

Arcuate Incisions in Corneal Surgery

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Abstract

This article describes the current status of the femtosecond generated arcuate incision to correct corneal steepening. It covers the history of the surgical correction of astigmatism and describes the entrance of the femtosecond laser into modern corneal and cataract surgery. The process of photodisruption is explained as are the current indications for use of the femtosecond laser to make corneal incisions. A detailed narrative for programming the laser to perform arcuate incisions is included. Nomograms are referenced, and advantages over bladed incisions are described. A case is presented to show the use of these incisions in clinical practice. Finally, future developments are contemplated.

Keywords

Arcuate, incision, femtosecond, astigmatism, cornea, nomogram

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History

The first recorded case of the surgical reduction of astigmatism was published in 1885 by the Norwegian ophthalmologist, Schiotz.¹ Much later, Richard Troutman proposed the concept of making arcuate corneal incisions for the reduction of post-keratoplasty astigmatism in a landmark article entitled 'Relaxing incision for control of postoperative astigmatism following keratoplasty'. This article was published in the journal *Ophthalmic Surgery* in 1980.² In 1986, Lee Nordan proposed a system to quantify the correction of astigmatism at lower levels using transverse incisions.³ Richard Lindstrom, also developed a nomogram to quantify the effects of corneal incisions to reduce astigmatism⁴, eventually leading to a clinical trial known as the ARC-T study group. These results were published by Price et al. in 1995.⁵ All of these systems, of course, relied on the use of a physical blade. The methods were efficacious but imprecise. These techniques remained the state of the art until very recently.

Advent of the Femtosecond Laser for Corneal Surgery

In 2001, the Intralase corporation obtained clearance for the use of a femtosecond laser for the creation of a corneal flap to be used in the Laser-assisted *in Situ* keratomileusis (LASIK) procedure. This was the genesis of a revolution; the dawn of the laser scalpel for creating corneal incisions. The acceptance of the femtosecond laser was slow.

There were two primary reasons; first, the predicate device, a microkeratome had a reasonably good safety and efficacy record. Second, economic factors created a barrier for many surgeons. Gradually, surgeons recognized the superior safety profile and improved results when using a femtosecond laser to create the flap. Today, the femtosecond laser has become the dominant device for creating flaps during LASIK surgery.

During these last eleven years while the femtosecond laser was slowly overtaking the microkeratome, engineers and scientists were developing this tool for other applications in the field of ophthalmology; specifically, cataract surgery.

Advent of the Femtosecond Laser for Cataract Surgery

In 2012, it was well known that the femtosecond laser could make a very precise cut into corneal tissue. The fact that corneal incisions had become a routine part of the cataract procedure, made for a likely entrance of this device into the arena of cataract surgery. The femtosecond cataract procedure of today involves a clear corneal incision for entry into the anterior chamber, an arcuate incision for the correction of astigmatism (if warranted), a capsulotomy and finally some level of fragmentation of the nucleus. This article is focused on the arcuate incision portion for the correction of astigmatism.

Capabilities of the iFS

The device uses an infrared laser beam to achieve its surgical effect by means of a process known as photodisruption. A laser pulse of ultra-short duration (one quadrillionth of a second, also known as a femtosecond) is focused and creates a plasma. As the plasma expands it forms a cavitation bubble and vaporizes tissue. The tissue disruption is on the order of one micron. The bubble is composed of water and carbon dioxide and is easily dissipated by the normal physiology of the cornea. By placing these pulses in an appropriately spaced pattern and by utilizing a proper energy level; a cleavage plane held together by tiny tissue bridges is created. These microscopic tissue bridges are easily transected with a blunt instrument. This process can be applied to make an infinite number of incisions in the cornea.

Currently, the iFS 150 kHz femtosecond laser is approved to create the following: 1) a corneal flap for LASIK surgery, 2) the initial lamellar resection of the cornea for lamellar or penetrating keratoplasty, 3) corneal donor procurement, 4) the creation of tunnels for the placement of corneal ring segments, 5) the creation of arcuate cuts/incisions, penetrating and or stromal and 6) clear corneal incisions. The device, when modified, is capable of performing a capsulorrhexis (off label).⁶

Programming an Arcuate Incision

The key elements in programming arcuate incisions include the following parameters: diameter, arc length, depth, and placement with regard to the steep axis. Additionally, proper energy levels are needed along with the correct spacing of the photodisruptive laser pulses. The diameter usually ranges somewhere between 6.5 and 7.25 mm. For those patients who have had prior penetrating keratoplasty, surgeons usually place the incisions central to the graft host junction. The arc length is the number of degrees that the excision extends in circumferential fashion, obviously, the longer the arc length, the greater the effect in reducing the corneal steepening. In order for incisions to be effective, they have to reach a significant depth. The traditional concept is that the incisions need to be 90 % of the pachymetry measurement at the site of the incision. Balanced against this deep placement must be the concern to avoid perforation into the anterior chamber. The iFS manufacturer currently recommends that the surgeon leave at least 125 microns of intact posterior cornea during the creation of these incisions.

The placement of the incisions is determined by the steep axis of the astigmatism. The arc is centered over the steep axis as either a single incision or two incisions which are separated by approximately 180 degrees. They do not have to be orthogonal. They can also be of different arc lengths. The surgeon can be guided by the refraction or the topography or some combination of the two. The incisions cannot be placed at two different diameters unless it is done in a staged fashion. Because these incisions are linear and take up such a small amount of area in the cornea, high energy levels can be utilized with very tight spacing of the spot and layers of the cut. Typically, the spot/layer separation is three microns between the pulses and the increasingly anterior layers. Energy levels are usually set at 0.2 microjoules below max energy. This allows for a powerful photodisruptive pulse to literally give you the 'most bang for your buck.' Even with very tight spot/layer separation, these incisions are performed very quickly. They occur one at a time, once the foot pedal is depressed, and the whole process takes less than 10 seconds.

Finally, because the laser can be precisely focused, it can be utilized in a way that a blade is incapable of reproducing. The laser can be programmed to perform two different types of incisions. The first type is known as an intrastromal incision. In the intrastromal variety, the laser is focused and the incision begins anterior to Descemet's membrane and is completed before it reaches Bowman's. In other words, the entire cut is within the stroma and Bowman's membrane and the epithelium are never violated. The second type of incision is referred to as a penetrating incision. In the penetrating version of the incision, the cut begins just like the intrastromal cut but it is carried up through Bowman's and the epithelium and ends up in the glass cone. This is more similar to the traditional bladed incision. In early analyses, the primary drawback of the intrastromal variety is that they appear to be less powerful

Figure 1: Pre-op Arcuate Incision Topography

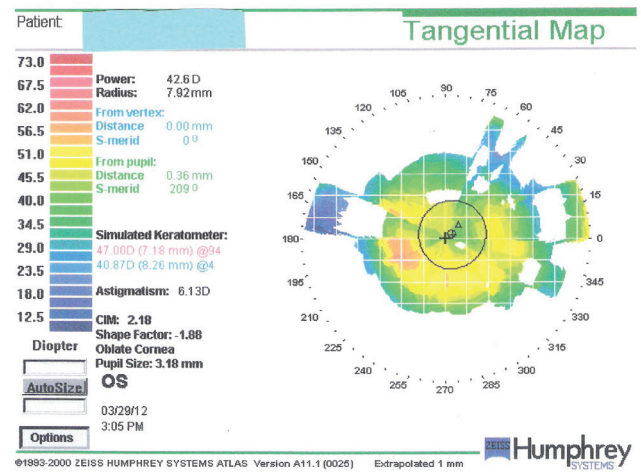
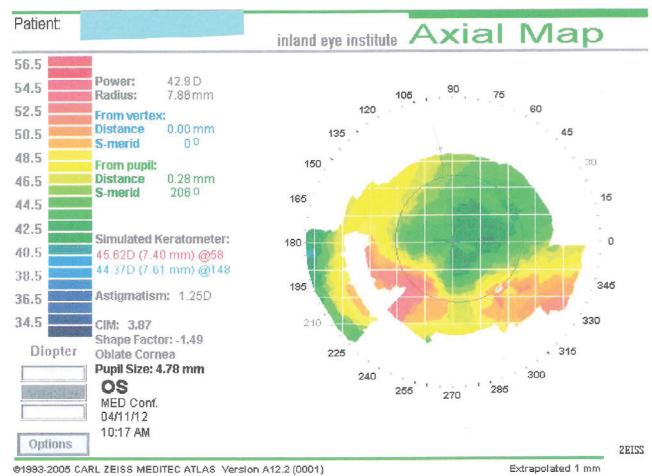


Figure 2: Post-op Arcuate Incision Topography



and therefore may be more appropriate in patients with lower levels of astigmatism.

Another advantage of the femtosecond laser is that the cut can be angulated very precisely with regards to the surface of the cornea. In a traditional bladed incision, the cuts are usually placed perpendicular to the corneal surface at 90 degrees. With the iFS, the cuts can be angulated with regards to the corneal surface anywhere from 30 to 150 degrees with great precision.

Nomogram Development

Most would readily agree that the laser is more precise than incisions created with the free hand. The procedure, however, is new and so there are many things to learn. The first peer reviewed article suggesting at a possible nomogram was a case study reported by Abbey in the British Journal of Ophthalmology.⁷ This early beginning was greatly advanced when Yoo published her more advanced nomogram for the treatment of naturally occurring astigmatism.⁸ Another critical peer-reviewed article was by Kumar and published in June of 2010.

The nomogram described in this article is for astigmatism following penetrating keratoplasty.⁹ In Yoo's nomogram for naturally occurring astigmatism, the primary variables are arc length and diameter with corneal depth staying constant at 90 % of pachymetry. There is also a slight modification based on the patient's age. In Kumar's nomogram, once again, the recommendation is for the depth to be set at 90 % of pachymetry. The incisions are placed 0.5 mm inside the graft-host junction and the primary variable is the arc length. The newest version of this type of surgery is the intrastromal incision and an early nomogram has been presented by Schallhorn, utilizing data from Optical Express, a European entity, with a significant database. These results and the accompanying nomogram were presented in the May 2012 edition of *Eye World* magazine.¹⁰ They confirm that the procedure does indeed have a 'coupling' effect. There is currently a significant body of work being done to investigate the effect of angulating the incisions. Future revisions are highly likely as more data accumulates and more is learned about the behavior of these incisions. Since the incisions are more precise than free-hand cuts, the likelihood of a successful, repeatable nomogram is very high.

Advantages Over Bladed Incisions

The most evident advantage of a laser created incision as opposed to a bladed incision is the repeatable level of precision. There are however, less obvious, but significant improvements. For example, the ability to create the incision entirely within the stroma, means that there is no break in the surface of the cornea. This should reduce the incidence of complications such as infection, pain and ocular surface complaints. Because the incisions can be angulated, there is the potential to decrease wound gape and epithelial plugging. Epithelial plugging leads to incomplete wound closure and variability in the healing process, it also may contribute to irregular astigmatism. Eliminating this complication of bladed incisions would represent a true advance. Finally, because these incisions are created with an approximately one micron photodisruptive process, the incisions are created with delicate tissue bridges that hold the two opposing pieces of corneal tissue together. This can be used to great advantage in the sense that they are titratable. In other words you can partially open the penetrating incisions, measure the effect and then open them further if there is under-correction. You can also place an intrastromal incision just below Bowman's membrane at the surface and then open it up if more effect is desired.

Case Presentation

I have now performed several cases with the iFS technology and wish to present one of the patients treated. The patient was a 35-year-old female who arrived at our clinic with unsatisfactory correction of her vision. Her

case history included legal blindness from keratoconus with bilateral count fingers vision and contact lens intolerance. She had undergone penetrating keratoplasty in each eye in the past. She was now several months out from suture removal in both eyes and presented with 7.0 D of refractive astigmatism in her left eye. Her refraction was +3.5 -7.00 D @010 degrees. Uncorrected distance visual acuity (UCDVA) was 20/80 and best corrected (BCDVA) was 20/30. She remained contact lens intolerant. We programmed 2 incisions of 70 degrees arc length each, centered at 100 and 280 degrees. The diameter of the cuts was 6.0 mm and located just inside the graft-host junction. The pachymetry at the incision sites was 580 and 635 respectively. Depth was set for 475 microns. Side cut angles were 90 degrees and the incisions came up through Bowman's membrane and the epithelium ending in the glass cone (penetrating). One week after receiving arcuate incisions, she had a refraction of +0.25-0.75 D @ 028 degrees, a dramatic reduction of almost 90%. A similar reduction is noted on her pre- and postoperative topographies (Figures 1 and 2). Her UCDVA went from 20/80 to 20/30 and BCDVA improved to 20/25. She was, of course, extremely happy.

Future Developments

The future of femtosecond created corneal incisions is quite promising. For the arcuate incision our most pressing problem is the development of a precise nomogram to help surgeons adopt the technique more easily and quickly. Data accumulation for this device is occurring globally. The generation of this data is critical to help design the most precise, accurate and safest incisions for the different classes of patients who will benefit. The primary groups of patients who will benefit are three-fold. First, patients with post-keratoplasty astigmatism that cannot be managed with spectacles or contact lenses. Second, patients who have such high levels of astigmatism that a combined approach with the excimer laser and the femtosecond laser may represent the optimal approach. Finally, cataract patients with significant astigmatism who would, in the past, have received a limbal relaxing incision but did not warrant a toric IOL. There may also be patients who might be managed with a toric IOL but choose instead to opt for the corneal incision.

Other areas of future development include further clarification of the use of the intrastromal incision. Which patients will benefit most from the intrastromal and who needs the penetrating type of arcuate incision? Also what angle relative to the corneal surface is best? Is the traditional 90 degree orientation best or is some different angle going to provide a benefit to our patients. The use of this technology in the other elements of the cataract procedure also remain to be optimized. There is plenty of work to do and the story remains far from complete. Stay tuned. ■

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