Arquivos Brasileiros de
Oftalmologia

Refractive and visual outcomes after Ferrara corneal ring segment implantation at a 60% depth in keratoconic eyes: case series

Resultados refrativos e visuais após a inserção do anel de Ferrara a uma profundidade de 60% em olhos com ceratocone: série de casos

Adimara da Candelaria Renesto[1], Flávio E. Hirai[1], Mauro Campos[1]

1. Departamento de Oftalmologia e Ciências Visuais, Universidade Federal de São Paulo, São Paulo, SP, Brazil.

ABSTRACT | Purpose: This report addresses refractive, topographic, visual acuity, and optical coherence tomography outcomes 12 months after femtosecond, laser-assisted insertion of Ferrara intrastromal corneal ring segments in keratoconic eyes at a depth of 60%. **Methods:** Interventional, prospective, non-comparative case series. We performed femtosecond, laser-assisted insertion of Ferrara intrastromal corneal ring segments in 15 keratoconic eyes. We included patients with documented keratoconus who voluntarily signed informed consents if they had best spectacle-corrected visual acuity ≥0.30 logMAR and corneal thickness ≥400 µm. We excluded patients with previous ocular surgery or corneal curvatures >65 diopters (D). Our main outcome measures were best spectacle-corrected visual acuity and corneal topographic parameters (flattest, steepest and average keratometry [K]), evaluated at baseline and at 1-,3-,6-, and 12-month follow-ups. **Results:** The mean ± standard deviation baseline uncorrected visual acuity and best spectacle-corrected visual acuity were 1.03 ± 0.46 and 0.42 ± 0.13, respectively; the 12-month mean standard deviation uncorrected visual acuity and best spectacle-corrected visual acuity were 0.72 ± 0.37 and 0.31 ± 0.16, respectively, without significant differences (p=0.05 for both). The mean best spectacle-corrected visual acuity improvements were statistically significant after 3- (p=0.02) and after 6-months (p=0.02). The mean baseline flattest (K1), steepest (K2), and overall keratometries (mean power) were 48.35 ± 3.65 D, 53.67 ± 3.38 D, and 50.84 ± 3.36 D, respectively. The 12-month mean ± standard deviations for flattest-K1, steepest-K2, and overall K were 46.53 ± 3.70 D, 49.83 ± 3.50 D, and 48.12 ± 3.49 D respectively, with statistically significant differences for all three topographic parameters (p=0.01). **Conclusions:** Ferrara intrastromal corneal ring segment insertions at a depth of 60% yield satisfactory visual, refractive, and keratometric results in keratoconic eyes.

Keywords: Cornea/pathology; Corneal diseases; Keratoconus; Corneal surgery, laser

RESUMO | Objetivos: Este estudo aborda os resultados refrativos, topográficos, acuidade visual e tomografia de coerência óptica, 12 meses após a inserção do segmento de Anel de Ferrara em túnel corneano a 60% de profundidade com o laser de femtosegundo, em pacientes com ceratocone. **Métodos:** Série de casos não comparativos, prospectivos e intervencionistas. Realizamos a inserção do Anel de Ferrara através de incisão com o laser de femtosegundo em 15 olhos ceratocônicos. Foram incluídos pacientes com ceratocone documentado que voluntariamente assinaram consentimentos informados que tivessem melhor acuidade visual corrigida ≥0.30 tabela logMAR, espessura corneana ≥400µm. Foram excluídos pacientes com cirurgia ocular prévia ou curvatura corneana > 65 dioptrias (D). As principais variáveis medidas foram acuidade visual corrigida e os parâmetros topográficos da córnea (ceratometria mais plana (K1), mais curva (K2) e ceratometria média (K médio), avaliadas no pré-operatório e com 1, 3, 6 e 12 meses de seguimento. **Resultados**: A média ± desvio padrão da acuidade visual sem correção e acuidade visual corrigida foi 1.03 ± 0.46 e 0.42 ± 0.13, respectivamente; o desvio padrão médio de 12 meses, a acuidade visual sem correção e acuidade visual corrigida foram de 0.72 ± 0.37 e 0.31 ± 0.16, respectivamente, sem diferenças significativas (p=0,05 para ambos). A melhora da acuidade visual corrigida foi estatisticamente significante após 3 meses (p=0,02), e após 6 meses (p=0,02). Os valores médios da linha de base K1, K2, e média (K médio) foram 48,35 ± 3,65D, 53,67 ± 3,38D, e 50,84 ± 3,36D, respectivamente. A média de 12 meses ± desvio

Submitted for publication: May 18, 2018
Accepted for publication: January 29, 2019

Funding: No specific financial support was available for this study.

Disclosure of potential conflicts of interest: None of the authors have any potential conflicts of interest to disclose.

Corresponding author: Adimara da Candelaria Renesto.

Rua Pedro de Toledo, nº 781- 2º andar - São Paulo - SP - 04039-032 - Brazil
E-mail: adimararenesto@uol.com.br

Approved by the following research ethics committee: Universidade Federal de São Paulo/Hospital São Paulo (Project # 1312/2015; Opinion # 1.347.475).

padrão para K1, K2, e K médio foi 46,53 ± 3,70D, 49,83 ± 3,50 D, e 48,12 ± 3,49D respectivamente, com diferença estatisticamente significativas para todos os 3 parâmetros topográficos (p=0,01). **Conclusões:** A inserção do Anel de Ferrara a uma profundidade de 60% no estroma corneano produz resultados visuais, refracionais e ceratométricos satisfatórios em olhos com ceratocone.

Descritores: Córnea/patologia; Doenças da córnea; Ceratocone; Cirurgia da córnea a laser

INTRODUCTION

Keratoconus is generally a progressive, bilateral, cone-like ectasia of the cornea affecting approximately 1 in 2,000 people in the general population. It is usually diagnosed in young adults[1]. The ocular symptoms and signs of keratoconus vary depending on disease severity. Hypotheses have been proposed to explain the genetic, environmental, and biomechanical underlying causes and mechanisms behind keratoconus[2], but its pathogenesis remains unclear.

While contact lens use remains the most successful option for managing mild to moderate cases of keratoconus, some surgical options, such as corneal ring implants and cross-linking procedures, have been developed to treat moderate to severe cases[2]. In 1986, Ferrara began implanting modified polymethylmethacrylate (PMMA) rings into rabbit corneas. In 1994 and 1996, he developed a better technique for implanting the rings in eyes with high myopia and keratoconus, and after penetrating keratoplasty (PKP)[3]. The first intrastromal corneal ring surgeries on human corneas were performed by Nosé et al.[4] in 1991 in nonfunctional eyes.

The aim of intrastromal corneal ring segment (ICRS) surgery is to induce a geometric change in the central corneal curvature that should reduce the refractive error and the mean keratometry while improving visual acuity. Additionally, corneal remodeling results in improvements in the optical quality of the cornea[5-10].

Surgeons differ on their preference of ICRS implantation depth. Published studies have reported ICRS insertions at 66%[11], 70%[5], 75%[12], and 80%[5,7-8] depths. These reports show favorable results in improving topographic and visual acuity after ICRS insertion in keratoconic eyes. In this study, we evaluated the refractive, topographic, visual acuity, and optical coherence tomography outcomes after femtosecond, laser-assisted Ferrara ICRS insertion depth at 60% (not described to date) in keratoconic eyes.

METHODS

We conducted an interventional, prospective, noncomparative case series between February 2016 and July 2017 in the Department of Ophthalmology and Visual Sciences at the Federal University of São Paulo, Brazil. The Institutional Ethics Committee approved the study in advance, and we followed the tenets of the Declaration of Helsinki. All patients provided written informed consent.

We evaluated 15 keratoconic eyes from 15 patients. We graded all eyes according to the Amsler-Krumeich classification[13] based on each patient's refraction, mean central K-reading, corneal signs, and corneal thickness. We graded the treated eyes as stage I, II, or III according to this classification.

We included interested patients with documented keratoconus (corneal topography and tomography), best spectacle-corrected visual acuity (BSCVA) ≥0.30 (logarithm of the minimal angle of resolution [logMAR] chart), increasing or proven intolerance of contact lenses, corneal thickness ≥400 µm at the thinnest point, good mental and systemic health, and a minimum age of 18 years. We excluded patients with previous ocular surgery, only one functional eye, axis corneal opacity, corneal curvature >65 diopters (D), pregnant or nursing, or with a history of herpetic keratitis, autoimmune disease, concurrent corneal infection, or other ocular diseases that modified visual acuity.

We scheduled follow-up examinations at baseline and at 1, 3, 6, and 12 months. The same examiner (ACR) performed all exams and evaluations. All patients underwent the following procedures during examinations: 1) uncorrected visual acuity (UCVA); 2) BSCVA in Feet Snellen and converted to logMAR chart; 3) manifest refraction in a bright environment; 4) slit-lamp biomicroscopy; 5) corneal topography and tomography (Pentacam® optical topography assessment, Oculus Optikgerate GmbH, Wetzlar, Germany); 6) corneal tomography (Visante® optical coherence tomography [OCT], Carl Zeiss Meditec, Dublin, CA, USA) with central and thinnest corneal pachymetry and corneal ring segment depth measurements (at 3 and 12 months), averaging three measurements of the nasal and temporal segments (inferior ring portion up to the corneal endothelium with Visante® software); 7) Goldmann applanation tonometer (GAT; Haag-Streit, Konig, Switzerland); and 8) ocular fundus examination.

Intrastromal corneal ring segments

The Ferrara ICRS (Ferrara Ophthalmics, Belo Horizonte, Brazil) has a variable apical diameter ranging from 5.0 mm to 6.0 mm, a triangular cross-section, and variable thicknesses ranging from 150 to 350 µm. The ring segments, which are made of yellow PMMA, have a 4.4-mm internal diameter, a 5.6-mm external diameter, and a 600-µm flat base. Arc segments of 90º, 120º, 140º, 160º, and 210º are available. See www.ferrararing.com.

In this study, we used only two 160º arc segments (200 µm, nasal and temporal) per eye. Moreover, we ensured that the thicker segment never exceeded half the value of the thinnest corneal thickness in the area where the tunnel was created.

Ferrara intrastromal corneal ring segment implantation

We inserted ICRSs in an operating room under sterile conditions using topical anesthetic drops. We initiated each procedure by marking a reference point for pupil centration, and we used a 5.0-mm marker to locate the exact ring channel. We set the tunnel depth at 60% of the thinnest corneal thickness on the tunnel location in the femtosecond laser (IntraLase, Irvine, CA, USA).

We made an incision on the steepest topographic axis and used a 150-kHz femtosecond laser to create the ring channels. We paid special attention to centralization of the disposable suction ring and marking the central point to minimize decentration. We set the following parameters: 1) a 5-mm channel's inner diameter; 2) a 5.9-mm channel's outer diameter; 3) a 1-µm entry cut thickness (at the steepest topographic axis); 4) 1 1.50-µJ ring channel; and, 5) a 1.50-µJ entry cut energy. The channel creation with the femtosecond laser was 15 seconds long. We implanted the ICRS using the accompanying forceps immediately after channel creation and before the disappearance of the bubbles revealing the exact tunnel location. After the operation, we prescribed a combination of 0.3% w/v gatifloxacin and 1.0% w/v prednisolone acetate eyedrops (Allergan Laboratories, Dublin, CA, USA) four times per day for two weeks. We instructed patients to avoid rubbing their eyes and to use artificial tears frequently. We performed slit-lamp biomicroscopic examinations on the first and seventh post-operative days to evaluate wound healing and segment migration. The same physician (M.C.) performed all the operations.

Statistical analysis

Contingency tables list relevant collected data. We presented continuous variables as means ± standard deviations (SDs) and categorical variables as frequencies (proportions). We compared pre- and post-operative variables using the Wilcoxon signed rank test and considered all p-values <0.05 as statistically significant. We performed all statistical analyses using the Stata v.14 software (College Station, TX, USA).

RESULTS

We enrolled 15 individuals (15 eyes) at baseline. The mean (SD) population age was 30.8 ± 5.4 years and the woman-to-man ratio was 5-to-10. We monitored all patients through scheduled examinations for 12 months. The two main outcome measures were BSCVA and keratometry (K) power.

Visual acuity

Figures 1 and 2 and table 1 display the values for the UCVA and BSCVA expressed in logMAR obtained in this study. The mean UCVA improvements were significantly different at 1 (p=0.02), 3 (p=0.01), and 6 months (p=0.03) post-surgery compared to the baseline. The mean BSCVA improvements were statistically significant at 3 (p=0.02) and 6 months (p=0.02). We found no statistical changes in either UCVA (p=0.05) or BSCVA (p=0.05) from baseline after 12 months post-surgery.

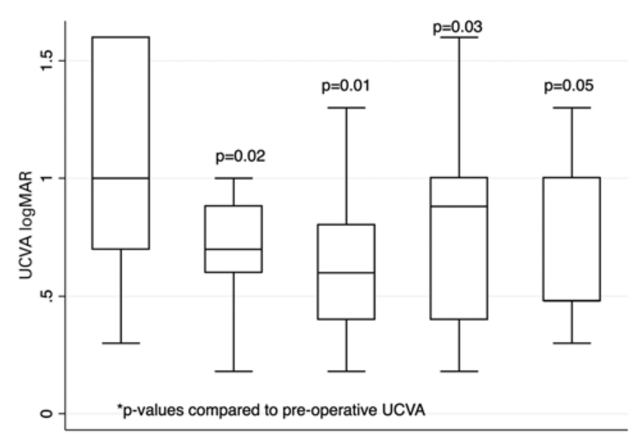

Figure 1. Uncorrected Visual Acuity in logMAR chart.

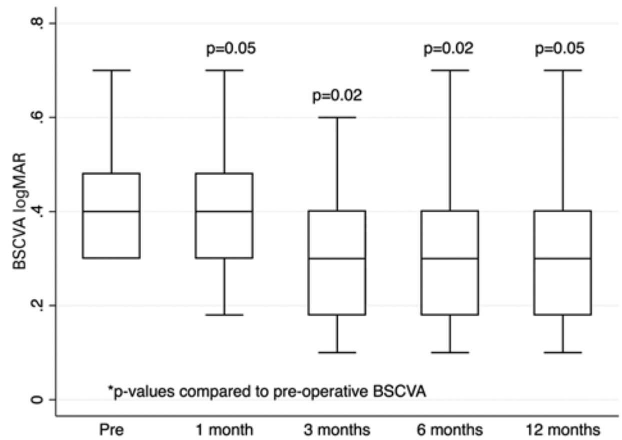

Figure 2. Best Spectacle-Corrected Visual Acuity in logMAR chart.

Topographic results

Table 1 shows the topographic data of our patients. The mean (SD) baseline flattest (K1), steepest (K2), and overall keratometries (mean power) were 48.35 ± 3.65 D, 53.67 ± 3.38 D, and 50.84 ± 3.36 D, respectively. At 12 months, these readings were 46.53 ± 3.70 D, 49.83 ± 3.50 D, and 48.12 ± 3.49 D, respectively, and all these changes were statistically significant (p=0.01).

Refractive results

The mean (SD) pre-operative spherical equivalent (SE) was -7.6 ± 3.58 D, and at 12 months post-surgery, it was -5.88 ± 3.13 D, for a statistically significant difference (p=0.03, Table 1).

Pachymetry results

Table 2 shows the pachymetry data at the central and thinnest position on the Pentacam and Visante OCT. We found no statistical differences from baseline to 12 months post-surgery in any parameter: central and thinnest Pentacam pachymetry (p=0.88 and p=0.84, respectively); central and thinnest Visante pachymetry (p=0.07 and p=0.09, respectively).

Depth of the Ferrara ICRS results

The incision depth depended on the corneal thickness at the intended incision site, aiming at 60% depth according to the Visante OCT pachymetry values. The mean (SD) baseline depth was 296.1 ± 19.95 µm. At 12 months, the values were 310.4 ± 26.12 µm for the nasal segment depth (p=0.02) and 265.2 ± 26.02 µm for the temporal segment depth (p=0.01), and they were statistically different from the pre-operative mean intended depths (Table 3).

Tonometry results

We evaluated tonometry data using a GAT. The intraocular pressures did not differ significantly after 1 (p=0.86), 3 (p=0.10), 6 (p=0.75), or 12 months (p=0.47) postoperatively.

Complications

During the fourth post-operative month, a patient's temporal segment migrated toward the incision site. The patient complained of foreign body sensation, pain, and photophobia, and we opted to remove of this segment. After one year of follow-up, no other complications occurred. Table 4 shows some published results after different ICRS insertion depths and related complications.

DISCUSSION

For this study, we implanted Ferrara ICRSs at a corneal depth of 60% in 15 individual eyes with keratoconus. The aim of the ICRS insertion is to provide refractive correction, flatten the cornea, and improve the UCVA and BSCVA in patients with keratoconus[14]. We observed UCVA and BSCVA improvements up to 6 months post-surgery. However, we found no statistical differences in acuity measurements at the 12-month follow-up (p=0.05). These findings agree with those in other published studies[7-10,15] on Ferrara ICRS insertion in keratoconic eyes. Miranda and associates obtained a significant reduction in the post-operative central corneal curvature, the BSCVA improved in 87.1% of patients at 12-month follow-up and the UCVA in 80.6% at the 12-month follow-ups[7]. Fernández-Vega Cueto et al. evaluated 409 keratoconic eyes after Ferrara ICRS insertion and showed that the UCVA (measured with the Snellen decimal scale) increased from 0.19 to 0.42 (p<0.0001) and the CDVA (measured using corrected distance visual acuity) increased from 0.69 to 0.77 (p<0.0001)[10]. Other studies with different types of ICRS (e.g., Intacs and Keraring) also showed improvements in UCVA and BSCVA in keratoconic patients[6,11,12]. Standardizing the staging of keratoconus diagnosis for each patient is difficult, which may explain the non-reproducibility of results after ICRS insertion in keratoconic eyes.

Regarding the topographic and SE results, we observed statistical differences in all parameters evaluated, including K1, K2, mean power (p=0.01 at all follow-up timepoints), and SE (p=0.01 at 1, 3, and 6 months post-surgery and p=0.03 at 12 months post-surgery). This is consistent with the ICRS mechanism of action, which works to flatten the cornea and quantitatively reduces the refractive error. These results also agree with those of other studies(14,16,17). Romeo et al.(16) and Al Bdour et al.(17) showed that, after Ferrara ICRS insertion, the keratometric reading and SE findings indicated an overall significant post-operative improvement because the Ferrara design allows a closer position to the corneal center. In a patient population, we observed ring effects due to corneal flattening; however, we did not observe corneal surface regularizations. We saw no cases of change from an irregular corneal astigmatism to a regular astigmatism. This may explain the significant difference in the SE (flattening of the cornea) but not in the BSCVA at the 12 months follow-ups.

In our study, we found no differences on corneal pachymetry maps (e.g., central and thinnest Visante OCT pachymetry, p=0.07 and p=0.09, respectively) and on central and thinnest Pentacam pachymetry (p=0.88 and p=0.84, respectively) when comparing baseline to 12 months post-surgery measurements. Studies aimed at relating Ferrara's ring and corneal pachymetry in keratoconic corneas have also shows variability in their results(7,16,18). Miranda et al.(7) compared corneal thicknesses, as measured by three devices, and demonstrated significant variation among the measurements. A five-year study by Romeo et al.(16) showed that pachymetry changed from 465 µm before surgery to a minimum of 434 µm at one year after surgery, and to 458 µm within five years.

We are unaware of published reports (PubMed) describing corneal rings implanted at a depth of 60% in the target tunnel location. Wachler et al.(11) inserted Intacs at a depth of 66%; during the operations, one eye experienced a superficial channel dissection, and they found segment migration and externalization in another eye on the first post-operative day. Fernández-Vega Cueto et

Table 1. Pre- and post-operative study variables.

	Pre-operative	1 month	3 months	6 months	12 months
UCVA	1.03 (0.46)	0.73 (0.33)	0.63 (0.30)	0.76 (0.37)	0.72 (0.37)
BSCVA	0.42 (0.13)	0.40 (0.15)	0.30 (0.14)	0.31 (0.14)	0.31 (0.16)
Flattest K1 (D)	48.35 (3.65)	46.62 (3.87)	46.60 (3.85)	46.83 (3.56)	46.53 (3.70)
Steepest K2 (D)	53.67 (3.38)	49.68 (3.62)	49.61 (3.42)	49.72 (3.48)	49.83 (3.50)
Mean K (D)	50.84 (3.36)	48.08 (3.66)	48.04 (3.56)	48.22 (3.41)	48.12 (3.49)
Spherical Equivalent (D)	-7.60 (3.58)	-5.75 (3.12)	-5.48 (3.11)	-5.63 (3.16)	-5.88 (3.13)

Values shown are mean (standard deviation); UCVA= uncorrected visual acuity; BSCVA= best spectacle-corrected visual acuity; K= keratometry; D= diopters.

Table 2. Pre- and post-operative pachymetric measurements.

Variable, mean (SD)	Pre-operative	1 month	3 months	6 months	12 months
Pentacam	-	-	-	-	-
Central position (µm)	494.5 (37.21)	481 (41.83)	484.3 (43.92)	483.2 (44.22)	495 (44.86)
Thinnest position (µm)	465.7 (37.52)	453.2 (41.93)	453.6 (41.92)	455.8 (43.47)	466 (44.65)
Visante	-	-	-	-	-
Central position (µm)	470.9 (38.24)	489.8 (44.78)	482.5 (44.25)	480.4 (46.09)	481.5 (45.55)
Thinnest position (µm)	445.7 (41.09)	443.2 (41.63)	443.1 (42.88)	442 (42.53)	443.1 (43.58)

SD= standard deviation.

Table 3. Post-operative nasal and temporal segment depths measured by Visante OCT after 3 and 12 months

Variable, µm	Pre-operative	Nasal 3 M	Temporal 3 M	Nasal 12 M	Temporal 12 M
Mean (SD)	296.1 (19.95)	317.5 (23.35)	277.4 (25.40)	310.4 (26.12)	265.2 (26.02)
Minimum	270	278	243	261	225
Maximum	337	355	326	357	323

OCT= optical coherence tomography; µm= micrometer; SD= standard deviation; M= month.

Table 4. Results of intrastromal corneal ring segments inserted at different depths

Study*	Eyes	Intacs®, Keraring®, Ferrara®	Mean follow-up	Visual acuity	Refractive changes	Complications
Boxer Wachler et al[11] (Target depth= 66%)	74	Intacs (mechanical technique)	9 months	Two lines of BSCVA improvement (20/50) to (20/32)	Mean SE reduced from -3.89D to -1.46D after surgery	Superficial channel dissection in one eye during surgery, externalization of the segment in one eye, and explantation in two eyes.
Fernández-Vega Cueto et al[10] (Target depth= 70%)	409	Ferrara (femtolaser technique)	6 months	The mean BSCVA (Snellen decimal scale) rose from 0.69 to 0.77 after surgery	The SE declined from a pre-operative -4.16D to a post-operative value of -2.81D	None
Kwitko et. al[24] (Target depth= 70% and 80%)	51	Ferrara (mechanical technique)	13 months	The BSCVA improved in 44 eyes (86.4%), and worsened in six eyes (11.7%)	The mean SE decreased from -6.08D to -3.81D postoperatively	Ring decentration in two eyes, extrusion in 10 eyes, disciform keratitis in one eye, and bacterial keratitis in one eye
Coskunseven et al[12] (Target depth= 75%)	50	Keraring (femtolaser technique)	15 months	Nine eyes (18%) maintained the pre-implantation BSCVA, whereas 39 (68%) experienced a BSCVA gain of one to four lines	Mean SE reduced from -5.62D to -2.49D postoperatively	Segment migration to the incision site was seen in three eyes (6%) on the first post-operative day
Ferrara et al.[14] (Target depth= 80%)	1073	Ferrara (mechanical technique)	24 months	The mean BSCVA increased from 20/100 to 20/40	The pre-operative SE decreased from -8.52D to -3.99D	Segment extrusion in six eyes (0.56%), progressive corneal steepening in two eyes (0.18%), and ring neovascularization in two eyes (0.18%)
Miranda et al.[7] (Target depth= 80%)	36	Ferrara (mechanical technique)	12 months	The BSCVA improved in 27 eyes (gain of 2 or more Snellen lines) and did not change in four eyes	The mean SE decreased from -7.29D to -4.80D 12 months after surgery	Segment decentration in one eye (2.7%), migration in two eyes (5%), extrusion in five eyes (13.8%), and infection (Nocardia SP) in one eye with segment extrusion
Shahhoseini et al. [22] (Target depth= ≥70% up to 85%)	30	Intacs (femtolaser technique)	25 months	Changes in the BSCVA were statistically significant on the first month after surgery (P=0.024) and remained stable thereafter; the mean logMAR BSCVA was 0.27 preoperatively and 0.15 at the 12-month follow-up	The mean SE change from baseline to one year after surgery was -1.57D to -1.48D (P=0.921)	None

Study*= only first author; SE= spherical equivalent; BSCVA, Best spectacle-corrected visual acuity; D, diopters.

al.[10] used Ferrara ring segments implanted at 70% of the corneal depth in 409 paracentral keratoconic eyes with no complications in a 6-month follow-up study. Other reports have described ICRS implantations at 75% and 80% depths with several complications of differing severity levels[7,10,12,16-17]. Our study had a low incidence and severity of complications when compared to those in the cited studies. According to Hashemi et al.[19] maximal flattening occurs with segments at 60%-79% corneal thickness. When inserted shallower than 60% deep, the effect may be reduced. When inserted deeper than 80%, the topographic effects may disappear.

In this case series, we used only two segments of 160º (200 µm, nasal and temporal) per eye. We always made the incision in the steep meridian to take advantage of the coupling effect achieved by the segments, and we did not follow Ferrara's nomogram for planning the segment insertions. The nomogram for implanting Ferrara ICRS has evolved based on new evidence[15]. Although many studies focused on improving nomograms' predictability and reproducibility after insertion of the corneal ring have been published, personalized procedures are not yet in practice to provide better refractive and visual results. Even without the nomogram, our results corroborate the results in the literature.

Our study showed a statistical difference in the pre-operative mean intended depth at 3 and 12 months post-surgery in both the nasal and temporal segments measured by Visante OCT. In particular, we observed shallowing of the temporal segments. We emphasize that we observed corneal pachymetry measurement variability in patients with keratoconus, and this may have led to variations in depth along the ring segment after surgery. Studies evaluating the depth after ICRS insertion, for the most part, also have shown shallower ICRS depths than intended. However, different methodologies have been used to measure segment depths. For example, different brands of tomographs and different ring segment types (e.g., Keraring, Intacs, Ferrara) have been implanted at varying depths (e.g., 70%, 75%, 80%, and 85%) with mechanical or femtosecond laser-assisted techniques[20-23]. Standardization of ICRS insertion depth measurements using tomographic devices has yet to be developed.

We recognize that there are limitations in our study. The sample size was small, we did not include a comparative group (focusing on the nomogram), and the follow-up time was relatively short. However, we chose to focus on a small number of patients to avoid complications, given the lack of evidence in the literature on ring implantation at a depth of 60%.

In keratoconic corneas, ICRS implantation is considered a valid alternative to cornea transplant and appears to arrest or slow pathogenesis, improving both UCVA and BSCVA[2,5-7,14]. However, the main goal of this therapeutic treatment is not to achieve emmetropia, but rather to increase BSCVA. The implant is reversible and can be removed or changed if necessary[16]. In conclusion, based on the present protocol, Ferrara ICRS implantation at a depth of 60% yields satisfactory visual, refractive, and keratometric outcomes in keratoconic eyes. The ICRS actual depth was less than we had anticipated. Further studies are needed to confirm these results.

REFERENCES

1. Rabinowitz YS. Keratoconus. Surv Ophthalmol. 1998;42(4):297-319. Review.
2. Romero-Jiménez M, Santodomingo-Rubido J, Wolffsohn JS. Keratoconus: a review. Cont Lens Anterior Eye. 2010;33(4):157-66.
3. Ferrara de A, Cunha P. Técnica cirúrgica para correção de miopia. Anel corneano intra-estromal. (Myopia correction with intrastromal corneal ring). Rev Bras Oftalmol. 1995;54(8):577-88.
4. Nosé W, Neves RA, Schanzlin DJ, Belfort Júnior R. Intrastromal corneal ring--one-year results of first implants in humans: a preliminary nonfunctional eye study. Refract Corneal Surg. 1993; 9(6):452-58.
5. Alio JL, Vega-Estrada A, Esperanza S, Barraquer RI, Teus MA, Murta J. Intrastromal corneal ring segments: how successful is the surgical treatment of keratoconus? Middle East Afr J Ophthalmol. 2014; 21(1):3-9.
6. Colin J, Cochener B, Savary G, Malet F. Correcting keratoconus with intracorneal rings. J Cataract Refract Surg. 2000;26(8):1117-22.
7. Miranda D, Sartori M, Francesconi C, Allemann N, Ferrara P, Campos M. Ferrara intrastromal corneal ring segments for severe keratoconus. J Refract Surg. 2003;19(6):645-53.
8. Siganos D, Ferrara P, Chatzinikolas K, Bessis N, Papastergiou G. Ferrara intrastromal corneal rings for the correction of keratoconus. J Cataract Refract Surg. 2002;28(11):1947-51.
9. Hamdi IM. Optical and topographic changes in keratoconus after implantation of Ferrara intracorneal ring segments. J Refract Surg. 2010;26(11):871-80.
10. Fernández-Vega Cueto L, Lisa C, Poo-López A, Madrid-Costa D, Merayo-Lloves J, Alfonso JF. Intrastromal Corneal Ring Segment Implantation in 409 Paracentral Keratoconic Eyes. Cornea. 2016; 35(11):1421-6.
11. Boxer Wachler BS, Christie JP, Chandra NS, Chou B, Korn T, Nepomuceno R. Intacs for keratoconus. Ophthalmology. 2003;110(8):1031-40. Erratum in: Ophthalmology. 2003;110(8): 1475.
12. Coskunseven E, Kymionis GD, Tsiklis NS, Atun S, Arslan E, Jankov MR, et al. One-year results of intrastromal corneal ring segment implantation(KeraRing) using femtosecond laser in patients with keratoconus. Am J Ophthalmol. 2008;145(5):775-9.
13. Krumeich JH, Daniel J, Knülle A. Live-epikeratophakia for keratoconus. J Cataract Refract Surg. 1998;24(4):456-63.
14. Ferrara G, Torquetti L, Ferrara P, Merayo-Lloves J. Intrastromal corneal ring segments: visual outcomes from a large case series. Clin Exp Ophthalmol. 2012;40(5):433-9.
15. Torquetti L, Berbel RF, Ferrara P. Long-term follow-up of intrastromal corneal ring segments in keratoconus. J Cataract Refract Surg. 2009;35(10):1768-73.
16. Pesando PM, Ghiringhello MP, Di Meglio G, Romeo S. Treatment of keratoconus with Ferrara ICRS and consideration of the efficacy of the Ferrara nomogram in a 5-year follow-up. Eur J Ophthalmol. 2010;20(5):865-73.
17. Ameerh MA, Hamad GI, Ababneh OH, Gharaibeh AM, Refai RM, Bdour MD. Ferrara ring segments implantation for treating keratoconus. Int J Ophthalmol. 2012;5(5):586-90.
18. Torquetti L, Arce C, Merayo-Lloves J, Ferrara G, Ferrara P, Signorelli B, et al. Evaluation of anterior and posterior surfaces of the cornea using a dual Scheimpflug analyzer in keratoconus patients implanted with intrastromal corneal ring segments. Int J Ophthalmol. 2016;9(9):1283-8.
19. Hashemi H, Yazdani-Abyaneh A, Beheshtnejad A, Jabbarvand M, Kheirkhah A, Ghaffary SR. Efficacy of intacs intrastromal corneal ring segment relative to depth of insertion evaluated with anterior segment optical coherence tomography. Middle East Afr J Ophthalmol. 2013;20(3):234-8.
20. Barbara R, Barbara A, Naftali M. Depth evaluation of intended vs actual intacs intrastromal ring segments using optical coherence tomography. Eye (Lond). 2016;30(1):102-10.
21. Naftali M, Jabaly-Habib H. Depth of intrastromal corneal ring segments by OCT. Eur J Ophthalmol. 2013;23(2):171-6.
22. Shahhoseini S, Hashemi H, Asgari S. Intracorneal ring segment depth in keratoconus patients: a long-term follow-up study. Int Ophthalmol 2017 Jun 12. doi:10.1007/s10792-017-0595-2.
23. Lyra JM, Lyra D, Ribeiro G, Torquetti L, Ferrara P, Machado A. Tomographic Findings After Implantation of Ferrara Intrastromal Corneal Ring Segments in Keratoconus. J Refract Surg. 2017;33(2):110-5.
24. Kwitko S, Severo NS. Ferrara intracorneal ring segments for keratoconus. J Cataract Refract Surg.2004;30(4):812-820.