and two segments in central cones [18].

Other works published in the literature support that the best location to implant the segments is by placing the corneal incision in the temporal site of the cornea [19–22] or in the steepest meridian of the cornea [23, 24]. There are other works that have reported good results when implanting the ICRS guided by the comatic axis [25]. Recently, Alió and co-workers published a scientific work in which we concluded that the best outcomes for implanting ICRS were observed in those cases where the refractive and topographic cylinder did not differ in more than 15° [12].

As we can see, there are different approaches regarding the guidelines to be used when implanting ICRS. Nevertheless, today the most widespread nomograms that are used in the clinical practice are those developed by the main manufacturers of ICRS:

17.6.1 Keraring Implant

Three types of nomograms (A, B and C) are used based on the type of corneal asymmetry (Fig. 17.4), on keratometric values and on corrected distance visual acuity (CDVA). The corneal asymmetry type is determined by studying the distribution of corneal irregularity (red) relative to the reference meridian. Accordingly, each case is classified according to Fig. 17.4:

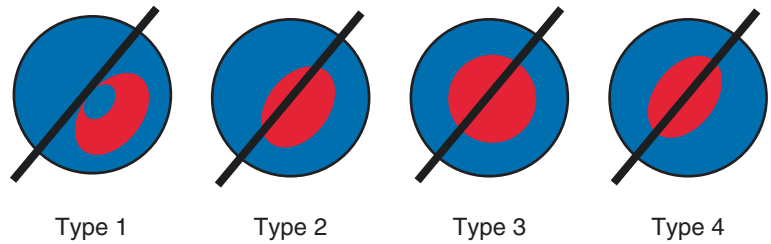

Fig. 17.4 Corneal asymmetry classification according to the area where the corneal irregularity (*red*) is found relative to the reference meridian (*black line*)

Type 1: 100 % of the steep area is located on one side of the reference meridian.
Type 2: The distribution of the steep area is approximately 20/80 %.
Type 3: The distribution of the steep area is approximately 40/60 %.
Type 4: The distribution of the steep area is approximately 50/50 %.

For type 1 and type 2 nomogram A is applied. Nomogram B for type 3 and nomogram C for type 4 (Fig. 17.5). These nomograms should be considered and used as a general guideline only and they should be customised by the surgeon depending on each patient particularities and the results obtained.

The steps and measures to be taken for ICRS implantation are as follows:

1. Obtain manifest subjective refraction.
2. Perform corneal topography (axial map).
3. Take pachymetric map. Determine the minimum corneal thickness at 5.5 and 6.5 mm optical zones.
4. Determine the steepest corneal meridian (SIM-K). If the refractive axis and the steepest topographic axis do not match, select the topographic meridian.
5. Compare the thickness of the proposed segment according to the selected nomogram with the minimal corneal thickness obtained in the 6 mm optical zone. The thickness of the segment should not exceed 60 % of the minimal corneal thickness. If it does, a segment with less thickness should be selected (Table 17.3).

Then we move on to select the reference meridian: If the CDVA > 0.5, we select the steepest meridian. If the CDVA < 0.5, select the total coma aberration axis or the steepest meridian by topography (SIM-K). Then draw a line along the reference meridian selected.

To determine the treatment strategy: If the CDVA > 0.4, program the treatment based on refractive sphere and cylinder obtained by manifest refraction. If the CDVA < 0.3 or if the manifest refraction is not very reliable, program the treatment based on kerometric values.

When it comes to implantation, when the nomogram suggests using two segments, the nomogram data appearing in the top line of the box should be used for the segment implanted in the area where the ectasia is smaller (flatter meridian), and the data on the lower line shall be for the segment implanted on the steepest meridian. When the nomogram suggests only one segment, this should be implanted on the steepest meridian, where the ectatic area is greater.

17.6.2 Ferrara Implant

Similar tasks must be performed before implanting these segments (Tables 17.4 and 17.5). From topographic astigmatism, the thickness of the ring is defined (Tables 17.6, 17.7 and 17.8). However, in the case of nipple keratoconus, this measurement is not used and the spherical equivalent is used to define the thickness of the ring, which it should be a 210° arc ring (exclusive for this type of keratoconus) (Table 17.9).

17.6.3 Intacs Implant

The recommendation is to select between symmetric or asymmetric segments depending on the ectatic area and spherical and cylindrical refractive power.

- Use *symmetric* segments when the ectatic area is within the 3–5 mm central optical zone and

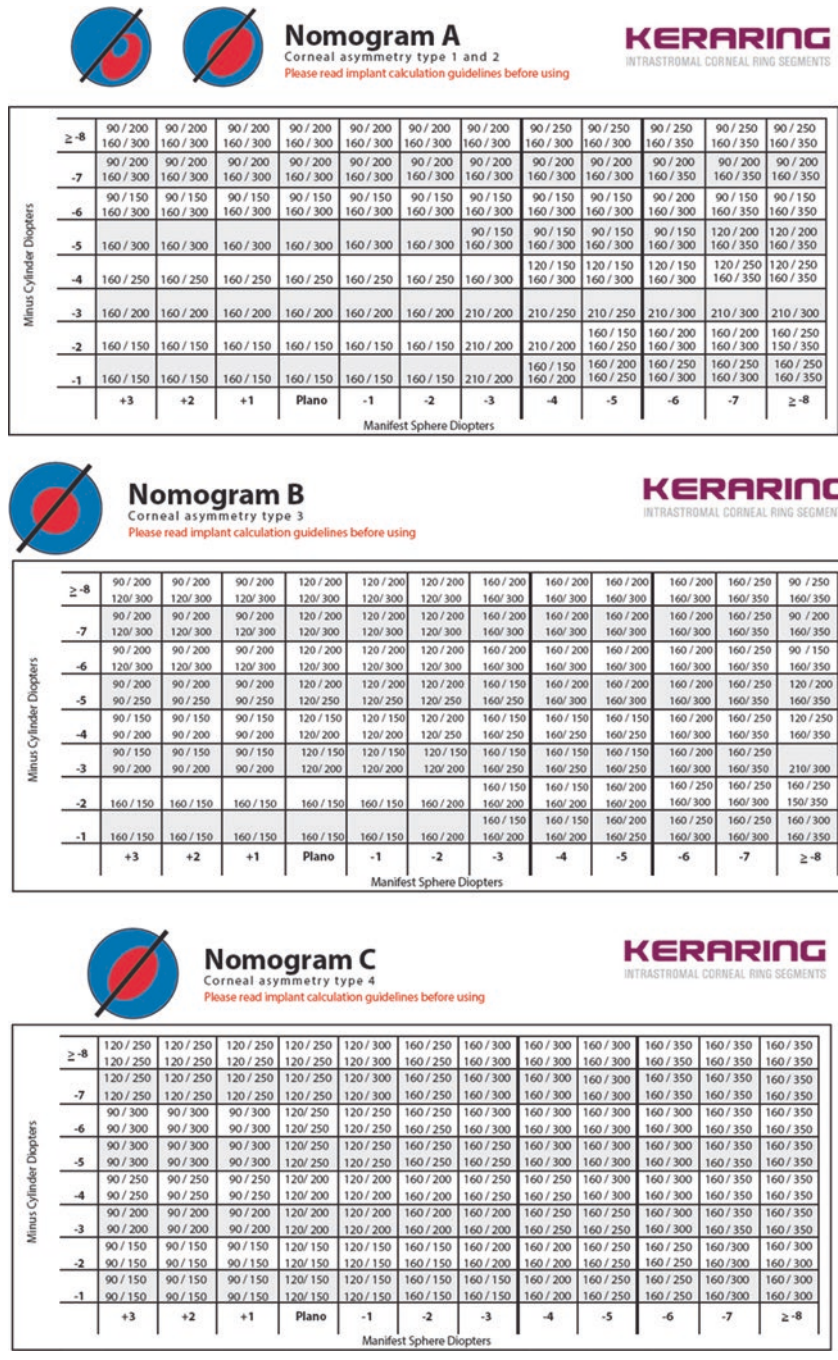

Fig. 17.5 Keraring implantation nomograms

when, in the manifest refraction with the positive cylinder, the spherical power is greater than the cylindrical power (Table 17.10).

- Use *asymmetric* segments when the ectatic area is outside the 3 mm geometric centre and when, in the manifest refraction with the positive cylinder, the cylindrical power is greater than the spherical power (Table 17.11).

Table 17.3 Safety thickness measurements for selection of intracorneal ring segments

Safety limits					
Proposed segment thickness (μm)	150	200	250	300	350
Minimal corneal thickness required for implant (μm)	250	335	420	500	580

Table 17.4 Step-by-step tasks for Ferrara ICRS implantation

Ferrara ring nomogram
1. Define the type of keratoconus: sag, bowtie or nipple
2. Distribution of the ectatic area in the cornea: 0/100, 25/75, 33/66 and 50/50
3. Corneal asphericity (Q)
4. Topographic astigmatism
5. Pachymetry at incision site and ring track

17.6.4 Myoring Implant

Some inclusion criteria must be met before its nomogram (Table 17.12) can be applied:

- Uncorrected visual acuity (UCVA) < 0.3.
- Minimal corneal thickness >360 μm.
- Average central keratometry (ACK) (K1 + K2)/2 > 44 D.
- No central corneal scarring.
- No history of previous corneal surgery.
- Age <50 years.

In spite of all these nomograms, complete predictability in postoperative results is still not possible due to changes in corneal biomechanics in keratoconic eyes [26]. It has been found a significant correlation between the corneal resistance factor (CRF), measured using an ocular response analyser (ORA; Reichert) and the magnitude of the corneal spherical-like aberrations [27]. Also it has been shown that the visual outcomes post-ICRS implantation correlated inversely with the magnitude of some corneal higher order aberrations. It should therefore be considered that larger amounts of corneal higher

Table 17.5 Distribution of area of corneal ectasia for Ferrara ICRS implantation nomogram

Map	Distribution of ectasia (%)	Description
	0/100	All the ectatic area is located at one side of the cornea
	25/75	75 % of the ectatic area is located at one side of the cornea
	33/66	66 % of the ectatic area is located at one side of the cornea
	50/50	The ectatic area is symmetrically distributed on the cornea

Table 17.6 Ferrara ICRS thickness choice in symmetric bowtie keratoconus

Topographic astigmatism (D)	Intracorneal segment thickness
<2.00	150/150
2.25–4.00	200/200
4.25–6.00	250/250
>6.25	300/300

Table 17.7 Ferrara ICRS thickness choice in sag keratoconus with 0/100 % and 25/75 % asymmetry index

Topographic astigmatism (D)	Intracorneal segment thickness
<2.00	None/150
2.25–4.00	None/200
4.25–6.00	None/250
6.25–8.00	None/300
8.25–10.00	150/250
>10	200/300

Table 17.8 Ferrara ICRS thickness choice in sag keratoconus with 33/66 % asymmetry index

Topographic astigmatism (D)	Intracorneal segment thickness
<2.00	None/150
4.25–6.00	200/250
<2.00	None/150
4.25–6.00	200/250

Table 17.9 Ferrara ICRS thickness choice in nipple keratoconus (210 arc ring)

Spherical equivalent (D)	Intracorneal segment thickness
>2.00	150
2.25–4.00	200
4.25–6.00	250
>6.25	300

Table 17.10 Intacs nomogram for symmetric segments

Symmetric		
Spherical power	Inferior Intacs (mm)	Superior Intacs (mm)
−0.00 to −1.00 D	0.210	0.210
−1.00 to −1.75 D	0.250	0.250
−2.00 to −2.75 D	0.300	0.300
−3.00 to −3.75 D	0.350	0.350
−4.00 to −4.75 D	0.400	0.400
>−5.00 D	0.450	0.450

Table 17.11 Intacs nomogram for asymmetric segments

Asymmetric		
Cylindrical power	Inferior Intacs (mm)	Superior Intacs (mm)
2.00–3.00 D	0.350	0.210
3.00–4.00 D	0.400	0.210
4.00 and higher	0.450	0.210

Table 17.12 Myoring implantation nomogram

Average central keratometry (D)	Implant diameter (mm)	Implant thickness (μm)
ACK < 44	7	280
44 < ACK < 48	6	240
48 < ACK < 52	6	280
52 < ACK < 55	5	280
55 < ACK	5	320

order aberrations are an important factor especially in advanced keratoconic corneas where biomechanical alteration would be more pronounced. Therefore, the predictability models could be improved if high order corneal aberrations were included. In other words, the introduction of the aberrometric factor could be an indirect manner of considering part of the biomechanical corneal factor. In any case, this indirect contribution of aberrometry to corneal biomechanics is limited, and it does not account for the total biomechanical effect. The analysis of the corneal biomechanical properties of the cornea in vivo is not an easy task in clinical practice and we also have to remember that the exact contributions of the elastic and viscous components to the magnitude of these parameters are not yet fully understood.

17.7 ICRS Outcomes

Since Colin reported for first time the results of ICRS implantation for the treatment of keratoconus in the year 2000 [4] several authors have demonstrated the efficacy of this surgical technique in reducing the spherical equivalent and keratometric readings in patients with keratoconus [28–32]. Most of these studies report an improvement in the uncorrected and corrected visual acuity, as well in the spherical equivalent and cylinder. The majority of the authors observed a central flattening of the cornea that was consistent with a mean reduction of the keratometric readings that goes between 3 and 5 dioptres [28–32]. Additionally, studies that have assessed the optical quality by analysing the changes in anterior corneal higher order aberrations have found a reduction in these variables after ICRS implantation, specifically in the asymmetric aberrations (coma and coma like). These changes observed in the aberrometric coefficient are expected to occur due to the capability of the implants in regularizing the geometry of the corneal tissue [14, 32, 33].

In a recent multicentric study performed by Alió and co-workers it was found that the efficacy of ICRS implantation is related to the visual impairment of the patients at the moment of the surgery [32]. In the aforementioned investigation, the outcomes of the surgical procedure were analysed based on a grading system that takes into account the visual acuity of the patients (RETICS classification) [34]. We observed that those patients with good visual function at the moment of the surgery were more prone to lose

Table 17.13 ICRS results in CDVA according to the RETICS classification [32]

CDVA	Pre	6 months	*p* value
STAGE I	0.97 ± 0.06 (0.90–1.15)	0.86 ± 0.18 (0.40–1.20)	<0.01
STAGE II	0.71 ± 0.08 (0.60–0.86)	0.75 ± 0.22 (0.30–1.20)	=0.04
STAGE III	0.45 ± 0.53 (0.40–0.58)	0.57 ± 0.22 (0.10–1.00)	<0.01
STAGE IV	0.27 ± 0.05 (0.20–0.38)	0.50 ± 0.22 (0.05–1.00)	<0.01
STAGE PLUS	0.09 ± 0.05 (0.01–0.15)	0.38 ± 0.26 (0.05–1.00)	<0.01

Table 17.14 Comparison of success and failure rates according to the degree of visual impairment [32]

Visual acuity	Gain ≥ 1 line CDVA (%)	Lost ≥ 1 line CDVA (%)	Lost ≥ 2 lines CDVA (%)
CDVA ≥ 0.6 GRADE I + II	37.90	36.29	25.80
CDVA ≤ 0.4 GRADE IV + PLUS	82.85	10.00	4.28

lines of vision after the procedure; on the other hand, those cases with a severe visual impairment before the procedure were the ones that benefit the most from ICRS implantation [32] (Tables 17.13 and 17.14).

This study also analysed topographical changes after ICRS implantation according to the visual impairment of patients with keratoconus. Table 17.15 summarizes the topographical results found in this study. Although they were able to demonstrate a significant reduction in all keratometry measurements in all groups ($p < 0.01$), the greatest reduction was in patients classified as Stage Plus, i.e. those with the most severe form of the disease. These findings lead us to the consideration that ICRS implantation in cases with keratoconus and good vision should be undertaken with extreme caution because of the risk of losing vision in this group of patients who have "little to gain and much to lose".

Long-term outcomes of ICRS implantation for the treatment of keratoconus have been always a topic of debate. There are some studies published in the literature that hypothesized that due to the distribution of the forces along the stroma that is observed after the implant this may help in reducing the stress on a specific point of the tissue thus leading to a more biomechanical stability of the cornea [35]. Nevertheless, these observations have not been proven in the clinical practice. Even when there are some long-term studies that have reported the stability of the surgical procedure [23, 33, 36] there is a clear limitation in most of these reports as they do not specify if the type of patients that they are evaluating within their cohort belong to cases with the progressive or stable form of the disease. In a recent study was observed that long-term stability of ICRS implantation depends on the progression pattern of the keratoconus at the moment of the surgical technique. Thus, in those cases with the stable form of the disease, ICRS implantation remains without significant changes after long period of follow up [33]. Nevertheless, in those cases that show clinical signs of progression, the benefit achieved immediately after the procedure is expected to be lost after long period of time. From that work, we conclude that stability of the disease should be confirmed before suggesting ICRS implantation in keratoconic patients [37], as in those progressive cases ICRS implantation should be combined with corneal collagen crosslinking in order to halt the progression of the disease and keep the response obtained with the ICRS in the long term.

It is important to take into account that ICRS have the advantage that they can be removed in the event of failure and can be combined with other techniques such as corneal collagen crosslinking, PRK and phakic intraocular lenses. They can also be exchanged for segments with different characteristics, being possible to improve the results when these prove unfavourable [38].

17.8 A Glance at the Future

Further changes in the ICRS design may enhance their results. Our investigation team is currently developing a new type of ICRS, the VR technology, which is not yet commercially available and combines an asymmetric design in an almost

Table 17.15 ICRS topographic results according to the RETICS classification [32]

	K1 Pre	K1 6 months	*p* value	K2 Pre	K2 6 months	*p* value	Km Pre	Km 6 months	*p* value
STAGE I	43.75 ± 2.95 (36.22–49.10)	41.95 ± 2.13 (35.50–46.10)	<0.01	45.91 ± 3.87 (36.00–58.82)	44.71 ± 2.20 (41.56–49.38)	<0.01	44.90 ± 2.96 (35.65–54.96)	43.35 ± 1.69 (38.63–47.45)	<0.01
STAGE II	45.09 ± 4.44 (34.07–56.00)	43.17 ± 4.47 (33.46–53.94)	<0.01	47.41 ± 5.42 (34.10–65.09)	46.08 ± 5.25 (34.10–59.23)	<0.01	46.24 ± 4.13 (34.57–59.10)	44.52 ± 4.41 (34.32–56.10)	<0.01
STAGE III	48.10 ± 6.00 (33.37–74.69)	44.56 ± 4.90 (32.45–54.49)	<0.01	49.88 ± 6.71 (37.25–83.67)	47.68 ± 5.68 (32.75–64.06)	<0.01	48.93 ± 5.67 (36.25–78.80)	46.09 ± 5.07 (32.60–59.52)	<0.01
STAGE IV	51.41 ± 6.69 (31.50–69.40)	45.94 ± 4.62 (38.00–58.02)	<0.01	51.89 ± 6.69 (33.80–74.48)	49.34 ± 5.74 (41.76–62.20)	<0.01	51.65 ± 6.06 (32.65–72.70)	47.64 ± 4.87 (39.88–60.11)	<0.01
STAGE PLUS	53.13 ± 8.10 (32.20–79.08)	47.73 ± 4.97 (35.37–59.10)	<0.01	55.68 ± 9.15 (38.10–85.51)	50.24 ± 5.11 (40.40–61.93)	<0.01	54.40 ± 8.00 (38.48–82.62)	48.81 ± 4.39 (39.54–57.34)	<0.01

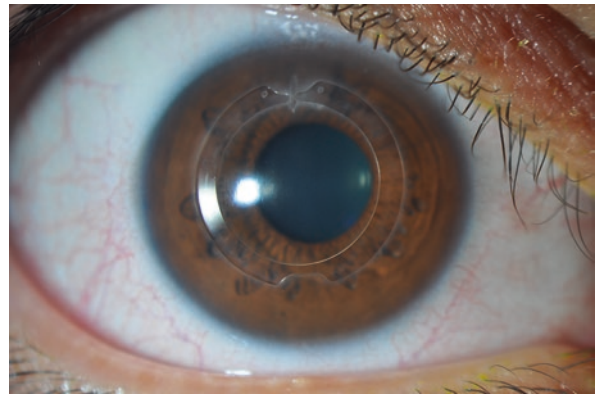

Fig. 17.6 VR Technology

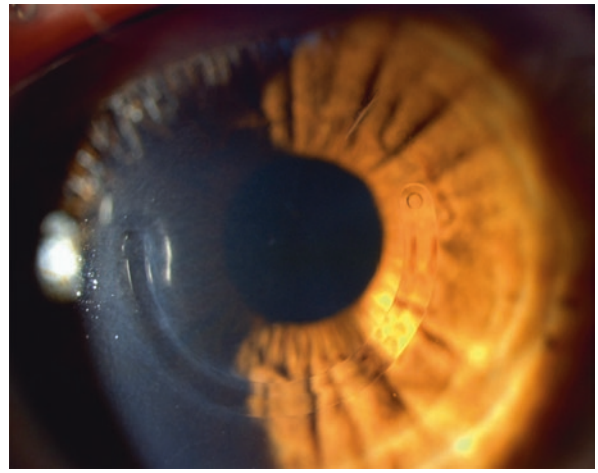

Fig. 17.7 Keraring 210° in a patient with pellucid marginal degeneration (courtesy of Efekan Coskunseven, Dunya Eye Hospital, Istanbul)

complete full ring of 350° of arc length (Fig. 17.6). The potential advantages of this design is that it may achieve both, the reduction of the asymmetry of the cornea that is observed with the segments and the significant flattening that is induced by the full ring devices (like Myoring). Also, as it is an incomplete ring, its implantation will be possible through a single incision in the cornea, avoiding then a stromal pocket.

Dr. Efekan Coskunseven (Dunya Eye Hospital, Istanbul, Turkey) is currently analysing the results obtained with the new 210° Keraring for the treatment of pellucid marginal degeneration (PMD), reporting encouraging results. Despite larger number of patients are still required before considering the introduction of this segment in the clinical practise, the initial results show an improvement of 1 or more lines of unaided vision in 55.5 % of patients with PMD, and a recovery of 1 or more lines of best corrected visual acuity (BCVA) in 77.7 % of the cases (Fig. 17.7).

ICRS are a powerful and useful therapeutic option for patients with corneal ectatic disorders, including keratoconus. Nevertheless, it's critical to understand their limitations and to discuss with the patient the impossibility of an accurate and predictable postoperative result, being often necessary their combination with other treatment options like crosslinking, PRK or phakic intraocular lenses. Subsequently it is necessary to expand our knowledge in corneal biomechanics and the changes induced by ICRS on it in order to be able to perform mathematical models that could predict better our results.

Compliance with Ethical Requirements Ayilin Kılıç, Jorge L. Alió del Barrio and Alfredo Vega-Estrada declare that they have no conflict of interest.

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all patients for being included in the study.

No animal studies were carried out by the authors for this chapter.

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