MANAGEMENT OF ASTIGMATISM AT THE TIME OF LENS-BASED SURGERY

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Introduction

When assessing recent changes in modern cataract and intraocular implant (IOL) surgery, arguably, the single most pressing challenge facing today's phacoemulsification (phaco) surgeon is the need to achieve predictable and accurate refractive outcomes. Surgeons and patients alike have come to largely measure the success of their surgery by the refractive outcome, and one of the leading causes for litigation in this field is the "refractive surprise."[1] In addition, refractive lens exchange has become an important component of the refractive surgeon's armamentarium.[2] As such, the fields of cataract and refractive surgery have merged to form an amalgam without distinct borders. Improved refractive results have come about by way of improvements in both surgical technique as well as advances in technology. Spherical results, for example, have become more predictable because of increased attention to biometry technique, as well as breakthrough technology such as partial coherence interferometry.[3]

No less important is the astigmatic component of the refractive equation. At one time during the evolution of small incision surgery, it was the surgeon's goal to not induce astigmatism.[4] Today, in order to fully embrace the concept of "refractive cataract surgery," one must be able to address and reduce significant preexisting cylinder.

Patient Selection and Considerations

Estimates of the incidence of significant, naturally occurring astigmatism vary widely from 7.5% to 75%.[5] It has been reported that 3% to 15% of eyes may have 2 or more diopters

(D) of astigmatism.[6] In our clinical experience, 10% of patients presenting for surgery have greater than 2.0 diopters, 20% have between 1-2 diopters, and 70% have less than one diopter of preexisting cylinder. In light of recent experience gained in the field of refractive surgery, many surgeons would agree that astigmatism of greater than 0.5 D will lead to symptoms of ghosting and shadows. Although the older cataract patient may be more tolerant of cylinder, the ambitious refractive cataract surgeon should likely approach an implant patient with the same high goals that he or she might with a younger keratorefractive candidate. Indeed, successful cataract practices are now aiming for both spherical and astigmatic outcomes of +/ – 0.5 D.[7]

When considering astigmatism correction, one must take into account the location of the cylinder, age of the patient, and status of the fellow eye. Since most patients will drift against-the-rule (ATR) over their lifetime—for example, toward plus cylinder at 180 degrees— some surgeons advocate a less aggressive approach to the reduction of with-the-rule (WTR) cylinder. Authors have also suggested that residual WTR astigmatism may favor better uncorrected distance acuity given that most visual stimuli are of a vertical nature.[8] Similarly, it has been contended that ATR cylinder may improve uncorrected near vision.[9] The tenet that residual (myopic) WTR astigmatism is a desirable goal in order to enlarge the conoid of Sturm and hence optimize depth perception has, however, recently been called into question.[10] Currently, with recent refinements in surgical technique, a spherical goal may be most desirable for the majority of patients undergoing implant surgery.

Treatment Options

The first decision faced by the surgeon is whether to address preexisting astigmatism at the time of cataract and IOL surgery, or to defer and treat the cylinder separately. One could reasonably argue that for optimal accuracy, sufficient time for wound healing should be allotted and a stable refraction ought to be documented prior to astigmatic correction. This consideration had been more germane with the use of rigid implants and larger incisions. Currently, most surgeons are utilizing foldable IOLs and studies have well documented the nearly neutral astigmatic effect that these incisions bear when kept at or near 3.0mm, as well as their early refractive stability.[11,12,13] As such, many surgeons feel that concomitant treatment of preexisting astigmatism is a more efficient approach and is favored since it will likely save the patient from having to undergo a second procedure.

The next major decision is whether to treat the astigmatism through a lenticular approach, that is, to employ a toric IOL, or to utilize a keratorefractive technique. From a theoretical perspective, it is hard to argue against the use of a toric implant and their effectiveness has been widely reported.[14] This option has the potential to avoid induced irregular astigmatism from corneal manipulation, and provides the option of reversibility. In the United States the first toric IOL to have received FDA approval was the single-piece plate haptic design manufactured by STAAR Surgical (Fig. 1A). This silicone implant is available in two toric powers of 2.0 and 3.5 D. Propitious outcomes have been obtained with this device even with minimal experience by community-based surgeons.[15] For surgeons using this particular toric implant, lens rotation is a recognized problem; Sun and coworkers reported a need to return to the operating room for repositioning in 9.2% of cases .[14] Ruhswurm further reported axis rotation of at least 25 degrees in 18.9% in their series.[16] According to Euclidean geometry, an axis deviation of 5, 10 or 15 degrees will result in 17%, 33% and 50% reduction, respectively, in effect.[5] Optimal timing of the IOL repositioning would appear to be between one and two weeks following implantation as capsular fibrosis is underway, and may serve to permanently fixate the toric device in the proper meridian. Some surgeons have avoided this particular implant because of its plate haptic design and for the first-generation silicone elastomer from which it is comprised. More recently, FDA has approved the single-piece AcrySof toric IOL (Fig. 1B). This hydrophobic acrylic device is available in three toric powers of 1.5, 2.25 and 3.0 diopters which are capable of correcting 1.03, 1.55 and 2.06 diopters respectively at the corneal plane. These newer designs offer better rotational stability and explains, in large part, their increased use and popularity.[17,18,19,20] The economic value of reducing spectacle dependence through the use of a toric IOL, as compared to a standard monofocal implant, has been demonstrated by a short and long-term analytic model.[21]

The notion of reducing astigmatism at the time of cataract surgery by way of adjunctive keratorefractive surgery, specifically astigmatic keratotomy, was first proposed by Robert Osher and dates back to the mid-1980's.[22,23,24] Our personal experience with this technique began in 1988 and was based upon the principles of astigmatic keratotomy as taught by Dr. Spencer Thornton.[29] A transition to (intra)-limbal relaxing incisions (LRIs) took place in 1994, spurred by the experience of Dr. Dave Dillman and his improved results using the peripheral limbal technique of Dr. Stephen Hollis, an early advocate and innovator in the use of LRIs. With refinement of the Hollis nomogram, we found this more peripheral approach to astigmatic keratotomy to be considerably more forgiving than conventional astigmatic keratotomy performed at a smaller (i.e.,7.0 mm) optical zone.[25,26,27]

Another viable option to decrease astigmatism is to manipulate the cataract incision by first placing it upon the steep corneal meridian, and then by varying its size and design, affect a desired amount of wound flattening, and hence a decrease in cylinder.[28] Specifically, one can increase or decrease the amount of wound flattening by increasing or decreasing the size of the incision. Similarly, wound flattening may be enhanced by moving closer to the visual axis, or by creating a more circum-parallel incision to the limbus. Also, a perpendicular component, or groove, may be added to the incision to further increase wound flattening and "against-the-wound" astigmatic drift.[29] This approach, however, presents logistical challenges including movement around the surgical table, often producing awkward hand positions. In addition, varying surgical instrumentation may be needed along with a dynamic mindset, and this approach is only effective for relatively small degrees of preexisting cylinder. For these reasons, this technique has largely been supplanted by the use of a consistent and essentially neutral phaco incision, typically located temporally for astigmatic stability, and then adding supplemental relaxing incisions (LRI's). A recent study by Kaufmann, et al. concluded that LRIs in combination with a temporal clear corneal incision provided superior astigmatic outcomes to that of "on-axis" surgery.[30]

Several other options to reduce astigmatism deserve mention. Lever and Dahan have suggested the novel use of opposing clear corneal incisions to address preexisting cylinder.[31] In this technique, a second opposite penetrating clear corneal incision is placed over the steep meridian 180 degrees away from the main incision. This approach is technically simple and requires no additional instrumentation; however, a second substantial penetrating incision is now present, possibly increasing the risk of wound leak or even infection. In addition, single-plane beveled incisions are known not to be as effective, for a given arc length, at flattening the cornea as are more conventional perpendicular relaxing incisions.[32,29]

Yet another important and increasingly popular alternative is that of "Bioptics," a laser technique originally described to address residual refractive error following implantation of myopic phakic IOL's, but one that is just as useful in the setting of pseudophakic lens surgery.[33,34,35] In this approach, one exploits the advanced technology and exquisite accuracy of the excimer laser. In a staged manner, one may treat both residual spherical as well as astigmatic error following implant surgery. In Zaldivar's original description, a LASIK flap was created prior to the phakic implant procedure, and then as necessary, the flap was lifted and residual refractive error was corrected with the laser. Today, most surgeons prefer to perform both the flap and laser ablation concurrently following cataract surgery, as needed, thus reducing the number of unnecessary flaps that would otherwise be created. It has been our experience that LASIK may be performed safely following IOL surgery at six weeks, perhaps earlier. Of course, wound stability and healing must be confirmed, along with a stable refractive error. It might further be argued that photo-refractive keratectomy (PRK) is particularly well suited for this older pseudophakic population that typically has only modest amounts of residual refractive error, and within whom a higher incidence of dry eye and corneal surface problems exist. Custom wavefront-guided ablation may also be considered since the pseudophakic eye no longer has a dynamic lens component, though obtaining a reliable wavefront aberrometry reading may be difficult with some lens designs, i.e. refractive multifocal optics.[36] For most refractive cataract surgeons, Bioptics has become an integral part of the preoperative discussion with the patient, and in our experience its use is required in approximately 10 percent of cases, depending upon the magnitude of the patient's preop refractive error. Although of limited popularity, conductive keratoplasty used in an off-label fashion has also been described as a means by which residual hyperopia and hyperopic astigmatism may be effectively reduced following cataract surgery.[37]

Finally, residual postop astigmatism, similar to residual spherical error, may be addressed by the implantation into the ciliary sulcus of a secondary low power IOL. Such implants are now available internationally and may be available in the U.S. in the future.[38]

Limbal Relaxing Incisions

The first description of the astigmatic effect of non-penetrating incisions placed near the limbus dates back to 1898 and is credited to the Dutch ophthalmologist L.J. Lans.[39] As noted, LRI's have become the most popular technique employed today to reduce pre-existing astigmatism at the time of implant surgery, though the use of toric implants is currently increasing.[40] Although our preference is to utilize a temporal single-plane clear corneal phaco incision, one may utilize LRI's with any type of cataract incision as long as the astigmatic effect is known and factored into the surgical plan. As previously noted, LRI's offer several advantages over astigmatic incisions placed within the cornea, at smaller optical zones. These would include less chance of causing a shift in the resultant cylinder axis. This presumably is due to a diminishing need for exact centration over the steep meridian with a more peripheral approach. There is also less of a tendency to cause irregular corneal flattening, and hence less chance of inducing irregular astigmatism. Technically, LRI's are easier to perform and more forgiving than shorter and more central corneal astigmatic incisions, and patients generally report less discomfort. Another important advantage gained by moving out to the limbus involves the "coupling ratio" which describes the amount of flattening that occurs in the incised meridian relative to the amount of steepening that results 90 degrees away. It has been our experience that paired LRI's (when kept at or under 90 degrees of arc length) exhibit a very consistent 1:1 ratio, and therefore elicit little change in spheroequivalent, obviating the need to make any change in implant power.

Admittedly, these more peripheral incisions are less powerful, but are still capable of correcting up to 3-4 diopters of astigmatism in the cataract-age population. One must keep in mind that the goal is to reduce the patient's cylinder, without overcorrecting or shifting the resultant axis. To achieve a given amount of correction, these peripheral intralimbal incisions must be longer in total arc length than more centrally placed corneal astigmatic incisions; however, unlike longer radial keratotomy incisions, they appear to be stable with regard to refractive effect, and show little sign of inducing problems such as dry eye syndrome or other pejorative effects from corneal denervation.[27] Their stability may be due to the proximity of well-vascularized limbal tissue as well as the differing histologic tissue pattern that exists at this intralimbal location as compared to the central cornea. There are, of course, potential complications with any surgical technique and these are addressed below.

The Plan:

Perhaps the most challenging aspect of astigmatism surgery involves the determination of the quantity and exact location of the cylinder that is to be corrected, and thereby formulating a surgical plan. Traditionally, most authors have recommended correcting astigmatism based upon keratometry measurements only, assuming any other refractive components would be lenticular in nature and eliminated by cataract extraction. I have found, however, that it is helpful to study as many preoperative parameters as is possible. Unfortunately, such preoperative measurements—keratometry, refraction, corneal topography and newer modalities such as the Pentacam—do not always correlate. Lenticular astigmatism may account for some of this disparity, particularly in cases where there is a wide variance between refraction and corneal measurements; however, some discrepancies are likely due to the inherent shortcomings of traditional measurements of astigmatism. Standard keratometry, for example, measures only two points in each meridian at a single optical zone of approximately 3 mm.

When confounding measurements do arise, one may compromise and average the disparate readings; for example, if refraction shows 2 D of astigmatism and keratometry reveals only 1 D, it would be reasonable to correct for 1.25 to 1.5 D, especially if the cataract were not too dense and the refraction was reasonably reliable, or if it were based upon a historical refraction obtained prior to cataract formation. Alternatively, if preoperative calculations vary widely, one may defer placing the relaxing incisions until a stable refraction post-implantation is obtained, and then correct, as needed, any remaining astigmatism; LRI's may be safely performed in the office in an appropriate treatment-room setting. Corneal topography is increasingly becoming the overall guiding measurement upon which the surgical plan is based. Topography is also helpful in detecting subtle corneal pathology such as keratoconus fruste which would likely negate the use of LRI's, or subtle irregular astigmatism such as that caused by epithelial basement membrane dystrophy.

Nomograms:

Once the amount of astigmatism to be corrected has been determined, a nomogram must be consulted to determine the appropriate arc length of the incisions. A number of popular nomograms are currently available.[41] As mentioned, our nomogram of choice originated from the work of Dr. Stephen Hollis and incorporates concepts taught by Spencer Thornton, M.D., particularly his age modifiers (Table 1).[29] After accounting for surgically induced cylinder from one's phaco and IOL incision, and assessing as many preoperative measurements as possible to determine the amount and location of the cylinder to be corrected, one consults the appropriate section of the nomogram. With-the-rule astigmatism is considered to be from 45-135 degrees, and against-the-rule from 0-44 and 136-180 degrees, as the arc length of the incisions differs somewhat based upon this distinction. One then aligns the patient's age with the amount of preoperative cylinder to be corrected and finds the suggested arc length that the incisions should subtend.

An empiric blade depth setting is commonly used when performing LRIs, typically at 600 microns. This would seem to be a reasonable practice when treating cataract patients; however, in the setting of refractive lens exchange surgery or when employing presbyopia-correcting IOLs—where ultimate precision is required—it is our preference to perform peripheral pachymetry and utilize adjusted blade depth settings. Pachymetry may be performed either preoperatively or at the time of surgery. Readings are taken over the entire arc length of the intended incision, and an adjustable micrometer diamond blade is then set to approximately 90% of the thinnest reading obtained. Refinements to the blade depth setting as well as nomogram adjustments may be necessary depending upon individual surgeon technique, the instruments used and, in particular, the style of the blade. It is highly suggested that a diamond knife specifically designed for LRI's be used, as the quality and precision of the blade will greatly influence one's results. It should also be noted that in eyes that have previously undergone radial keratotomy, the length of the incisions should be reduced by approximately 50%, and in eyes that have undergone "significant" prior keratotomy surgery, it may be best to avoid additional incisional surgery and employ a toric IOL or laser technology instead.

Paired incisions are preferred to optimize symmetric corneal flattening and are expressed in degrees of arc rather than chord length. This is done in order to diminish over and under corrections for unusually small or large corneas, since corneal diameter may significantly impact the relative length of the arcuate incision and its resultant effect (Fig. 2). Incisions are usually symmetric and orthogonal unless reliable topography strongly suggests asymmetric astigmatism. Irregular astigmatism, as seen in forms of keratoconus, may lead to unpredictable results when treated with relaxing incisions and is likely better dealt with using other modalities.

The emerging field of Femto-Second Laser-Assisted Cataract Surgery will surely prove to be a revolutionary advance in many ways, not least of which will be in the “automation” of our astigmatic relaxing incisions. Table II in this chapter also provides our adjusted LRI Nomogram for use with the femto-second laser, with incision placement at the 9.0 mm optical zone (OZ). Current generation femto lasers cannot always image the most peripheral intra-limbal tissue well, particularly if there is a significant Arcus Senilis present. As such, most laser-assisted incisions are placed at approximately the 9.0 mm OZ. If the laser relaxing incisions are placed at a larger zone, then the nomogram may need to be adjusted for slightly longer arcuate lengths, and opposite is true if a smaller OZ is utilized. Also, if “sub-Bowman’s” membrane, or intra-stromal incisions are created without penetration through the corneal epithelium, less effect will be seen, at least until the epithelium is later opened and the incisions are spread apart. This latter technique can be a helpful way in which the effect of laser LRI’s may be titrated in the early post-op period.

Surgical Technique:

Some surgeons prefer to perform LRI’s at the conclusion of surgery in the event that a complication occurs necessitating a modification to the phaco incision. For routine cases, however, our preference is to place these relaxing incisions at the outset of surgery in order to minimize epithelial disruption. The one exception to this rule occurs in the case where the phaco incision will intersect or be superimposed upon an LRI of greater than 40 degrees of arc length. For a surgeon utilizing a temporal clear corneal phaco incision, this would occur when correcting a moderately high amount of ATR astigmatism. In such a case, if the temporal relaxing incision were to be extended to its full arc length at the start of surgery, significant gaping and edema may result secondary to intraoperative wound manipulation. To avoid this potential problem, the temporal incision is first made by creating a two-plane, deeply "grooved" phaco incision (depth being based upon pachymetry, as noted above, and arc length determined by the implant that is being used). Later, just prior to lens implantation with a firm viscoelastic-filled eye, the partial relaxing incision is extended to its full arc length as dictated by the nomogram. The keratome entry when fashioning this combined, or superimposed LRI and phaco tunnel, is best achieved by pressing the bottom surface of the keratome blade downward upon the outer or posterior edge of the partial LRI. The keratome is then advanced into the LRI at an iris-parallel plane. This angulation will promote a dissection that takes place at mid-stromal depth which will help assure adequate tunnel length and a self-sealing closure.

Proper centration of the incisions over the steep corneal meridian is of utmost importance. Increasing evidence supports the notion that significant cyclotorsion may occur when assuming a supine position.[42] As previously noted, an axis deviation of only 15 degrees may result in a 50% reduction of surgical effect.[5] This reduction in effect holds true for both relaxing incisions and toric IOLs. For this reason, an orientation mark(s) is placed at the patient's limbus while in an upright position. This is particularly important when employing injection anesthesia wherein unpredictable ocular rotation may occur. I personally prefer placing multiple radial marks using a dedicated marking instrument to assure proper orientation (Fig. 3A&B)**.** Some surgeons prefer to place their orientation mark with the patient seated at the slit-lamp, thereby achieving better control and higher magnification. Newer digital photographic instruments are being designed to further improve and facilitate this critical orientation step.[43] (Fig. 4 A,B&C)

An additional measure that may be employed to help center the relaxing incisions is to identify the steep meridian (plus cylinder axis) intraoperatively using some form of keratoscopy. The steep meridian over which the incisions are to be placed corresponds to the shorter axis of the reflected corneal mire. A simple hand-held device such as the Maloney (Storz, Katena) or Nichamin (Mastel Precision) keratoscope works well, or a more robust and well-defined mire may be obtained through a microscope-mounted instrument such as the Mastel Ring of Light (Mastel Precision). Recently, intraoperative wavefront aberrometry has become commercially available which may further help to guide both the positioning and length of the relaxing incisions, allowing for real-time refinements during the actual surgical procedure. This device is also used to aid in the meridional positioning of toric IOLs, and can be used to affirm proper spherical power selection of an implanted IOL.[44,45] (Fig. 5)

One then utilizes a Mendez Ring or similar degree gauge which, when aligned with the limbal orientation mark(s), yields the desired meridian over which the incisions are to be centered. (Fig. 6) The LRI should be placed at the most peripheral extent of clear corneal tissue, just inside of the true surgical limbus. This holds true irrespective of the presence of pannus or blood vessels. If bleeding occurs, it may be ignored and will cease spontaneously. One must avoid placing the incisions further out at the true surgical limbus in that a significant reduction of effect will likely occur due to both increased tissue thickness and a variation in tissue composition; these incisions are, therefore, really ***intra***-limbal in nature. In creating the incision, it is important to hold the knife perpendicular to the corneal surface in order to achieve consistent depth and effect. Good hand and wrist support is important, and the blade ought to be held as if one were throwing a dart such that the instrument may be rotated between thumb and index finger as it is being advanced, thus leading to smooth arcuate incisions. Typically, the right hand is used to create incisions on the right side of the globe, and the left hand for incisions on the left side. In most cases it is more efficient to pull the blade toward oneself, as opposed to pushing it away. A lightly moistened corneal surface will help to prevent epithelial disruption, but may mask an unintentional perforation.

The extent of arc to be incised may be demarcated in several different ways. Various press-on markers are available, such as those made by Rhein Medical (Dell-Nichamin Marker). (Fig. 7) Our currently preferred method uses an engraved ring that is centered over the steep meridian and its surface markings delineate the arc length to be incised.(Fig. 8) Ink marks may be placed on the corneal surface, according to this ring, showing the start and end points of the relaxing incision.(Fig. 9A-G) Adequate exposure of the peri-limbal region is important to allow for perpendicularity between the corneal surface and the diamond blade. As such, a locking lid speculum is helpful, and is further facilitated through the use of a modified Fine-Thornton fixation ring (The Nichamin Fixation Ring and Gauge, available from Mastel Precision, Storz, Rhein Medical) that aids in moving the globe into an optimal position for creation of the relaxing incision. This fixation ring also assists in verifying the arc length of the incision by virtue of 10 degree incremental radial marks on the surface of the ring. (Fig. 10)

As noted, in the setting of concomitant cataract surgery, an empiric blade depth setting of 600 microns has been traditionally employed. More recently, adjusted blade depth settings based upon pachymetry are favored for optimal precision. Various knives have been designed specifically for this application, ranging from disposable steel blades to exquisite gemstone diamond knives. Synthetic diamond materials are also available and vary in quality from nearly perfect single crystal materials that rival natural occurring gemstones, but are often yellow in color, to less expensive polycrystal-fused materials that are typically less durable and whose edges are laser cut which may yield less precise cutting characteristics. Some of these less expensive designs are intended for limited reuse. Our preference, once again, is for high-quality diamond blade technology which incorporates a single small and arced footplate for enhanced visualization at the limbus. Two such models, one with a pre-set depth of 600 microns and the other with an adjustable micrometer handle, are made by Mastel Precision (Fig. 11A&B). Similar designs are available from Rhein Medical, Storz, ASICO and other manufacturers.

Increased Comfort for Patient and Doctor

Interestingly, one of the most common patient complaints following contemporary phaco surgery is that of a foreign body sensation. Intralimbal relaxing incisions, as compared to more central corneal incisions (smaller optical zones), definitely improve patient comfort. A lightly moistened corneal surface will help to prevent epithelial disruption, but may mask an unintentional perforation—a very rare event with proper technique and instrumentation. If epithelial drag is seen to occur during surgery, it is best to stop, exit the incision, then re-enter the incision and continue advancing the blade in gradual increments thus avoiding stripping of a large sheet of epithelium.

With the addition of a postop topical NSAID, patient comfort is quite acceptable, and topical lubricants are further used as needed. Upon examination, these incisions appear to heal quickly and are nearly unidentifiable within several days. The astigmatic effect is generally stable within days to weeks, depending upon the arcuate length of the incisions.

Complications:

As discussed, LRI's are proving to be a safer and more forgiving approach to managing astigmatism as compared to more central corneal incisions. Nonetheless, as with any surgical technique, potential complications exist, and several are listed in Table III. Of these, the most likely to be encountered is the placement of incisions upon the wrong axis. When this occurs, it typically takes the form of a 90 degree error with positioning upon the opposite, flat meridian. This, of course, results in an increase and likely doubling of the patient's preexisting cylinder. Compulsive attention is required in this regard. The surgeon ought to consider employing safety checks to prevent this frustrating complication from occurring such as having a written plan that is brought into the OR and is kept visible and properly oriented. Incisions are always placed upon the plus (+) cylinder axis, and opposite to the minus (-) cylinder axis.

Although very rare when utilizing a blade depth determined by pachymetry measurements, or an empiric setting of 600 microns, corneal perforation is possible. This may be due to improper setting of the blade depth, or as a result of a defect in the micrometer mechanism. This latter problem may arise after repeated autoclaving and many sterilization runs. Periodic inspection and calibration is therefore warranted, even with preset single-depth knives. When encountered, unlike radial microperforations, these circumferential perforations will rarely self-seal and will likely require placement of temporary sutures.

Enhancement Techniques:

As mentioned, LRI's lend themselves well to in office "touch-ups." Although some surgeons will place or extend incisions at the slit-lamp, it is our preference to use a small operating microscope and to perform the procedure within a dedicated treatment room. It has been our experience that this provides better surgical control as well as patient comfort. In the case of residual astigmatism without prior incisional correction, one uses the same technique and nomogram as described above.

In the case of an under-correction following previous LRI's, one should inspect the length and positioning of the incisions. As indicated, placement of the incisions too far out into the true surgical limbus and beyond clear cornea will often lead to under-correction. If the arc length and location appear to be adequate, one ought to suspect that the patient has an unusually thick cornea. This occurs most frequently in hyperopic eyes. In this situation, pachymetry should be performed and the incisions may be re-deepened or extended. When faced with an overcorrection, one should resist the temptation to place additional incisions in a new meridian. This can lead to an unstable cornea with unpredictable refractive results, or worse, induce irregular astigmatism. Rather, one should consider non-incisional modalities such as PRK or

LASIK. We also have had good results in this setting using conductive keratoplasty, off-label, particularly if the overcorrection involves hyperopic astigmatism.[36] As previously mentioned, secondary low power piggyback IOLs are also an option, especially if further corneal surgery is contraindicated.[38]

To correct unusually high levels of astigmatism, LRI's may be used in conjunction with a toric IOL or excimer laser surgery (bioptics). In several rare cases we have combined all three modalities and safely corrected up to 9 D of preexisting astigmatism!

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Table I

The "NAPA" Nomogram

Nichamin Age & Pachymetry-Adjusted Intralimbal Arcuate Astigmatic Nomogram

Louis D. "Skip" Nichamin, M.D. ~ The Laurel Eye Clinic, Brookville, PA

WITH-THE-RULE

(Steep Axis 45°-135°)

PREOP CYLINDER *(Diopters)*	Paired Incisions in Degrees of Arc 20-30 yo	31-40 yo	41-50 yo	51-60 yo	61 -70 yo	71-80 yo
0.75	40	35	35	30	30	
1.00	45	40	40	35	35	30
1.25	55	50	45	40	35	35
1.50	60	55	50	45	40	40
1.75	65	60	55	50	45	45
2.00	70	65	60	55	50	45
2.25	75	70	65	60	55	50
2.50	80	75	70	65	60	55
2.75	85	80	75	70	65	60
3.00	90	90	85	80	70	65

AGAINST-THE-RULE

(Steep Axis 0-44°/136-180°)

PREOP CYLINDER *(Diopters)*	Paired Incisions in Degrees of Arc 20-30 yo	31-40 yo	41-50 yo	51-60 yo	61-70 yo	71-80 yo
0.75	45	40	40	35	35	30
1.00	50	45	45	40	40	35
1.25	55	55	50	45	40	35
1.50	60	60	55	50	45	40
1.75	65	65	60	55	50	45
2.00	70	70	65	60	55	50
2.25	75	75	70	65	60	55
2.50	80	80	75	70	65	60
2.75	85	85	80	75	70	65
3.00	90	90	85	80	75	70

Blade depth setting is at 90% of the thinnest pachymetry

Table II

Nichamin Femto – LRI Nomogram

Louis D. "Skip" Nichamin, M.D. ~ The Laurel Eye Clinic, Brookville, PA

WITH-THE-RULE

(Steep Axis 45°-135°)

PREOP CYLINDER	Paired Incisions in Degrees of Arc					
(Diopters)	20-30 yo	31-40 yo	41-50 yo	51-60 yo	61 -70 yo	71-80 yo
0.75	39	34	30	27	25	23
1.00	44	39	35	33	31	28
1.25	50	45	41	38	35	33
1.50	55	51	47	43	40	37
1.75	60	56	52	48	44	41
2.00	65	60	56	52	48	45
2.25	70	64	60	56	52	48
2.50	75	69	64	60	56	52
2.75	80	73	68	64	60	56
3.00	85	78	73	69	65	60

AGAINST-THE-RULE

(Steep Axis 0-44°/136-180°)

PREOP CYLINDER	Paired Incisions in Degrees of Arc					
(Diopters)	20-30 yo	31-40 yo	41-50 yo	51-60 yo	61-70 yo	71-80 yo
0.75	40	35	31	28	26	25
1.00	46	41	38	36	33	31
1.25	52	48	45	41	37	35
1.50	58	54	50	46	42	39
1.75	63	59	55	51	47	43
2.00	67	63	59	55	51	47
2.25	71	67	63	59	55	51
2.50	75	71	67	63	59	55
2.75	80	75	71	67	63	59
3.00	85	79	75	71	67	63

Approximate 9.0 mm OZ 90% Depth

Table III

Potential Problems

- Infection
- Weakening of the globe
- Perforation
- Decreased corneal sensation
- Induced irregular astigmatism
- Misalignment/axis shift
- Wound gape and discomfort
- Operating upon the wrong (opposite) axis!

<u>Legends for figures:</u>

Figure 1A STAAR Surgical Toric IOL

Figure 1B Alcon AcrySof Toric IOL

Figure 2 Nomogram design. Note relative disparity in incision length between a large and small corneal diameter if measured in millimeters. Degrees of arc lend consistency irrespective of corneal size

Figure 3A Corneal marker with bubble level for placement of meridional orientation marks (Mastel Precision)

Figure 3B Upright patient receiving corneal orientation marks prior to surgery

Figure 4A,B&C SMI digital photographic reference and orientation technology

Figure 5 WaveTec ORange Intraoperative Wavefront Aberrometer

Figure 6 Gimbel-Mendez Ring used to locate the steep corneal meridian based upon preplaced orientation marks (Mastel Precision)

Figure 7 Dell-Nichamin Marker may be used to mark both the central steep meridian and intended arc length of the incisions (Rhein Medical)

Figure 8 Jarvi-Olson Arcuate Ring Guide used to mark the arc length of the relaxing incisions (Mastel Precision)

Figure 9A 90 degree reference mark of Mendez Gauge aligned with 6:00 limbal orientation ink mark

Figure 9B Additional mark placed at the steep 15 degree meridian over which relaxing incisions will be centered

Figure 9C Two-ray corneal marker is used in conjunction with Jarvi-Olson Ring to delineate the extent of arc to be incised

Figure 9D Nichamin Fixation Ring placed outside of limbus to optimally position the globe. Note black hash mark on ring is aligned with the steep meridian and the 10 degree radial marks may be further used to delineate the arc length of the incision

Figure 9E Nasal LRI started

Figure 9F Nasal LRI completed

Figure 9G Keratome placed through temporal LRI to compete the phaco incision

Figure 10 Nichamin-Modified Fine Thornton Fixation Ring (Mastel Precision)

Figure 11A LRI diamond blade with preset depth of 600 microns (Mastel Precision)

Figure 11B LRI diamond blade with adjustable depth micrometer (Mastel Precision)

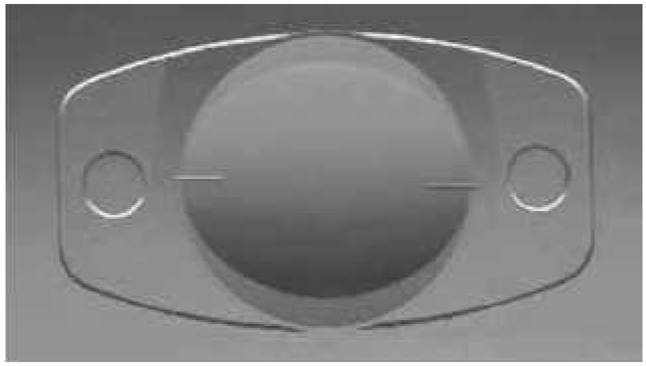


Fig. 1A

Figure 1B

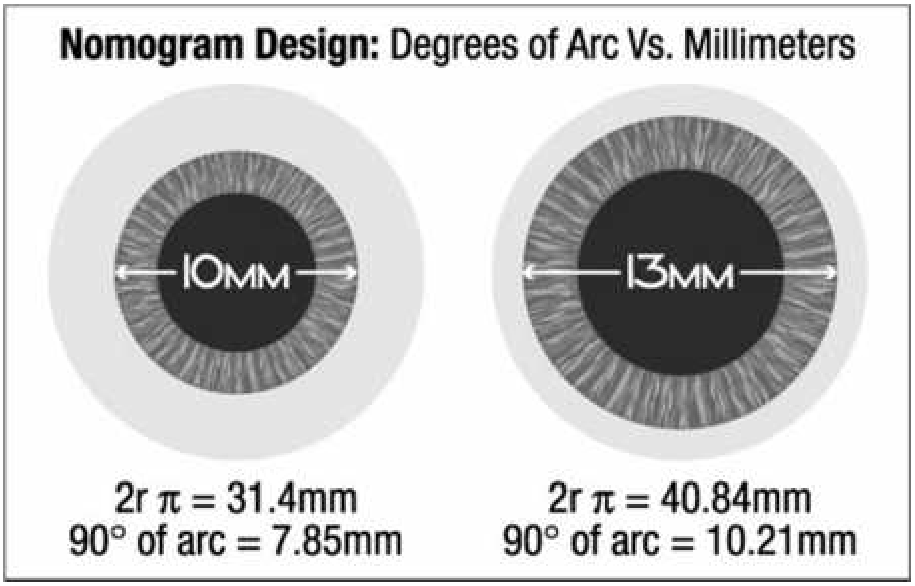
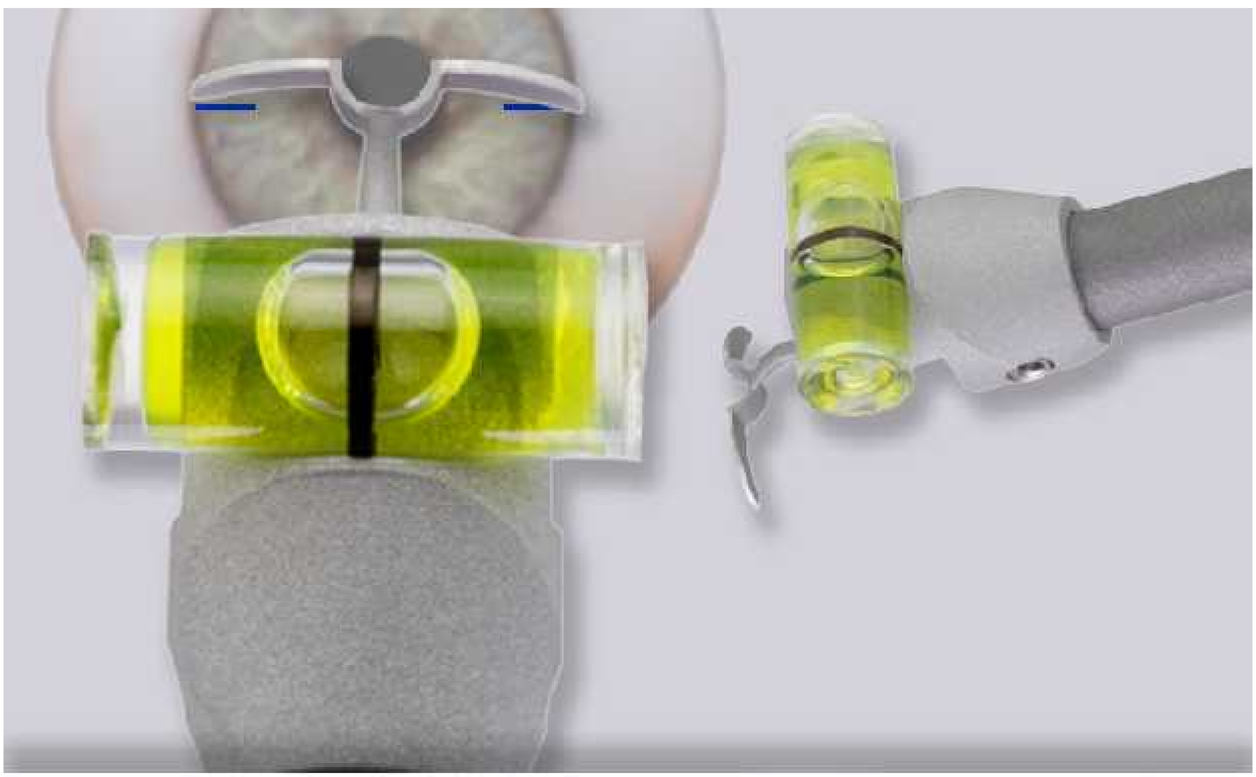


Figure 2



Bakewell Bubble Level for Orientation MASTEL

Figure 3A

Figure 3B

Figure 4A

Figure 4B

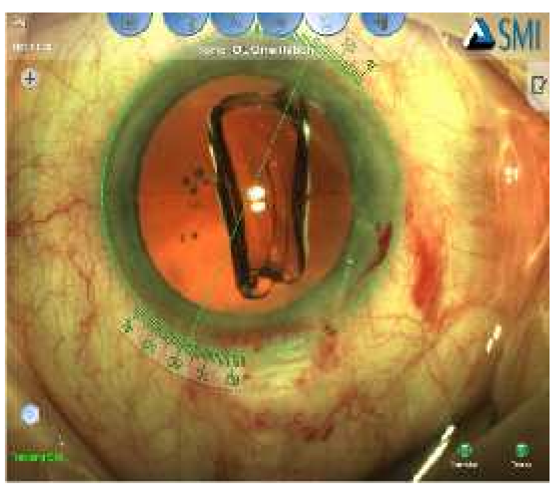


Figure 4C

Figure 5

Figure 6

Figure 7

Figure 8

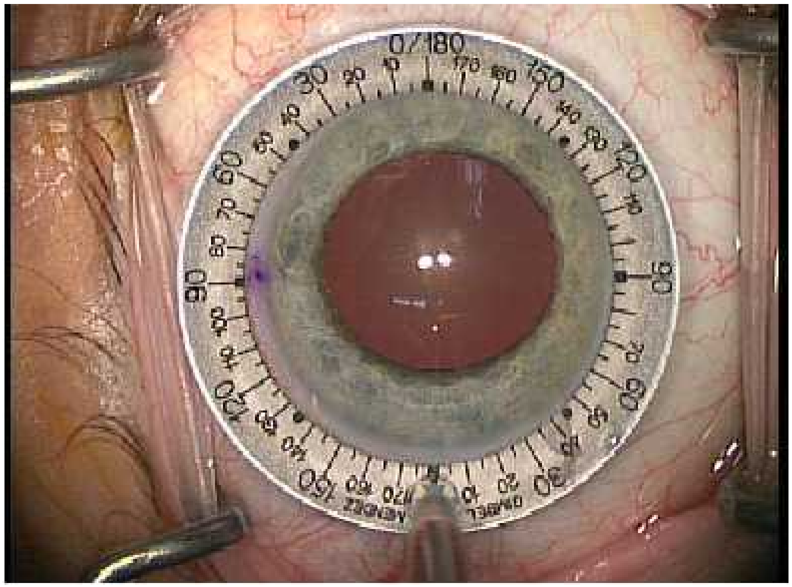


Figure 9A

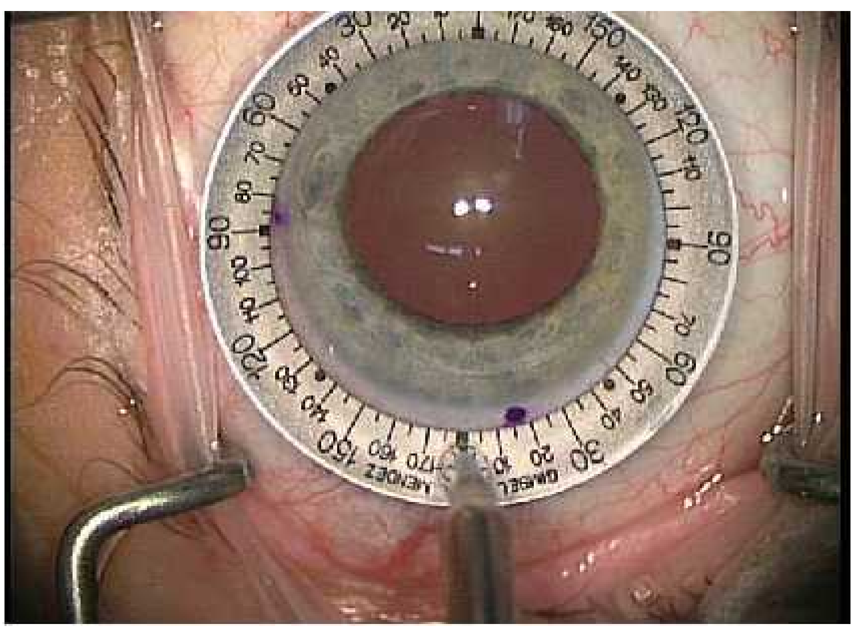


Figure 9B

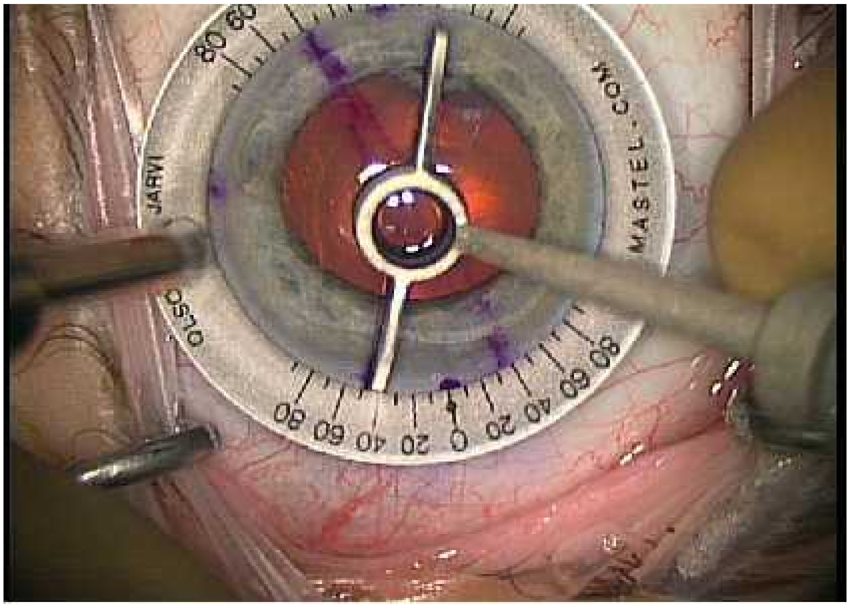
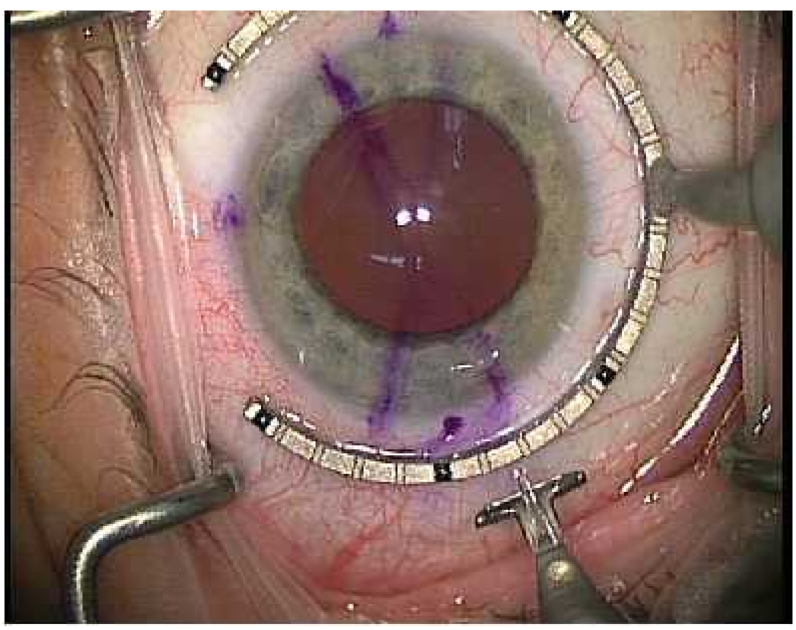


Figure 9C



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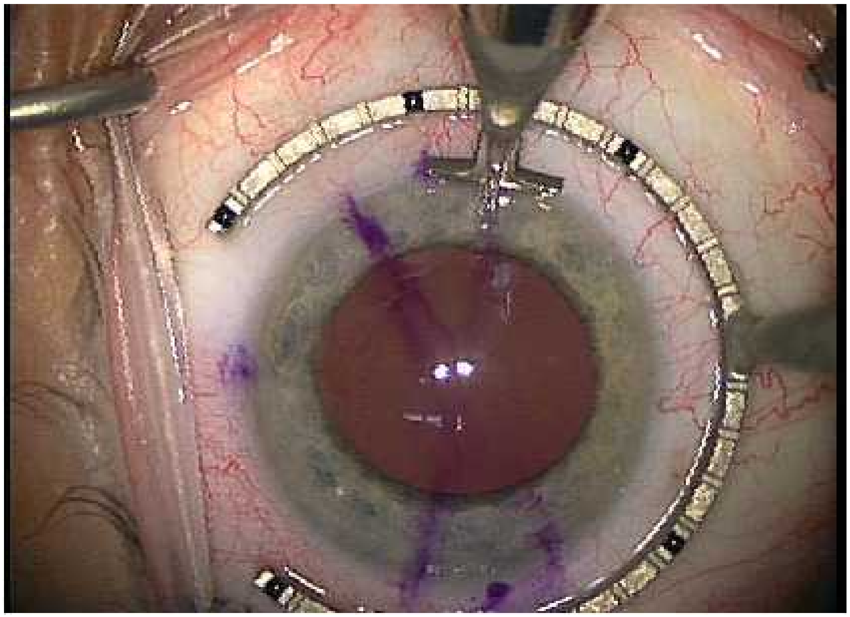

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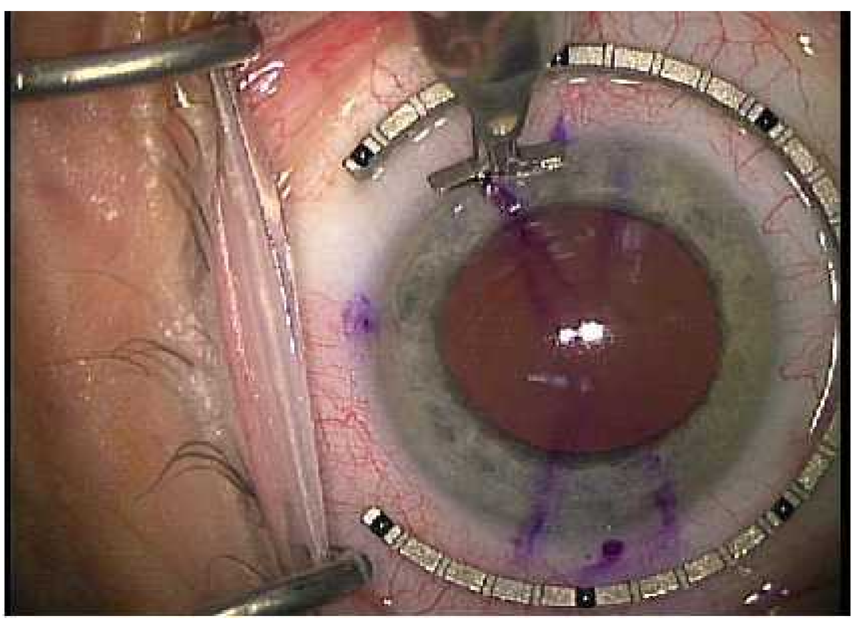

Figure 9F

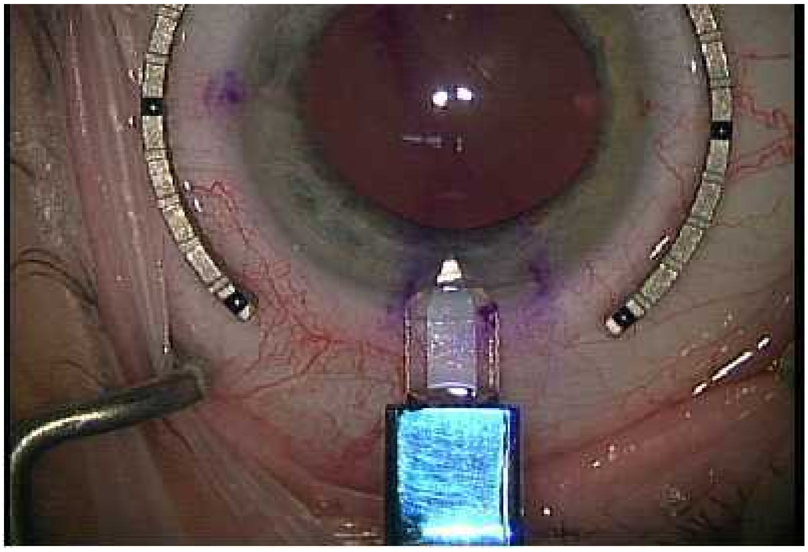

Figure 9G

Figure 10

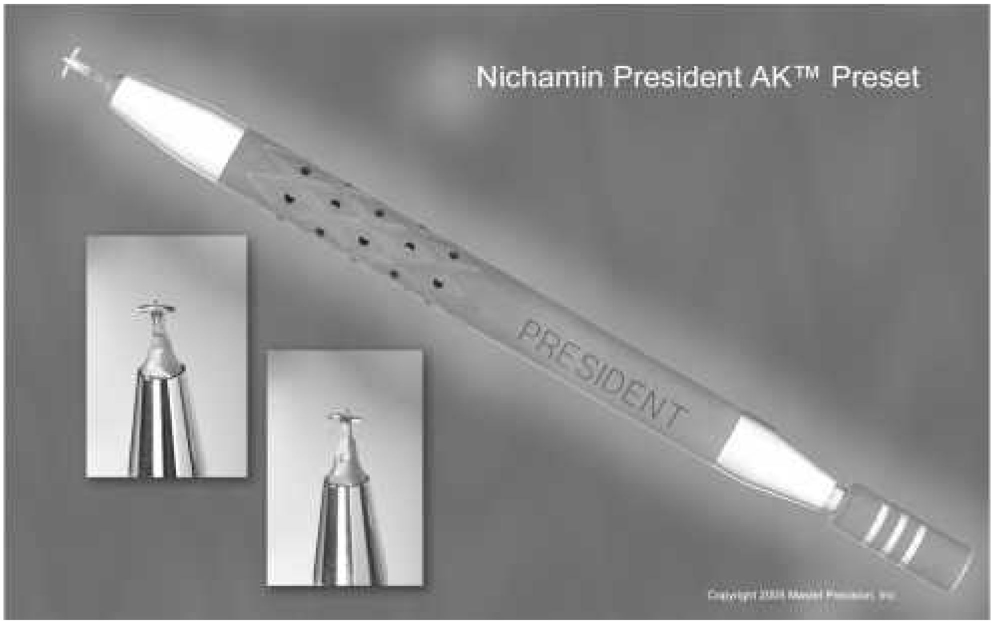

Figure 11A

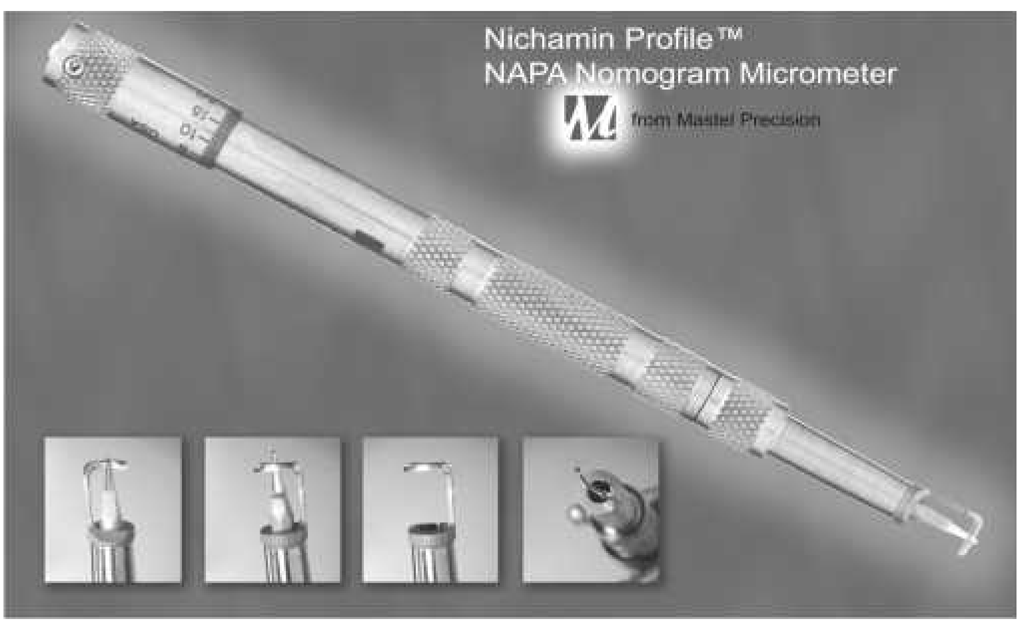

Figure 11B