Abstract
Intracorneal ring segments (ICRS) are small synthetic implements designed to achieve refractive adjustment by flattening the cornea. Three common types of commercially available ICRS are Intacs, Keraring and Ferrara rings. Low myopia was the initial indication for implantation of ICRS, and indications later included ectatic corneal diseases (such as keratoconus and pellucid marginal degeneration) and ectasia after laser-assisted in situ keratomileusis. Two surgical procedures are used for implantation of ICRS: a mechanical technique, performed using two manual semicircular dissectors, and a femtosecond laser technique, performed with the assistance of femtosecond laser photodisruption for tunnel creation. The design parameters of ICRS, such as shape, thickness and diameter, have different effects on corneal curvature. Several nomograms have been developed in order to improve the outcome of refractive correction, depending on centration of the cone, corneal steepness and refraction. Implantation of ICRS is minimally invasive, although intraoperative and postoperative complications have been reported, depending on the surgical procedure. Combination with other treatment modalities, such as corneal collagen crosslinking and/or photorefractive keratectomy, has also been reported.

Introduction
Keratoconus is a progressive, noninflammatory ectatic disorder of the cornea that results in significant protrusion and thinning that are typically diagnosed during the second decade of life. The main symptoms are increasing irregular astigmatism and a decrease in best-corrected visual acuity. Corneal topography may reveal the disease early and is very useful in detecting progression. Inferior corneal steepening is the most common topographic finding. Management of keratoconus includes the use of glasses and contact lenses for visual rehabilitation at early stages, corneal collagen crosslinking (CXL) in the case of progression to achieve stabilization and penetrating or deep lamellar keratoplasty in advanced cases.

Intracorneal ring segments (ICRS) are implanted deep into the corneal stroma and were originally used to treat low to moderate myopia [1, 2]. Currently, they are used to manage ectatic corneal disorders such as keratoconus [3, 4], pellucid marginal degeneration [5] and ectasia after laser-assisted in situ keratomileusis (LASIK) [6].
Intrastromal corneal ring segments are polymethyl methacrylate implants that are implanted at the midperipheral corneal stroma in order to flatten the central corneal zone. There are three types of ICRS commercially available: Intacs (Addition Technologies Inc., Fremont, California, USA), Keraring (Mediphacos, Belo Horizonte, Brazil) and Ferrara rings (Ferrara Ophthalmics, Belo Horizonte, Brazil). Ferrara rings have a smaller optical zone and more of a flattening effect than Intacs does.

Indications for Intracorneal Ring Segment Implantation in Keratoconus

Implantation of intracorneal rings is indicated in ectatic corneas when visual acuity cannot be improved with spectacle correction. Patients with keratoconus, post-LASIK ectasia or pellucid marginal degeneration may be treated. In these patients, contact lens intolerance is also an indication since implantation of intracorneal rings has been shown to improve visual acuity and tolerance of contact lens wear.

In order to be successful, intracorneal ring implantation should be implemented in corneas with a clear optical zone and a corneal thickness >450 µm in the area of implantation. Intrastromal corneal ring segments are inserted in intrastromal channels (created either manually or with femtosecond (FS) lasers) at a depth of 75% of the thinnest pachymetry (fig. 1).

Surgical Techniques for Intracorneal Ring Segment Implantation

Mechanical Technique

Topical anesthesia is performed, and the center of the cornea is located. A marker is used to mark the sites and the incision points on the steep axis of the cornea. A diamond knife is set to a depth between 70 and 80% of the corneal thickness measured by ultrasound corneal pachymetry. A radial incision of 1.2–1.8 mm width is created in the marked position. Pocketing hooks create corneal pockets on each side at the bottom of the incision. A vacuum system is started after a suction
Ring is placed around the limbus. Two semicircular dissectors are placed (one clockwise and the other counter-clockwise) into the pocket and are advanced by rotational movement, creating two semicircular tunnels with specific diameters. Ring segments may be placed into the tunnels at least 1 mm away from the incision.

**Femtosecond Laser Technique**

The surgical procedure with an FS laser is also performed under topical anesthesia. The disposable suction ring of the FS laser system is centered after marking a reference point on the cornea (pupil center or first Purkinje reflex) and measuring the corneal thickness at the area of implantation (5- or 6-mm diameter). The disposable glass lens is app Planed to the cornea to fixate the eye and to help maintain the precise distance from the laser head to the focal point. An entry cut with the FS laser is created in order to allow access ring placement in the tunnel. Ring segments are inserted into the created tunnels (pupil center or first Purkinje reflex) at approximately 70–80% of the corneal thickness.

Compared to the manual technique, the FS laser makes tunnel creation easy, quick and more reproducible and also offers accurate tunnel dimensions (width, diameter and depth) [7]. With mechanical dissectors, the segment depth may be shallower at positions further from the incision. Theoretically, compared with mechanical tunnel creation, which relies on the surgeon’s skills, the FS laser-assisted procedure should generate more accurate stromal dissection, leading to better visual and refractive results.

However, similar visual and refractive outcomes were reported for the two procedures in a short-term follow-up of eyes effected by keratoconus or post-LASIK ectasia [8, 9].

Kubaloglu et al. [10] compared the clinical outcomes of keratoconic patients treated with Keraring to those of patients treated with Intacs. Both implants were safe and effective. No difference was recorded in visual or refractive outcomes when comparing mechanically and FS laser-created channels. However, it was reported that use of the FS laser made the procedure faster, easier and more comfortable. Further experience and the development of more accurate nomograms should improve clinical outcomes.

**Mechanism of Action**

The implantation of ICRS results in redistribution of the corneal peripheral lamellae, producing flattening of the central cornea and decreasing refractive disorders, myopia and astigmatism [4]. The effect is proportional to the implant’s thickness and inversely proportional to the implant’s diameter [2]. The refractive result of the surgical intervention is possibly reversible since the ring segments can be explanted and replaced with ring segments of a different thickness to produce a different result. Unlike with surface ablation or LASIK, the central clear zone of the cornea is not directly treated. The normal cornea is generally prolate, or steeper centrally than peripherally. The ring segments flatten the peripheral cornea more than the central cornea, and therefore, the central cornea profile is maintained after placement of the ring segments. This is important because it has been suggested that a prolate cornea may minimize glare and halo symptoms. Additionally, since the ring segments are narrow, the overlying stroma can receive nutrients from surrounding tissue (fig. 2–4).

**Nomogram for Intracorneal Ring Segment Implantation**

Currently, several different nomograms have been published in the literature regarding the best choice of ICRS in each case. Authors have used either one or preferably two symmetrical or asymmetrical rings implanted in the horizontal, vertical or oblique position in order to achieve the best possible correction. There are also nomograms proposed by the manufacturers of...
Intracorneal Ring Segment in Keratoconus

DOI: 10.1159/000381493

(For legend see next page.)