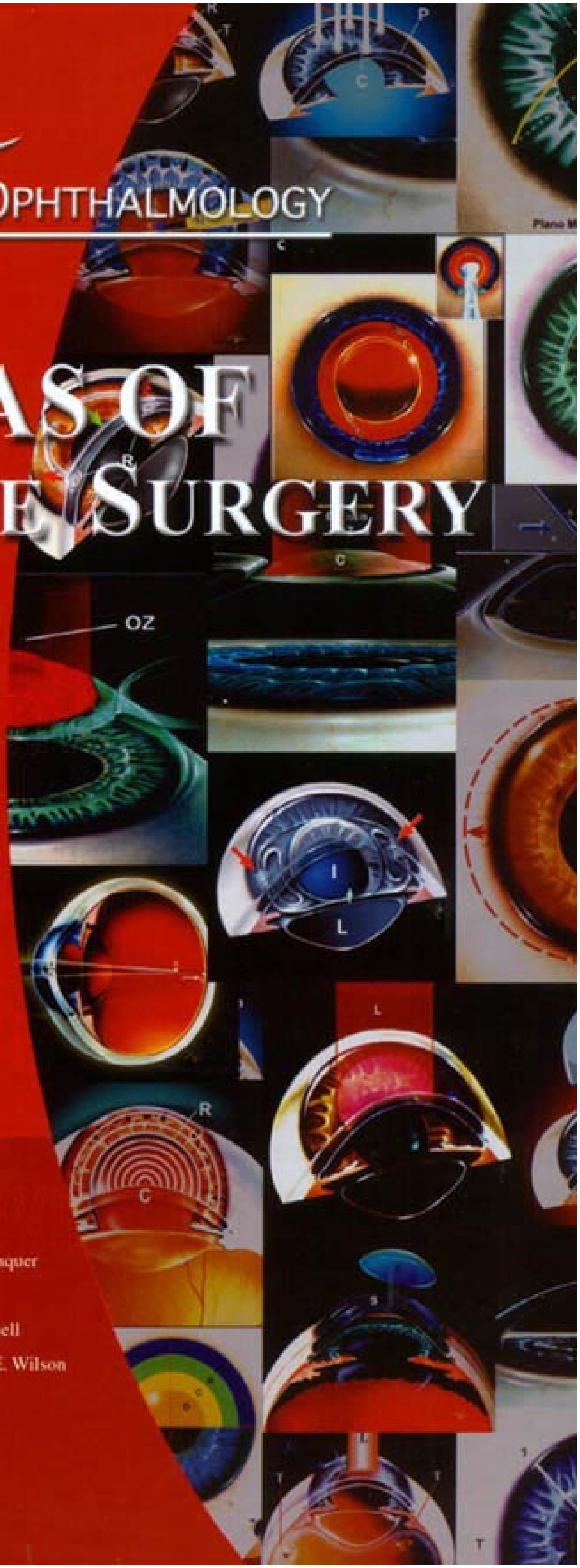
HIGHLIGHTS OF OPHTHALMOLOGY

ATLAS OF REFRACTIVE SURGERY



by: Benjamin F. Boyd, M.D., F.A.C.S.

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Maria Clara Arbelaez • Carmen Barraquer • Joaquin Barraquer
Rubens Belfort • Lucio Buratto • Virgilio Centurion
Ricardo Guimarães • Richard Lindstrom • Peter McDonnell
Juan Murube • Harold Stein • George Waring • Steven E. Wilson
Jan Worst • Roberto Zaldivar

Highlights of Ophthalmology

Atlas of Refractive Surgery

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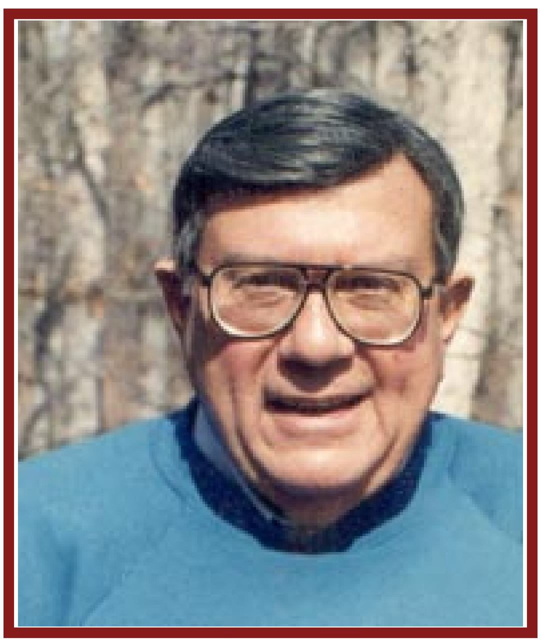

Welcome By Benjamin F. Boyd, M.D.

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Outline of Major Subjects

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Acknowledgements

All the text in this Volume has been created by the author. I am very much indebted to the Master Consultants and to all Guest Experts who are listed in this section. They are all highly recognized, prestigious authorities in their fields and provided me with most valuable information, perspectives and insights.

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Professor Juan Murube, M.D.,Cristela F. de Aleman, M.D., and Cecilia Contreras, M.D., have been responsible for the simultaneous spanish translation.

This CD-Book has been produced for the benefit of humanity. To accomplish this task has required a significant amount of personal sacrifice, intense concentration, isolation from family and friends and the loyal support and stimulus of one special woman, my dear wife **Wylma Cordovez de Boyd.**

This is being written, on my birthday, October 1, 1999.

Benjamin F. Boyd, M.D. F.A.C.S.

Guest Experts and Consultants

Cristela F. de Aleman, M.D. - Clinica Boyd - Panama, R.P.
Maria Clara Arbelaez, M.D. - El Maghrabi Eye Center
Carmen Barraquer, M.D. - Barraquer Institute - Bogota
Joaquin Barraquer, M.D. - Barraquer Center - Spain
Rubens Belfort, M.D. - Federal Univ. Sao Paulo, Brazil
Samuel Boyd, M.D. - Clinica Boyd - Panama, R.P.
Rosario Brancato, M.D. - University of Milan, Italy
Lucio Buratto, M.D. - Centro Ambrosiano - Milan, Italy
Virgilio Centurion, M.D. - Inst. for Eye Diseases, Brazil
Robert C. Drews, M.D. - Washington Univ. Missouri
Ricardo Guimaraes, M.D. - Inst. of Minas Gerais, Brazil
Arthur Lim, M.D. - Inst. of Ophthalmology, Singapore
Richard Lindstrom, M.D. - Phillips Eye Inst.,Minneapolis
Peter McDonnell, M.D. - Univ. of California, Irvine-USA
Juan Murube, M.D. - Univ. of Alcala, Madrid - Spain
Pran Nagpal, M.D. - Eye Research Center, India
Harold Stein, M.D. - Maxwell Bochner Eye Inst., Canada
Enrique Suarez, M.D. - Centro Medico Trinidad, Caracas
George Waring, M.D. - Emory Univ. Atlanta - Georgia
Stephen Wilson, M.D. - Univ. Washington - Seatle, Wash.
Jan Worst, M.D. - Leiden University, Holland
Roberto Zaldivar, M.D. - Zaldivar Eye Inst. Argentina

Fundamental Principles of Refractive Surgery

CHAPTER 1

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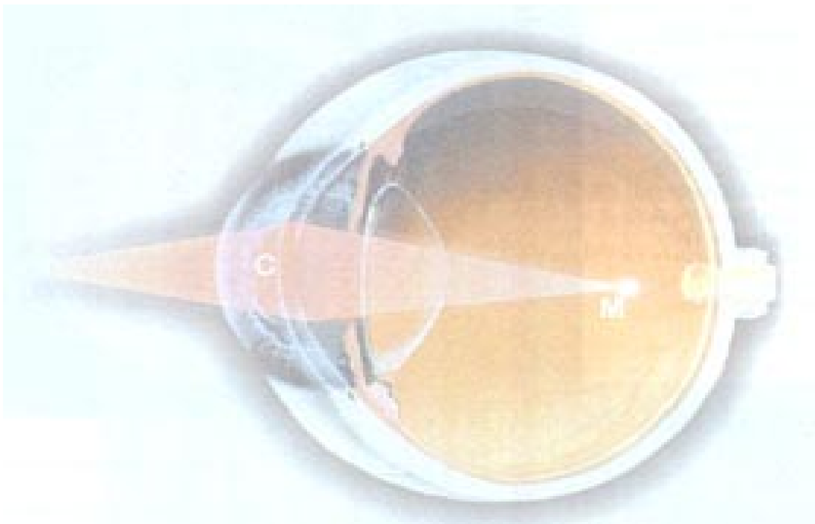


General Overview

The chapter presents the extraordinary developments in the now broad field of refractive surgery, emphasizing the state of the art methods that every clinical ophthalmologist can apply to his/her practice. Further progress is being made through modifications of already highly successful surgical techniques such as LASIK and further improvements in corneal topography, microkeratomes, surgical nomograms, and laser delivery systems will allow for more user-friendly procedures and improvement of results in the future.

In this special Atlas, you will find an evaluation of all the presently available methods, their indications, limitations, advantages, disadvantages, surgical techniques, complications and their management.

PRINCIPLES OF REFRACTIVE SURGERY

Modifying the Corneal Curvature

The cornea is a plastic, transparent, colorless and elastic medium which maintains its curvature (power) or takes a different one as it is modified surgically for refractive purposes. This is clearly demonstrated in Fig. 1 for LASIK (laser-in-situ keratomileusis), Fig. 2 for PRK (photorefractive keratectomy) and Fig. 3 for RK (Radial Keratotomy). In the specific case of Fig. 3, we show the Mini-RK as advocated by **Lindstrom**.

Surgical modification of the refractive power of the eye by changing the corneal curvature is possible because the cornea and the air/tear film interface is the

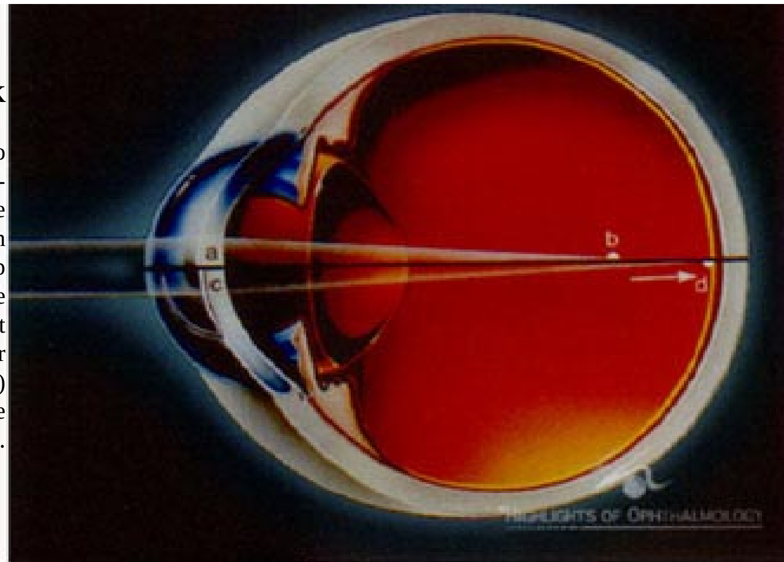


Figure 1 (above): Refractive Concepts of LASIK

The globe shown is divided into two halves (superior and inferior) for direct comparison of pre and post-op corneal curvature change from LASIK, as it relates to the resulting change in refraction. The upper half shows a steep, pre-op corneal curvature (a) causing a myopic refractive effect. Note that the focal point (b), (from a point source of light), is anterior to the retina. The lower half shows the flatter, treated central cornea (c) following LASIK. The resulting minus refractive change now causes light to focus on the retina (d).

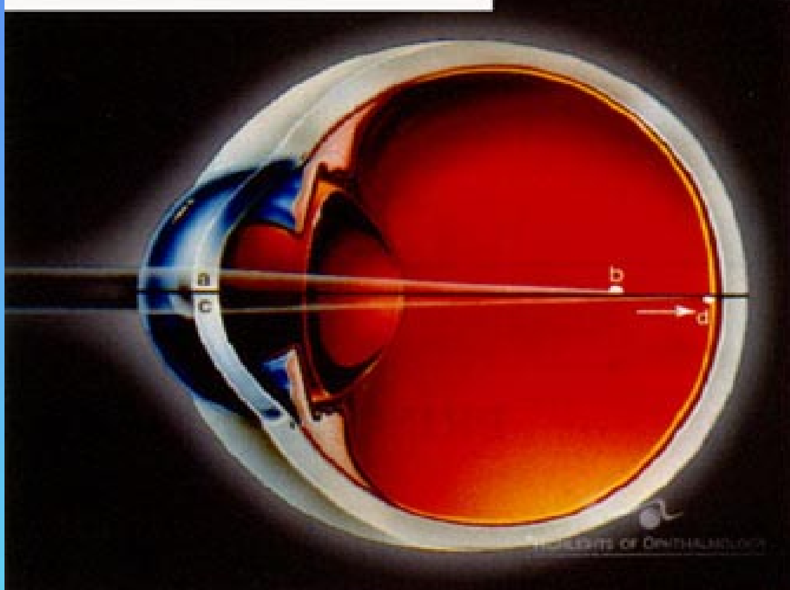
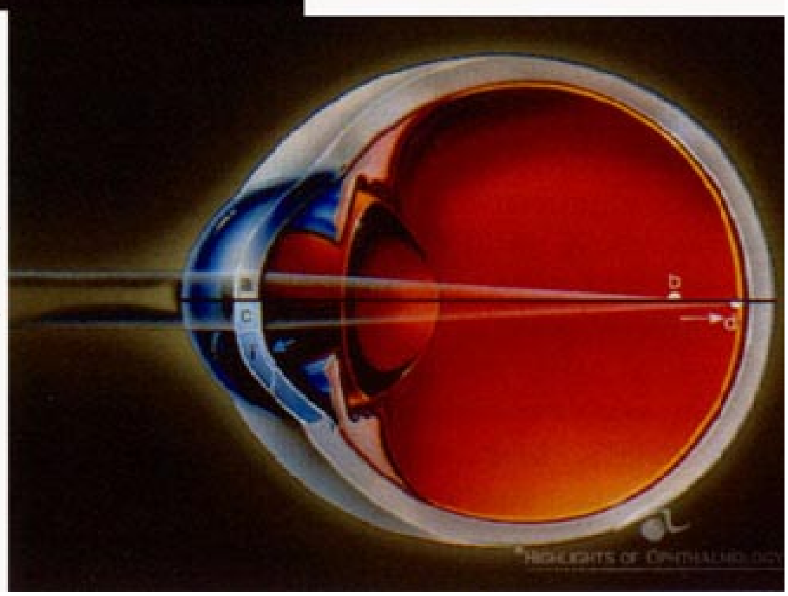


Figure 2 (center): Refractive Concepts of PRK

The globe shown is divided into two halves (superior and inferior) for direct comparison of pre and post-op corneal curvature change from PRK, as it relates to the resulting change in refraction. The upper half shows a steep, pre-op corneal curvature (a) causing a myopic refractive effect. Note that the focal point (b), (from a point source of light), is anterior to the retina. The lower half shows the flatter, treated central cornea (c) following PRK. The resulting minus refractive change now causes light to focus on the retina (d). The laser has removed the epithelium and anterior corneal layers.

Figure 3 (below): Refractive Concepts of the Mini-RK Procedure to Flatten the Cornea

The globe shown is divided into two halves for direct comparison of pre and post-op corneal curvature change related to the change in refraction following a Mini-RK procedure. The upper half shows the pre-op corneal curvature (a) resulting in a myopic refractive effect, as a point source of light is focused (b) in front of the retina. The lower half shows the flattened central cornea (c) resulting from the Mini-RK incisions (i). The resulting refractive effect of the flattened cornea is to allow light to now focus on the retina (d).



primary and most powerful refractive surface of the eye, representing about 80% of the phakic eye's total refractive power (Fig. 4). It is the only refractive surface of the eye once the lens is removed.

Important refractive surgery techniques are now available for a variety of indications. Some involve changing the corneal curvature, others the implantation of phakic and aphakic intraocular lenses, and some, newly developed scleral incision techniques, all of which may be seen in Figs. 22-25.

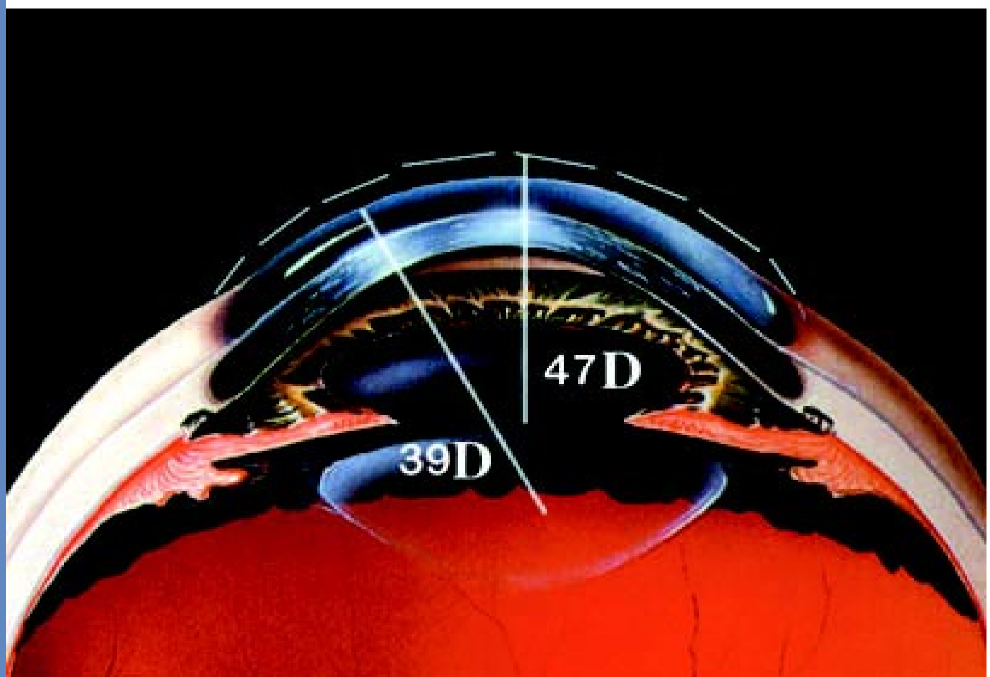


Figure 4: Changes of Power Related to the Corneal Radius of Curvature - Why Changes in Corneal Curvature Improve Refractive Errors

The cornea and the air/tear film interface is the primary and most powerful refractive surface of the eye, representing about 80% of the eye's total refractive power. The anterior curvature of the normal cornea has the greatest power. This illustration shows examples of two corneas of different radii and consequently different dioptric powers. The anterior curvature of the cornea shown in the **dashed line** has a steep curvature of 7.18 mm with a resultant power of 47 diopters. If present in a myopic eye, it would need to be flattened in order to move the image onto retina, by means of any of the procedures shown in Figs. 1, 2 or 3. The cornea shown in the **solid line** has a flatter curvature radius of 8.65 mm with a power of 39 diopters. The less the diopters of curvature the flatter the cornea. This principle clearly explains why the refractive power of the eye can be modified by surgical procedures that change the corneal curvature.

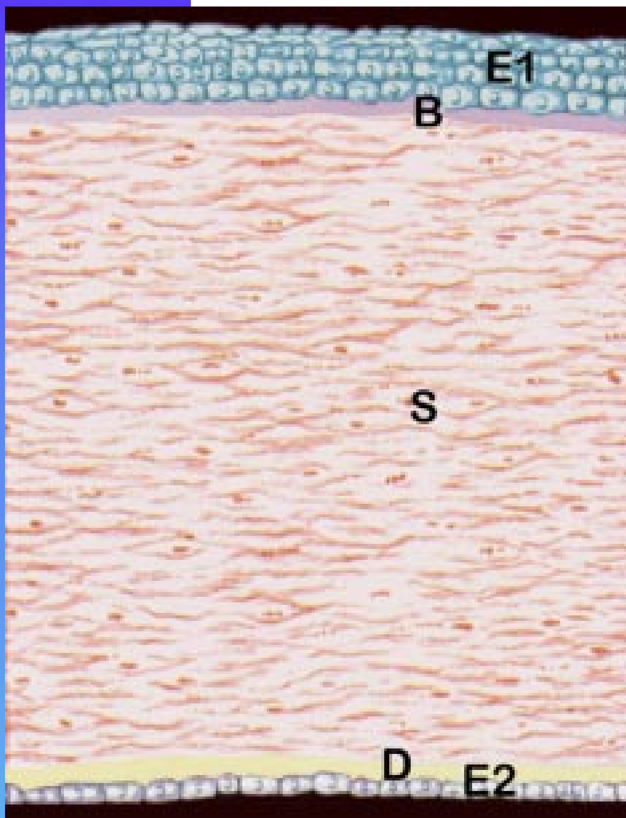


Figure 5 :Anatomical and Physiological Highlights

This cross section of the cornea represents a magnified view of the corneal tissue structure. (E1) identifies the epithelium (30-50 microns), (B) Bowman's membrane (10-14 microns), (S) stroma (500-900 microns), (D) Descemet's membrane (3-12 microns), (E2) endothelium (4-6 microns). The corneal epithelium consists of squamous cells stratified into 6-7 layers. The epithelium uses glucose as an energy source and amino acids as nourishment. They both originate from aqueous humor through the endothelium and the stromal portion. The turnover of the corneal epithelium takes about 1 week. Bowman's membrane (B) is a uniform membrane found between the basement membrane of the epithelium and the cellular stroma. It helps to maintain the shape of the cornea. The corneal stroma connective tissue (S) has three basic functions: 1) protection through the collagen fibers; 2) determination of shape; 3) transparency. Most importantly, the stromal thickness is different at the cornea's center (500-550 microns) than at the periphery (700-900 microns). The center is where the excimer laser ablations are performed for myopia and/or astigmatism (LASIK). The central and paracentral zones are those mostly ablated when using excimer laser for hyperopia. The mid-periphery and periphery are those mostly incised when performing RK (Figs. 1, 2, 5, 6, 7). Descemet's (D) supports the uniform mono-stratified endothelium which is adherent to the membrane. The endothelial cells (E-2) function as a pump to remove water from the stroma and maintain transparency.

New Findings on Wound Healing Important in Refractive Surgery

Steve E. Wilson, M.D., Professor and Chairman, Department of Ophthalmology at the University of Washington Medical Center, in Seattle, has emphasized that important communications exist between the epithelial cells and the keratocytes in the cornea. *If the epithelial cells are injured in any way, for instance through scraping before a laser procedure (PRK) or ablation through the epithelium (PRK), they release many growth factors or mediators (cytokines).* When released from the epithelial cells, these can stimulate the keratocytes to die beneath the epithelial wound. ***Wilson*** *has shown that these cells undergo programmed cell death, or apoptosis* when merely scraping the epithelium during an excimer laser photorefractive keratectomy (PRK). This causes the keratocytes in the front part of the cornea to disappear.

The Cause of Regression and Haze After PRK

Apoptosis occurs in all organisms and organs during development, wound healing, or even normal tissue maintenance. It is a subject of great interest as a possible explanation for optic nerve atrophy in glaucoma. *The wounding of epithelial cells in the cornea* causes the cells to release mediators, which stimulate *programmed cell death.* The keratocytes remaining in the posterior cornea become activated within a day or two and divide and move into the front of the cornea. *They produce excess collagen and other products of wound healing, which cause the regression and haze that occur* as a complication of excimer laser surface ablation by PRK.

Importance of Central Cornea to the Refractive Result

The cornea is approximately 12.5 mm in diameter, horizontally and 11.5 mm vertically (Fig. 7). Yet the only part of the cornea that actually contributes to the image on the macula is that portion which is approximately the same diameter as the pupil (Fig. 6). The average pupil is approximately 2.5 to 3 mm in diameter in bright light and about 4 to 4.5 mm in dim light. The pupil can get larger in younger patients. (This is important in cases of high myopia treated with LASIK or pre-crystalline foldable posterior chamber IOL's, where the presence of a small optical diameter may give rise to visual problems at night.)

The only portion of the cornea that actually determines the refraction and contributes to the image on the macula is the central 3 to 4 mm with a 3 mm pupil (Fig. 6). The peripheral part of the cornea does not contribute to the foveal image.

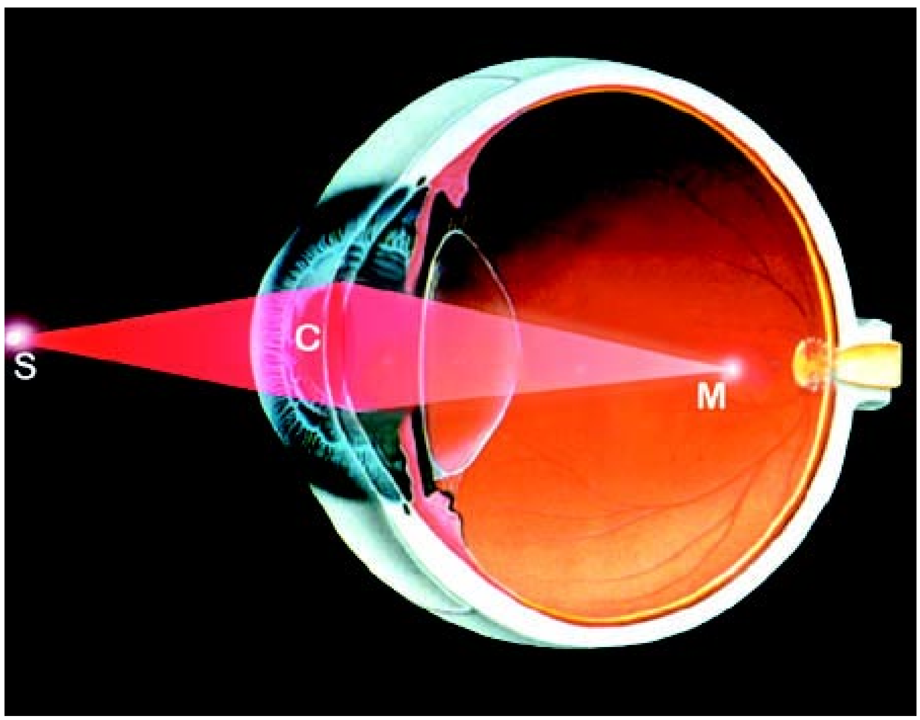


Figure 6: Importance of the Central Cornea to the Refractive Result

The only portion of the cornea that contributes to the image on the macula (M) is that shown in (C) which is approximately the same diameter as the pupil (normally 2.5 to 4.5 mm). In this figure, the light emanates from source (S). The peripheral part of the cornea does not contribute to the macular image. For further understanding of these relations, see figure 7.

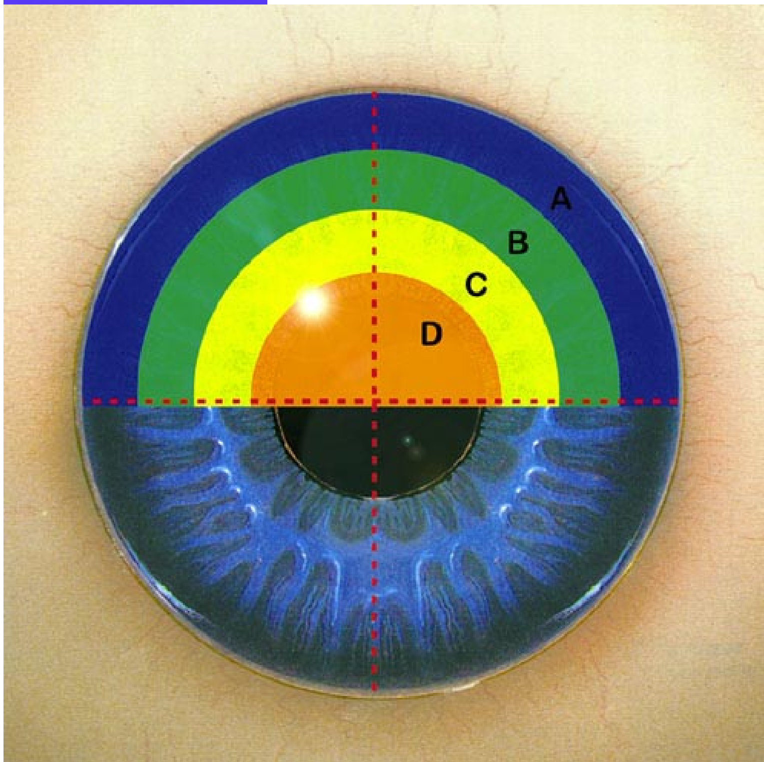


Figure 7: Anatomical Regions of the Cornea of Clinical Importance in Refractive Surgery

In this schematic illustration you may observe the main areas of refractive interest of the cornea divided into four basic concentric zones. Zone A describes the extreme peripheral and limbal sector with thickness between 700-900 microns. Zone B shows the peripheral sector of approximately 2-3 mm in width and 670 micron thickness. Zone C identifies the paracentral area of approximately 2-3 mm in width and 610 micron thickness. Zone D describes the central sector approximately 3-4 mm in diameter and 500-550 micron thickness. Zone D is slightly larger than the pupil. These relationships are important for the surgeon's judgment when performing various refractive procedures.

Central Zones C and D are the areas where the excimer laser procedures are done to manage myopia and or astigmatism. "D" is also the central optical zone from which the radial keratotomy incisions start toward the periphery. Zones B and C represent the areas where excimer ablation is performed for correction of hyperopia. Zones C and B represent the areas in which the radial keratotomy incisions are performed.

The interrupted lines show the greater axis as being horizontal (12.5 mm) and the vertical axis slightly shorter (11.5 mm).

Relation of Various Corneal Zones to Different Refractive Techniques

This important relation is shown and amply described in Figure 7. All surgeons performing refractive procedures **must** understand the relations that each corneal zone and the corneal depth in each area have with a particular technique.

UNDERSTANDING ASTIGMATISM

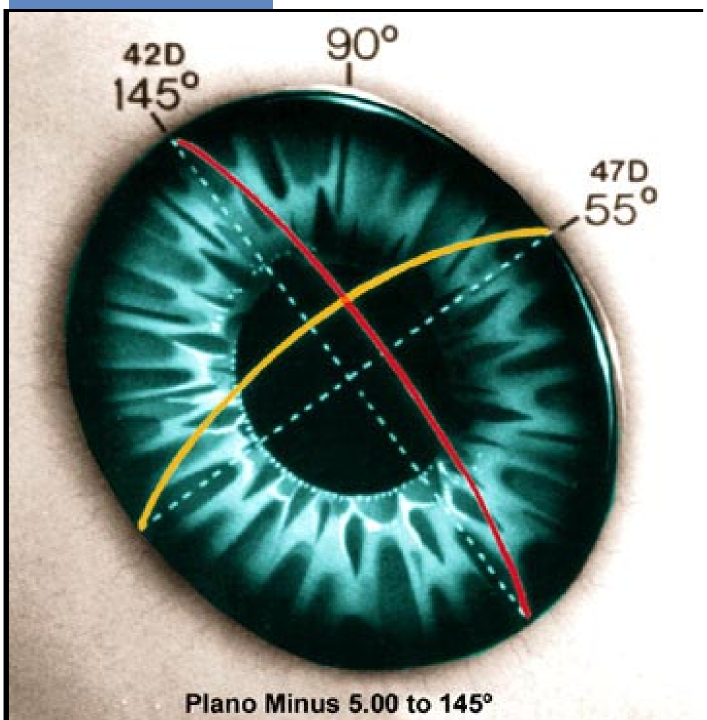
Throughout this Volume we will necessarily refer to astigmatism in various chapters. How to manage this important refractive error is discussed among the last chapters of this Volume. It is essential that we define a common terminology now. We need to unify concepts when referring to the different types of astigmatism and when determining in which specific axis the surgical correction must be made.

Importance of Proper Identification of Steepest Meridian to Avoid Confusion

In clinical terms, a patient may be referred to as having an astigmatism of, for example, five diopters at 145 degrees. Some ophthalmologists work with minus cylinders, others prefer plus cylinders. Consequently, some people may perceive that the 145 degrees corresponds to the flattest meridian and other persons may deduce that 145º refers to the steepest meridian.

If we have a patient with five diopters astigmatism at 145 degrees, we first have to unify the concept of what this means. It is preferable to think in terms of the amount of diopters in each axis, just to be completely sure to work in the axis we need, because if we work on the wrong axis, we may change from the original five diopters to 10 diopters in cylinder. The main point is to be sure which is the steepest meridian.

Let us place ourselves in the mind of a surgeon who works with minus cylinders. If he/she has a patient Plano -5.00 at 145 degrees, this means that 145º is the flattest meridian and he has to work 90 degrees opposite that axis, that is, at axis 55 degrees because he has to flatten the steepest meridian (Fig. 8). Contrariwise, if you have a patient Plano plus 5.00 at 145 degrees, that means you have to work in the 145º axis (Fig. 9). The proper identification of the steepest meridian is extremely important. There are surgeons who have worked in the wrong axis. That is why it is preferable to think in terms of the diopters in each axis; in our example, Plano -5.00 at 145º in a patient who's keratometer base curve is 42.00, is best described as 42 diopters at 145 degrees and 47 diopters at 55 degrees (Fig. 8).



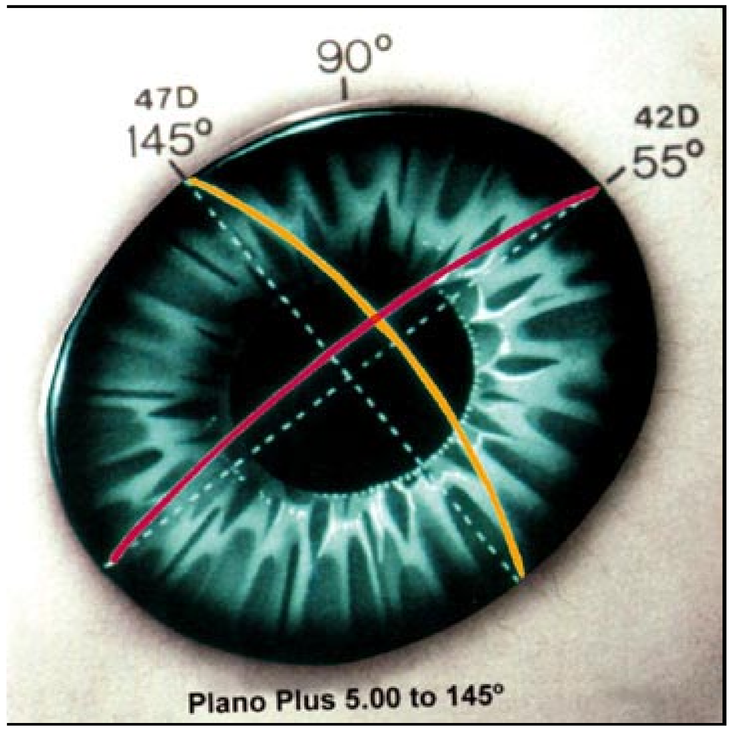


Figure 8 (above left): Proper Identification of Steepest Meridian to Avoid Confusion (Steepest at 55º)

A description of five diopters of astigmatism at 145º is understood by some to mean that the flatter meridian is at 145º and by others that 145º is the steeper meridian. To avoid confusion, we should think in terms of the diopters in each axis. This example is best described as 42 diopters at 145º and 47 diopters at 55º which is the **steeper meridian** and avoid using the term Plano minus 5.00 at 145º**.** One must perform any corrective astigmatic keratotomy at 55º, which is the steeper meridian.

To facilitate your interpretation of this relationship, the yellow curve is always in the steepest axis.

Figure 9 (above right): Proper Identification of Steepest Meridian (Steepest at 145º)

Plano plus 5.00 at 145º describes the steeper meridian, which is to be corrected at 145º. The flatter meridian is at 55º as shown. In our example, this is best described as 42 diopters at 55º and 47 diopters at 145º. The flatter curvature corresponds to less dioptric astigmatism.

As in fig. 8, the yellow curve is shown in the steepest axis.

Identifying With the Rule and Against the Rule Astigmatism

This principle is a familiar term known to all ophthalmologists but it is important to present it here **graphically** for a better understanding of its nature, as shown in Figs. 10 and 11. **"With the rule"** astigmatism is when the steeper curvature is in the vertical direction (Fig. 10). It is always preferable to end up with "with the rule" astigmatism because it is more physiologic. The reverse of this is termed "against the rule" (Fig. 11). We **cannot** overemphasize enough how important it is to keep this relation in mind. There are surgeons who have performed an astigmatic keratotomy in the wrong meridian, thereby aggravating the already existing against the rule astigmatism.

Figures 10 and 11 provide an instant mental picture of these two entities. Each figure consists of four illustrations showing first the surgeon's view of with the rule astigmatism (Fig. 10-A) and against the rule (Fig. 11-A), accompanied by a color representation of the optics and where the image is focused through the different axis (Figs. 10-B and 11-B), the view of each entity through the Placido disc (Figs. 10-C and 11-C), and the characteristic picture of corneal topography (Figs. 10-D and 11-D).

Identifying Different Combinations of Astigmatism

Figure 12 will provide you with an instant mental picture of the different combinations of astigmatism. By definition we refer to astigmatism when an image is not focused with equal clarity in all the focal points. One meridian has a different focusing power than another. This leads to a variety of combinations, as follows:

1) Simple myopic astigmatism (Fig. 12-A). Please observe that one meridian is focused in front of the retina (F-1) and the other meridian is focused right on the retina (F-2).

2) Simple Hyperopic Astigmatism (Fig. 12-B). In these cases, one meridian is focused right on the retina (F-2) and the other meridian focuses behind the retina (F-1).

3) Mixed Astigmatism (Fig. 12-C). One meridian is in front of the retina (F-1) and the other focuses behind the retina (F-2).

4) Compound Myopic Astigmatism (Fig. 12-D). Both meridians focus in front of the retina (F-1 and F-2).

5) Compound Hyperopic Astigmatism (Fig. 12-E). Both meridians focus behind the retina (F-1 and F-2).

Each different type and combination of astigmatism and the various axis in which they are located require a distinct surgical approach in order to have the very best end results. It also makes a difference whether the condition is congenital or postoperative, such as following corneal transplantation. We will discuss each specific approach in the chapter on astigmatism.

Unfortunately, postoperative corneal astigmatism following clear corneal grafts occurs commonly and can produce significant visual impairment. Astigmatic correction may include spectacle correction or contact lenses, but if this fails, then various surgical options are considered.

Some of these refractive astigmatic procedures can dramatically reduce postoperative astigmatism after penetrating keratoplasty and lead to improved, functional vision. However, significant variability between results in individual patients can occur. So although general guidelines are useful, it is important to individualize and modify the planned surgery based on qualitative keratoscopy and corneal topography, which we discuss in Chapter 3.

A clear understanding of the different types and combinations of astigmatism that we present in Figs. 8, 9, 10, 11 and 12 is essential for arriving at the right decision.

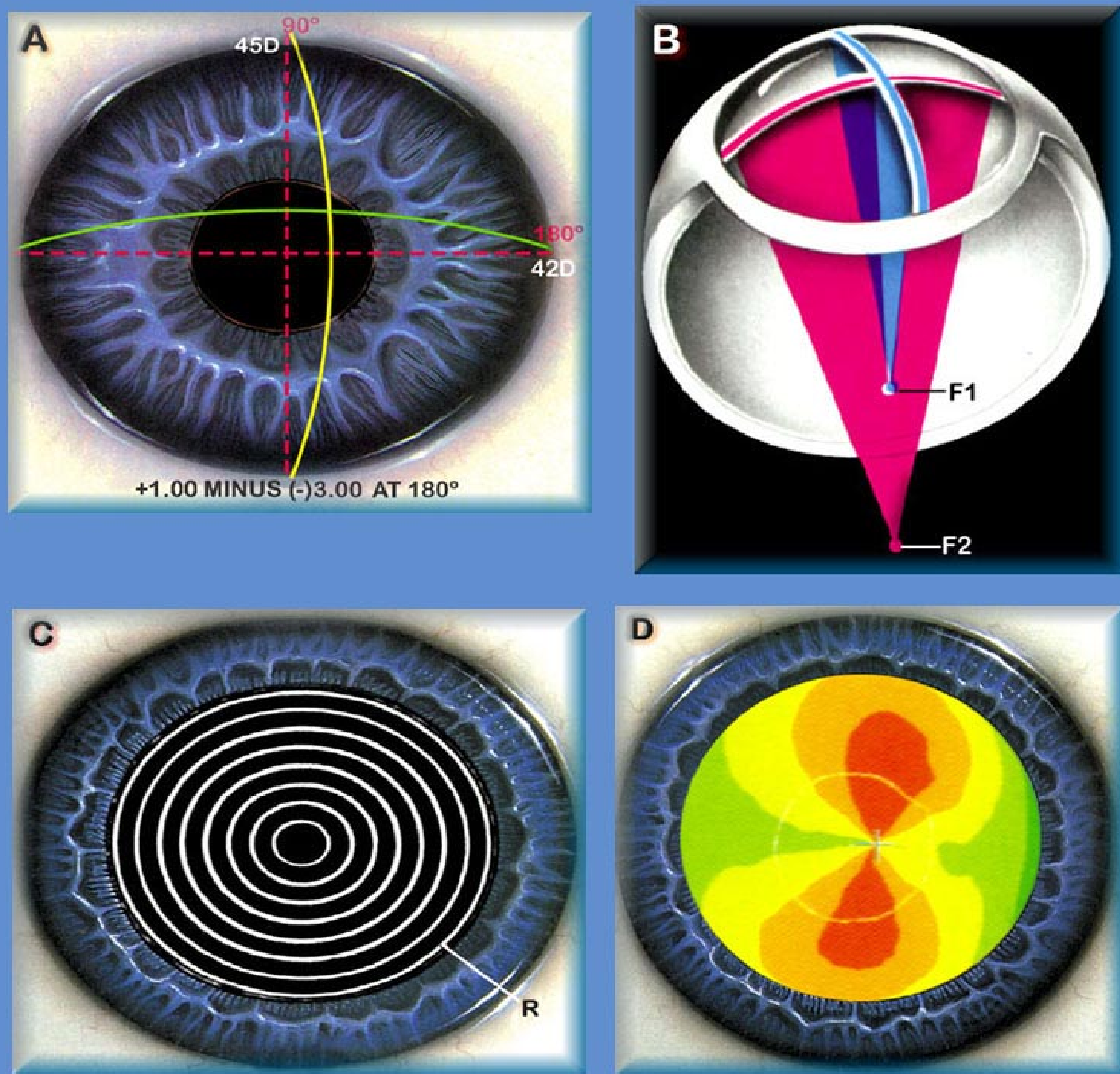


Figure 10: With the Rule Astigmatism

(A) The precise location of the visual axis and axis of cylinder is a must for any effective correction in refractive surgery. This conceptual view presents the steepest curvature (shown in the yellow curve) located at 90º with 45 keratometric diopters. The flattest curvature shown in green is at 180º with 42 keratometric diopters. As a result, there are 3.00 diopters of **with the rule astigmatism**. (B) This optical cross section demonstrates how the light rays focus on different foci. In this example of a mixed astigmatism shown in 10 (A), the light rays are passing through the steepest vertical meridian (blue - F1) compared to the flattest meridian in the horizontal axis of the cornea (red - F-2). (C) In this view, the reflected Placido rings from corneal topography (R) show the oval shape of the cornea in the horizontal position characteristic of this type of astigmatism (Please see Chapter 3). (D) This corneal topographic picture map shows the typical shape of with the rule astigmatism, with the steepest meridian at 90º (more solid colors orange - reddish) and the horizontal meridian in lower intensity colors (yellow and green) representing the flattest curvature, with the characteristic bow-tie appearance vertically.

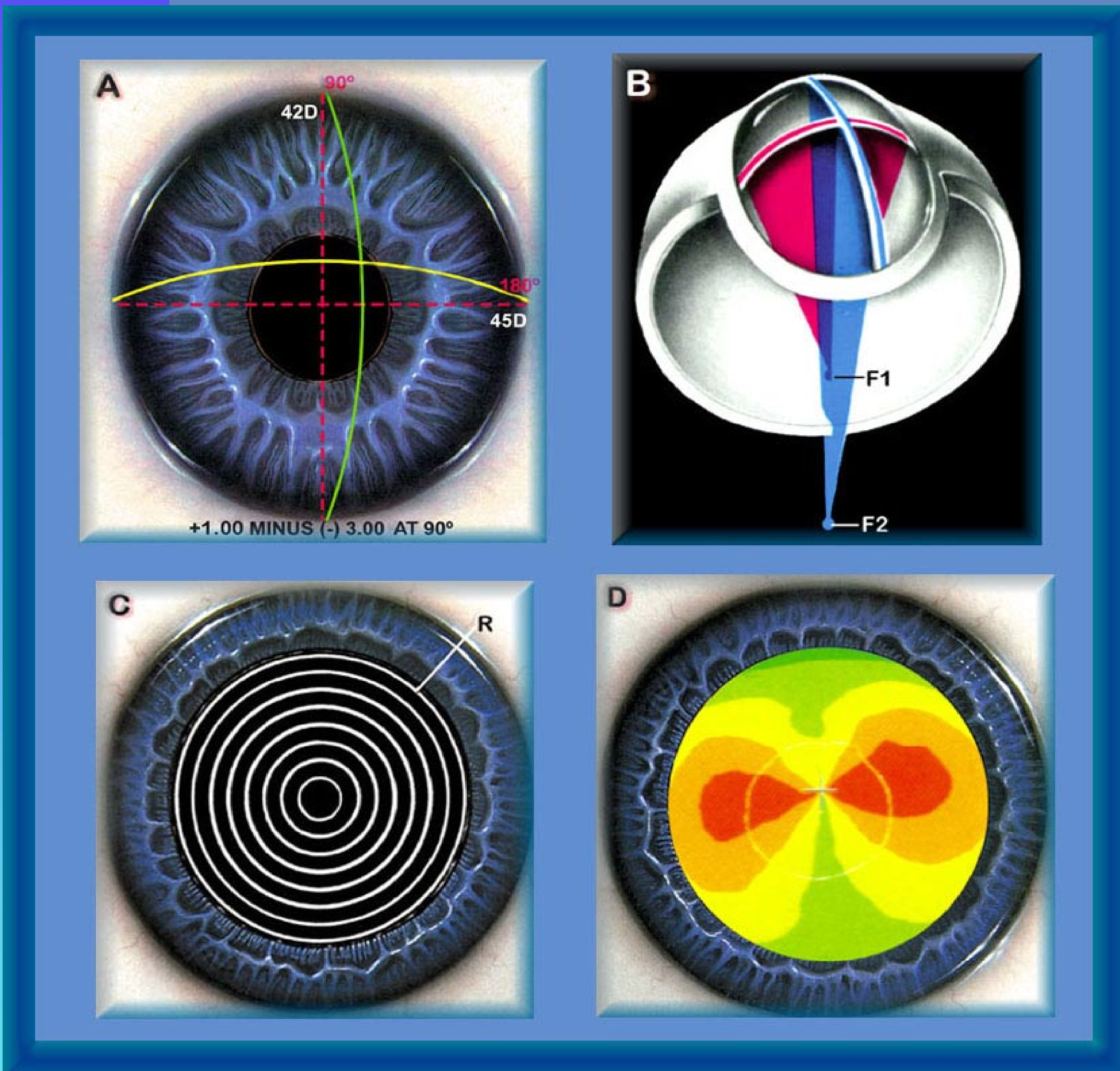
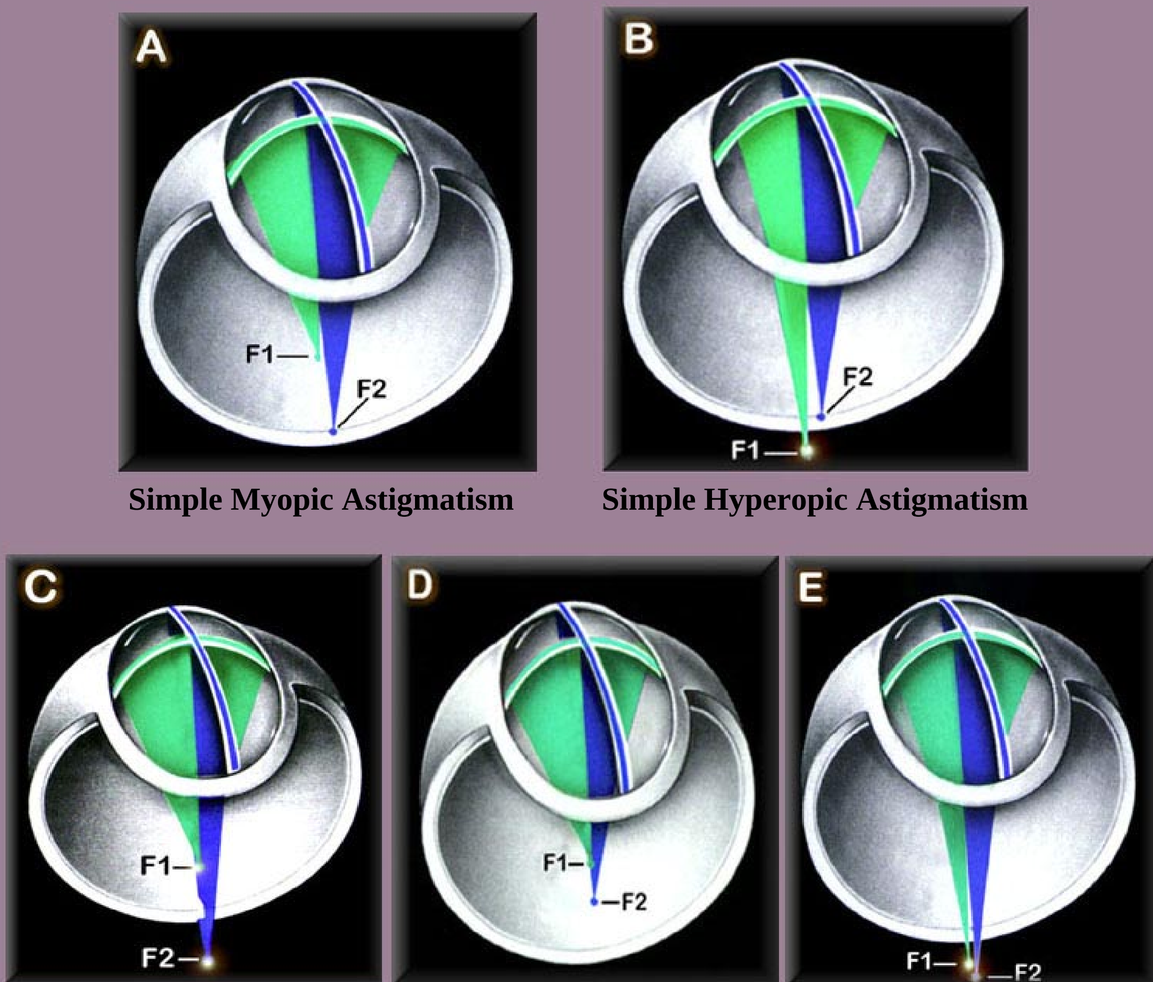


Figure 11: Against the Rule Astigmatism

(A) This conceptual view presents the steepest curvature again in yellow with 45 diopters at 180º in the horizontal axis and 42 diopters at 90º with the flatter vertical meridian in green. (B) This optical cross section shows myopic astigmatism (red) at 180º in horizontal axis with the light rays passing through this steeper meridian (F1). In the opposite focus the light rays are passing through the vertical or flatter meridian (blue -F2). (C) The reflected Placido rings (R) from the topography monitor show the oval shape in the vertical position characteristic of against the rule astigmatism. (D) The corneal topography map shows the typical picture of against the rule astigmatism with the steepest meridian (orange - red) at 180º and the flattest at 90º (yellow - green) with the bow-tie appearance at the center.



Simple Myopic Astigmatism

Simple Hyperopic Astigmatism

Mixed Astigmatism

Compound Myopic Astigmatism

Compound Hyperopic Astigmatism

Figure 12: Identifying Different Combinations of Astigmatism

1) Simple myoipic astigmatism (Fig. 12-A): Please observe that one meridian is focused in front of the retina (F-1) and the other meridian is focused right on the retina (F-2). ***2) Simple Hyperopic Astigmatism (Fig. 12-B):*** In these cases, one meridian is focused right on the retina (F-2) and the other meridian focuses behind the retina (F-1). ***3) Mixed Astigmatism (Fig. 12-C)***: One meridian is focused in front of the retina (F-1) and the other focuses behind the retina (F-2). ***4) Compound Myopic Astigmatism (Fig. 12-D):*** Both meridians focus in front of the retina (F-1 and F-2). ***5) Compound Hyperopic Astigmatism*** (***Fig. 12-E):*** Both meridians focus behind the retina (F-1 and F-2).

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The Broad Horizons of Modern Refractive Surgery

CHAPTER 2

Different Options and Techniques of Choice Their Indications

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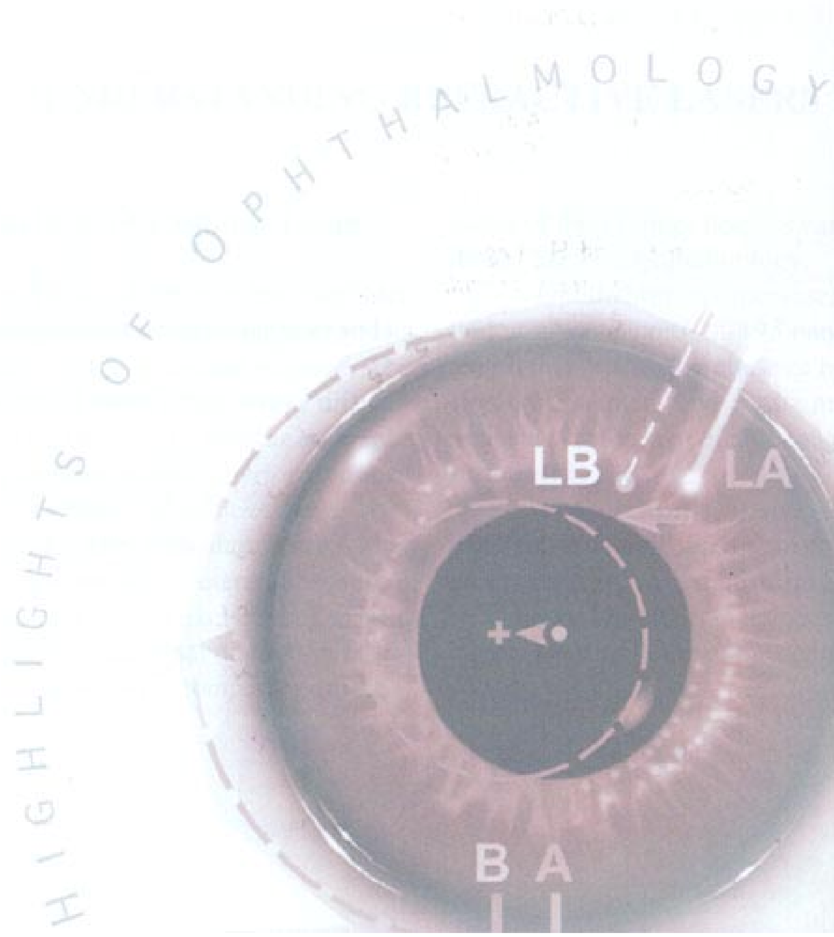
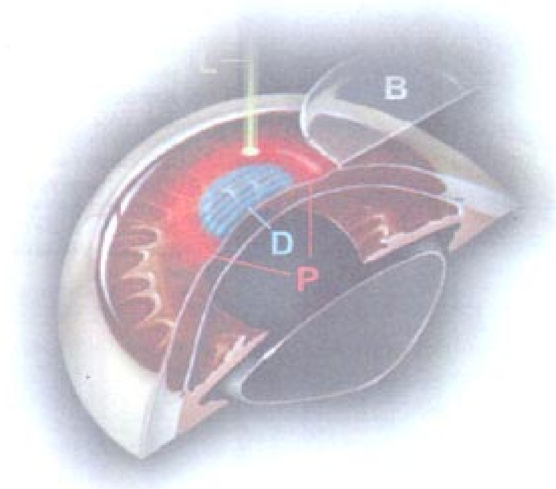




UNDERSTANDING REFRACTIVE LASERS

Therapeutic Principles of Excimer Laser

The most significant advance in the past three years has been the emergence of the excimer laser and its rapid rise to dominate refractive corneal surgery. The excimer laser is a source of energy that is very difficult to control and apply to the human eye with the assurance of safety. Harnessing this laser to safely perform corneal surgery has been a major technical achievement.

The argon fluoride (ArF) 193 nanometer excimer laser is a pulsed laser that has wide potential because it can create accurate and very precise excisions of corneal tissue to an exact depth with minimal disruption of the remaining tissue. Fig. 13 presents the comparative mechanisms of the excimer laser vs various other lasers commonly used in ophthalmology.

Ophthalmic excimer lasers use ultraviolet radiation at a wavelength of 193 nanometers. It is a wavelength that practically does not heat the tissue but actually breaks inter- and intra- molecular bonds. The molecules in the area of ablation explode away from the surface (Fig. 14).

The concept of ablative surgery is that by removing small amounts of tissue from the anterior surface of the cornea (Fig. 15) a significant change of refraction can be attained. The effect in myopes is achieved by flattening the anterior dome of the central cornea over a 5 mm disc shaped area.

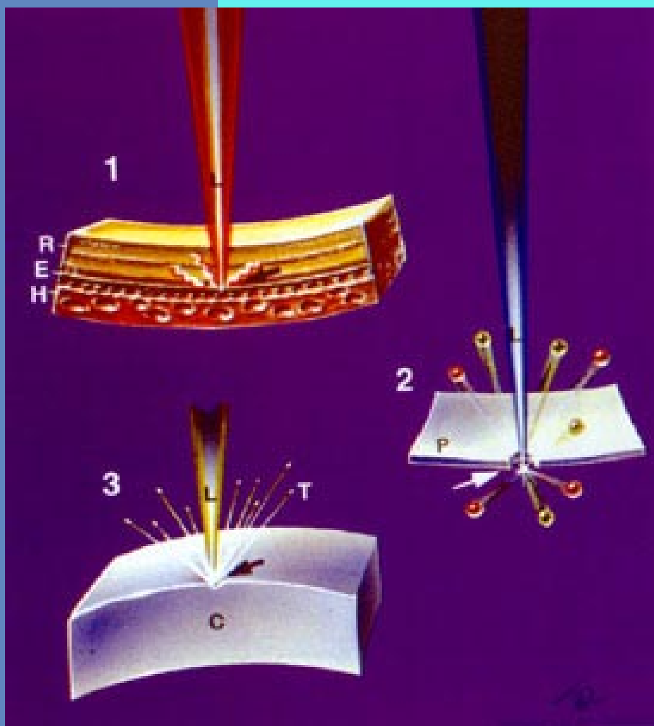
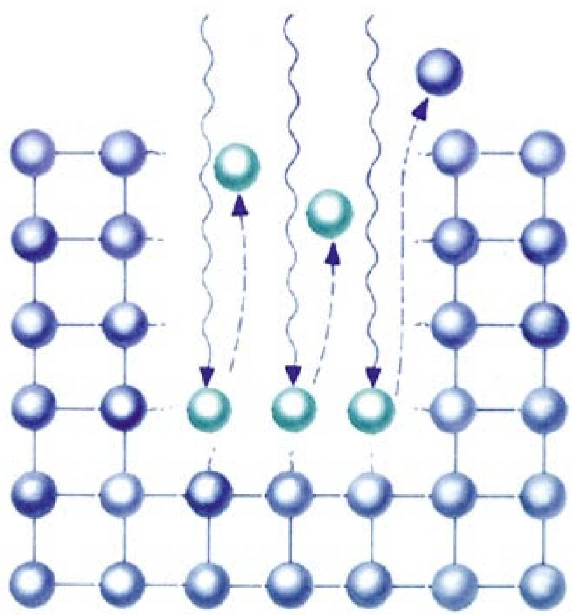


Figure 13 (left): Comparative Mechanisms of the Various Lasers Used in Ophthalmology

(1) The argon and krypton lasers employ a thermal mechanism whereby the laser (L) heats the chorioretinal photocoagulated tissue and produces scarring (arrow). Retina (R), choroid (H) and pigment epithelium (E). (2) The YAG laser works by photodisruption of tissues, creating small acoustical explosions that produce openings (arrow) such as we make in posterior capsulotomy (P). A plasma screen of ions (+ and -) is created. (3) Excimer ultraviolet laser works by photoablation. Small amounts of tissue (T), essentially the stroma in cases of LASIK, are removed from the cornea (C - arrow) with each pulse.

Figure 14 (right): Excimer Laser - Effects on the Tissue

The high intensity energy of ultraviolet light from an excimer laser during tissue ablation breaks inter and intramolecular bonds, causing the molecules of the area of ablation to explode away from the surface. Please observe that there is minimal disruption of the remaining surrounding tissue.



ADVANCES IN EXCIMER LASER TECHNOLOGY

Scanning Lasers

As pointed out by **Peter McDonnell, M.D.,** Professor and Chair, Department of Ophthalmology, University of California, Irvine, and Professor of Ophthalmology and Director of Refractive Surgery at the Doheny Eye Institute, University of Southern California at Los Angeles, in most parts of the world broad beam lasers still predominate in the laser market (Fig. 15). Recently, however,

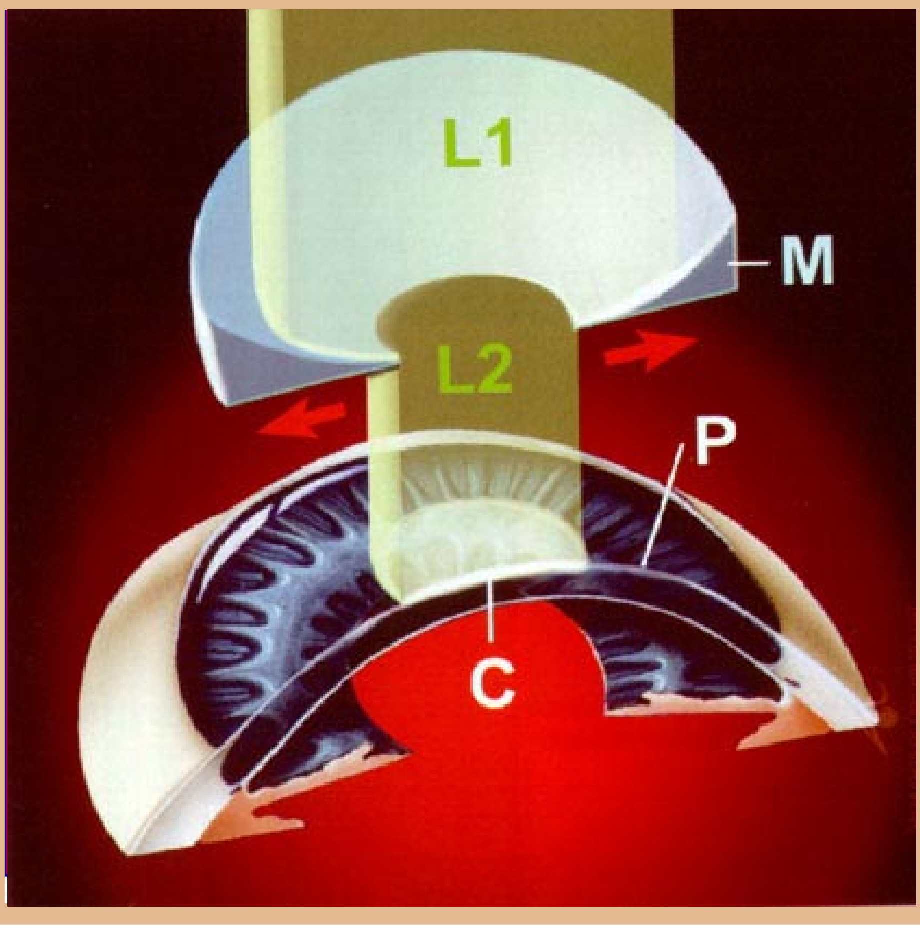


Figure 15: Concept of Broad Beam Laser Application for Refractive Surgery

The most common type of excimer laser is the broad beam laser (L1). The method of application uses a widening diaphragm or pre-shaped ablatable mask (M) through which the laser beam (L2) passes. To produce more ablation of the cornea in the center (C) than in mid-periphery (P), the thinner central portion of the mask allows the laser to ablate the central cornea longer. As the disk is ablated in a peripheral direction (arrows), the cornea is shaped accordingly in a desired gradient fashion.

scanning or flying spot lasers have gained attention. Instead of using an iris diaphragm to control a broad beam, some scanning lasers use a small slit that is scanned across the corneal surface (Fig. 16). Flying spot is another type of scanning laser. Instead of a slit that scans the surface , flying spot lasers (Fig. 17) have a small circular or elliptical spot perhaps 1 mm to 2 mm in diameter that is moved across the surface of the cornea by computer-controlled galvanometric mirrors.

Advantages of Scanning Lasers

Scanning lasers (Figs. 16 and 17) have several potential advantages over broad beam lasers (Fig. 15). The postoperative corneal surface may be smoother, resulting less often in a healing response which can progress to corneal haze or opacity. A higher quality of vision and improved visual acuity may also result from the smoother and more uniform corneal surface when using scanning lasers.

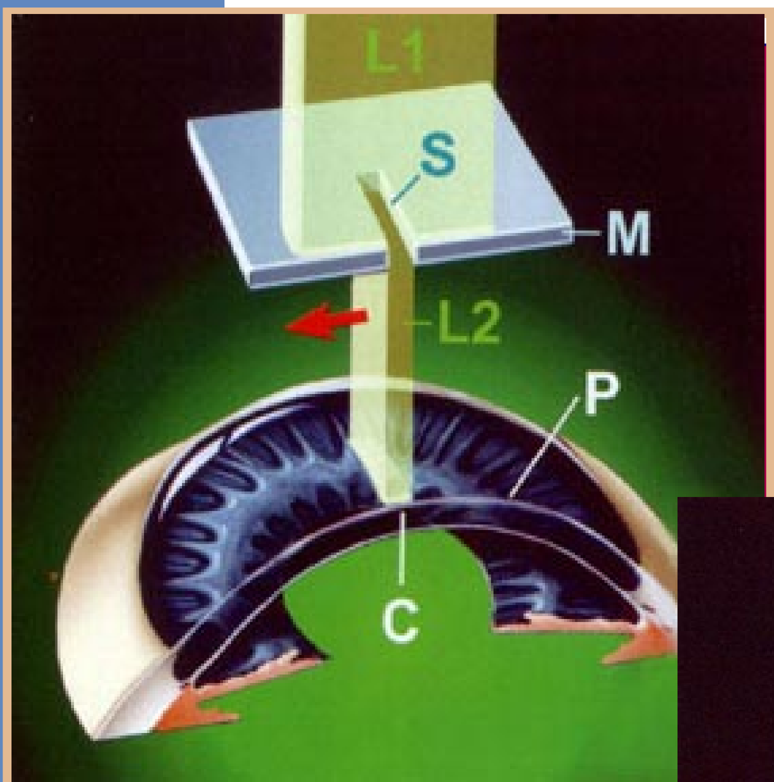
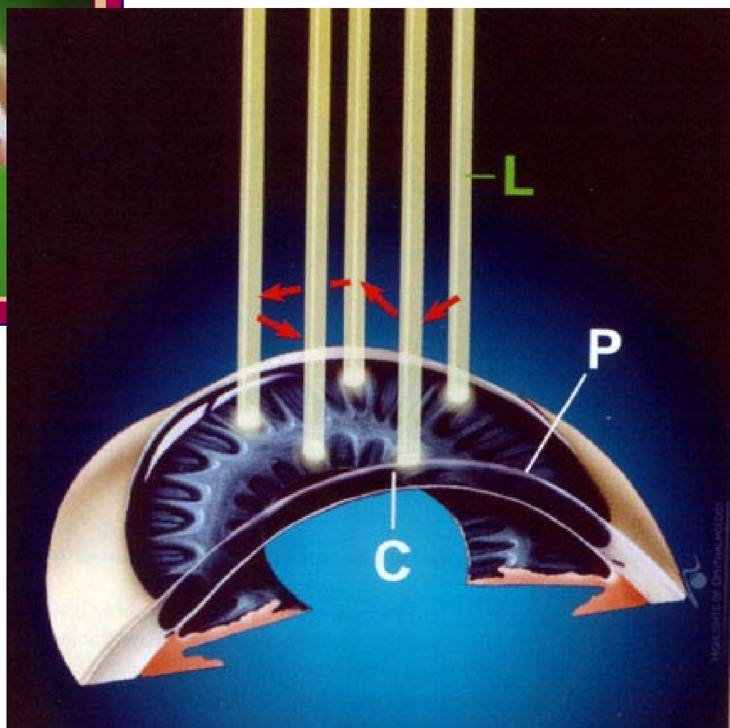


Figure 16 (above left): Concept of the Scanning Type Laser for Refractive Surgery

Another type of excimer laser uses a scanning laser beam. The laser beam (L1) strikes a moving mask (M-arrow) which has a slit through which the beam passes (L2) in a predetermined fashion. More ablation occurs centrally (C) and less peripherally (P) to achieve the desired corneal reshaping.

Figure 17 (below right): Concept of the "Flying Spot" Scanning Laser Application for Refractive Surgery

A third type of excimer laser application is known as the "flying spot". A small laser beam (L) moves across the cornea (arrow) in a predetermined, computer driven pattern to ablate more tissue centrally (C) than in the mid-periphery (P). This type of laser application is very flexible with regard to the type of ablation pattern that can be applied.



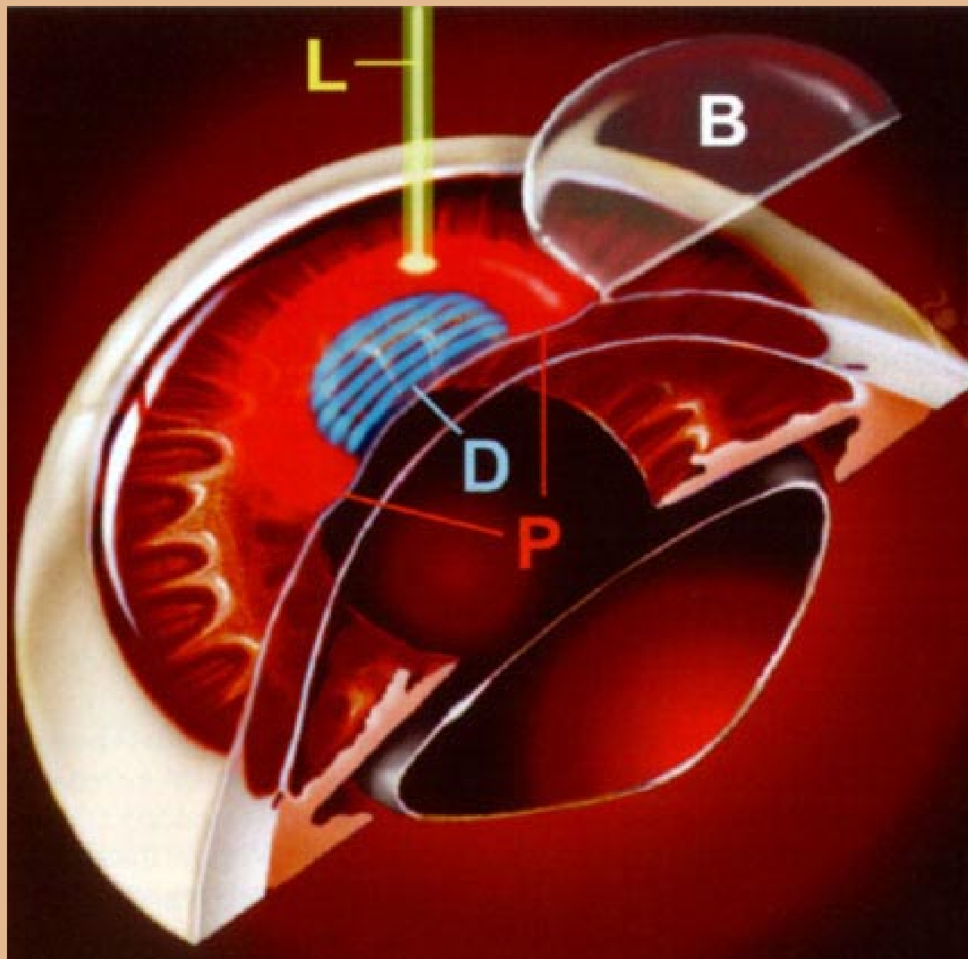


Figure 18: Flexibility of the "Flying Spot" Scanning Laser May Provide Customized Ablation

The "Flying Spot" type excimer laser has an advantage over other broad beam and slit scanning lasers by providing increased flexibility in the ablation profile. The profile can be altered to provide aspheric as well as spherical ablations. The mid-peripheral cornea (red shaded area-P) can be treated with the laser (L) to produce a different curvature than that of the central cornea (D - blue line shaded area). This allows the possibility of a customized ablation unique for every cornea. A lamellar corneal flap (B) is retracted.

McDonnell emphasizes that another possible advantage of scanning technology is increased flexibility in the ablation profile or algorithm. The profile can produce aspheric rather than only spherical ablations (Figs. 18 and 19). Larger diameters of ablation can be made. The possibility of using topographical maps of the cornea to guide the ablation is a distinct advantage, which will allow for more flexibility in treating astigmatism. Some patients do not have perfect symmetry of the cornea, particularly those with surgically induced astigmatism after penetrating keratoplasty or cataract surgery (Fig. 12), or those with keratoconus (see Chapter 3). Broad beam lasers do not take the asymmetry of irregular astigmatism into account; they treat all corneas the same. The scanning technology allows the possibility of a customized ablation that is unique for every cornea (Fig. 19).

(**Editor's Note:** this flexibility of ablating different profiles in the same cornea is being utilized by some surgeons to create or "sculpt" the so-called "multifocal cornea" which is a significant step forward **when it works** but of increased risk to the patient's quality of vision when even a minor error in the sculpting occurs. See Fig. 23. This procedure is experimental).

It may even be possible to improve upon the naturally occurring corneal surface, with improvement in best corrected visual acuity, bringing patients who are 20/20 with correction preoperatively to 20/15 uncorrected postoperatively. We still need more experience to know more definitively whether scanning lasers can actually fulfill their early promise.

Currently Available Scanning Lasers

Several companies are now working on developing scanning lasers. **Chiron** (now a division of Bausch & Lomb) has the Technolas laser. **Autonomous Technologies,** recently purchased by Summit, the company that manufactured one of the first broad beam lasers, also manufactures a superior quality scanning laser. This indicates that they believe the **future of lasers is in scanning technology**. The Japanese company **Nidek** and the U.S. company **Laser Sight** also manufacture scanning lasers. The Nidek laser involves a slit that can be moved across the surface like the rectangular beam of a slit lamp . The **Meditech** is similar. The Visx laser has recently been modified ("Smooth Scan") to achieve a scanning effect. Although it is a broad beam laser, the smooth scan modification allows the broad beam to be broken up into individual beams that scan the surface. It is predicted that the smoother ablation that results will improve results of surgery. **McDonnell** explicitly adds, however, that improved surface smoothness has yet to be proven in a prospective, randomized trial to translate into improved visual acuities.

The **Nidek** and **Autonomous** lasers are now commercially available, with recent approval by the U.S. Food and Drug Administration (FDA). Other scanning lasers, such as the **Technolas** laser, remain under study.

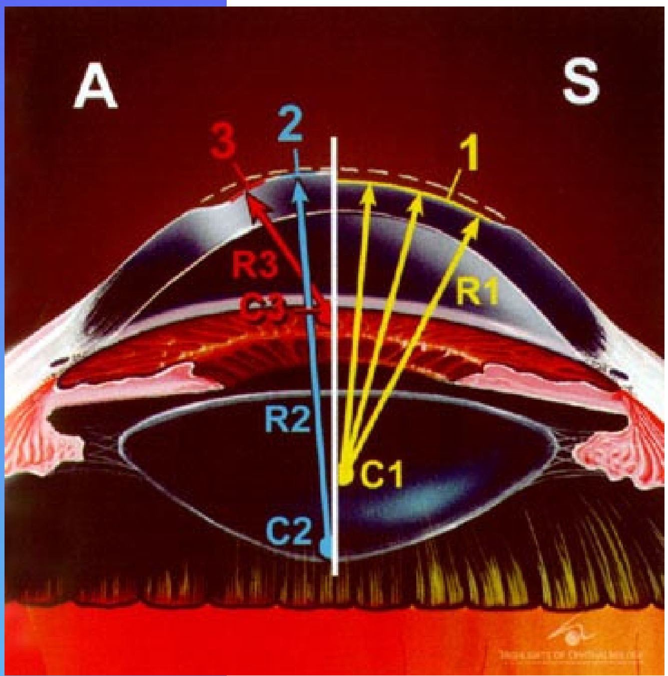
Eye Tracking Systems

Another advantage of the scanning lasers is that they can be used in combination with eye tracking technology and computer controlled mirrors (Fig. 20) to move the spot automatically in microseconds to compensate for eye movements. At least theoretically, such a laser is not dependent on absolute fixation and can thereby improve the quality of the surface.

As described by **McDonnell,** landmarks are identified at the beginning of the procedure. Without eye-tracking systems, if the patient looks slightly away from the fixation target while a broad beam laser is being used, the surgeon must quickly release the foot pedal and stop the ablation. With eye tracking technology, however, the laser immediately registers the movement of the eye and moves the spot accordingly without interrupting the surgery. Technologically, some of these eye tracking devices are quite impressive. Even if a patient moves considerably, the ablation spot can be placed perfectly.

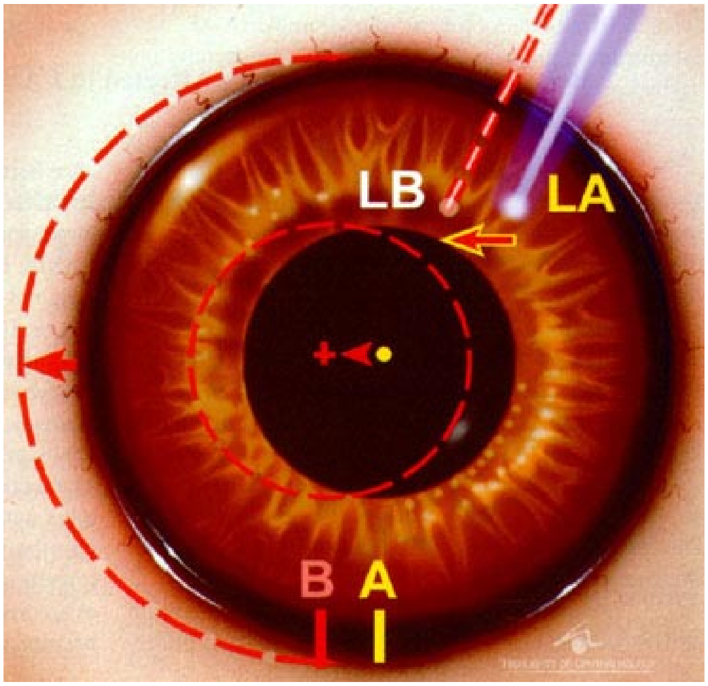
Autonomous Technologies, Nidek, and several other companies now manufacture eye tracking systems. Proof that these trackers improve surgical outcomes is still to be established, according to McDonnell. Data have not yet shown that the eye tracker prevents decentration, or results in improved vision compared to results from a broad beam laser without eye tracking capacity.

Figure 19 (left): Concept of Spherical vs. Aspherical Ablation Profile as Obtained by the "Flying Spot" Type Laser



This cross section of the anterior globe compares a spherical ablation profile (S) to an aspherical profile (A). A spherical treatment results in a corneal surface (1) which has the same radius (R1) throughout its curvature. The common center of the spherical curvature is shown at (C1). By comparison an aspherical ablation profile, made possible by the "flying spot" type excimer laser, is defined as one which has varying curvatures across the treatment zone. In the aspherical example (A), the central curvature (2) has longer radius (R2) than the mid-peripheral curvature (3), which has shorter radius (R3). The centers of curvature for the two areas of the cornea are different (C2 and C3). The curvature change between these two areas is gradual. Thus, the central cornea has a "flatter" curvature than the mid-peripheral cornea in this case. The dotted line represents the pre-op corneal curvature.

Figure 20 (right): Concept of Eye Tracking For More Accurate Corneal Ablations During Movements of the Eye



New eye tracking technology can trace eye movements by detecting displacement of the pupil. In microseconds the eye tracking computer can move the treatment spot of an Excimer laser beam appropriately to compensate for these eye movements. For example, laser beam (LA) is treating an area of the cornea when the eye is in position (A). Suddenly, during treatment, the eye moves slightly to the left to position (B). The eye tracking computer detects the movement of the pupil to the left (dotted circle) and commands the laser to track left (LB) the same amount, within microseconds. Thus the laser continues treating the same area of the cornea as desired before the eye movement took place. Such technology aims to increase the accuracy of the desired ablation and resulting correction.

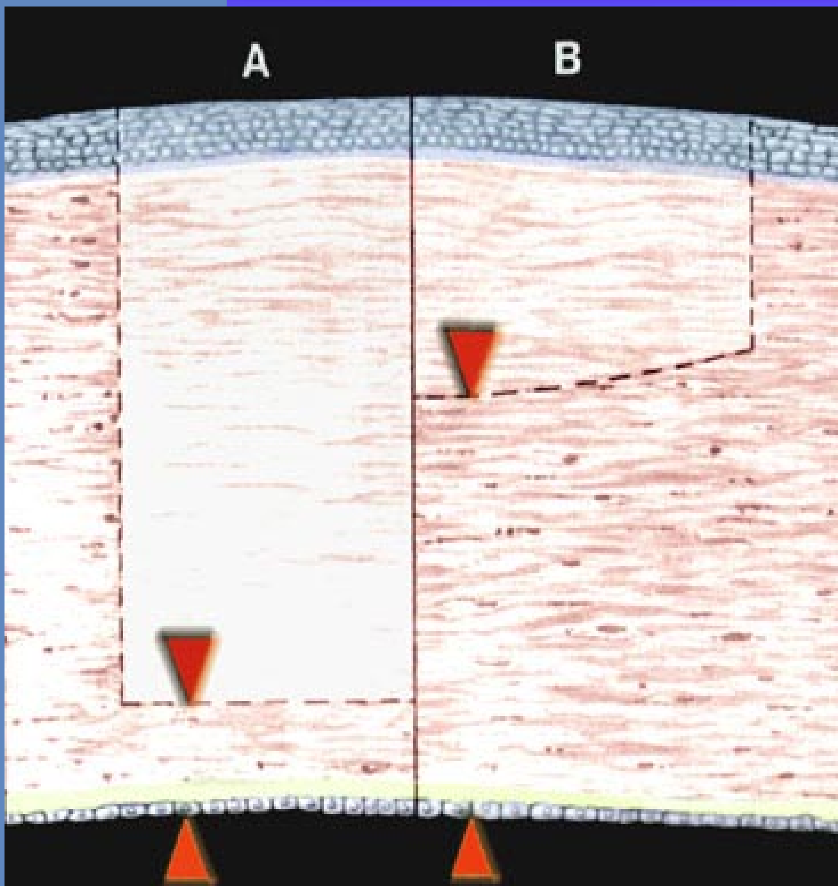


Figure 21: How Corneal Tissues are Affected with Different Refractive Techniques

In this figure, you will clearly observe the differences in corneal tissue invasion comparing incisional keratotomy to laser in situ keratectomy (LASIK). (A) This cross section view of the cornea shows the tissue penetration of the diamond knife in RK with a deep incision of 500 microns reaching down close to Descemet's. The space shown between the arrows demonstrates the thin, untouched and intact corneal area. The corneal tissue strength is significantly weak and unstable because of the radial cuts. (B) This represents the corneal depth reached in LASIK by the excimer laser in a patient with -8.00 (myopic) diopters. The higher the myopia, the larger the ablation but limited by Jose Barraquer's thickness law. (See Chapter 3). In this case the ablation depth reaches 240 microns (160 microns: corneal flap + 80 microns: stromal laser ablation). The rest of the corneal stroma is untouched (between arrows).

How the Corneal Tissues are Affected in LASIK vs Incisional Keratotomy

With excimer ablation in LASIK (laser in situ keratomileusis) and PRK (Photorefractive Keratectomy) most of the tissue is removed from the central part of the cornea. The ultraviolet light has so much energy that it smashes the inter- and intra-molecular bonds, ejecting the molecules at high speed (Fig. 14). Tissue ablation in LASIK reaches an average of 250 microns (Fig. 21-B) from the original surface of the cornea. On the other hand, during incisional keratotomy (radial keratotomy for myopia and astigmatic keratotomy for astigmatism) the depth of incision into the corneal stroma reaches down to 500 microns, close to Descemet's membrane and almost 90% of the corneal thickness (Fig. 21-A).

Compare this figure with Fig. 5 for identification and respective thickness of each layer. This major difference between the two techniques clearly shows how the stroma is significantly weakened in incisional keratotomy thereby affecting the strength and stability of the globe. LASIK involves no heat damage, no permanent scarring, not even a thermal effect.

In the **long run**, RK patients carry two swords of Damocles over their heads. One is the threat of a blow to the eye severe enough to cause a rupture. The RK patient is always more susceptible to rupture because the corneal scars will never be as strong as the original cornea. The second threat is that these scars apparently stretch or relax with time, which may give the patient more effect than the original result. An undercorrected patient moves toward a better result, but a properly corrected or overcorrected patient moves into hyperopia, and can become quite farsighted.

DIFFERENT OPTIONS, SURGICAL APPROACHES AND INDICATIONS

George Waring, M.D. emphasizes that, after about a hundred years of development, refractive surgery is now a legitimate subspecialty of ophthalmology. There are now refractive surgery specialty societies and congresses. Journals and a significant number of papers on the subject appear in the major ophthalmology journals around the world.

Refractive surgery in the 21st century requires that the surgeon develop multiple skills. A good cataract surgeon should have a variety of skills and techniques, including the ability to employ a variety of intraocular lenses where they are needed. In the same way, the surgeon who performs refractive surgery should have a variety of approaches at his/her command to meet the individual needs of each patient.

Surgeons who perform refractive surgery must be capable of offering their patients at least some of the main techniques available that may be effective, affordable and safe. These techniques are identified in Figs. 22, 23, 24 and 25.

If the surgeon uses only one technique for refractive surgery, then the patient must meet the needs of the surgeon -- not an optimal clinical circumstance. At the Emory Vision Correction Center where **Waring** is Director and founder, he and his colleagues perform a full variety of modern refractive surgical techniques. Modern refractive surgical techniques are grouped in the following categories:

I. PROCEDURES TO CHANGE THE CORNEAL CURVATURE

These may be done with lasers or with the diamond knife or other surgical instruments. They are all shown in Figs. 22 and 23.

Those Done With Lasers:

1) LASIK (Fig. 22-A) - Performed with Excimer Laser and Microkeratome - Indications:

A) Myopia from -1.00 D to -10D. Performing LASIK for patients with myopia higher than -10D has a larger risk to the patient's final **quality of vision** because they may have difficulty with night vision such as glare and halos. Some patients who have undergone this operation with myopia higher than -10D are **very unhappy** because they have to go home as soon as night starts and the pupil becomes larger. This is due to the reduced optical zone used with LASIK in treating high myopes.

B) Hyperopia from +1.00 D to +4.00 diopters.

C) Astigmatism from 1.50 D to 5.00 diopters.

D) Anisometropia: in children under 10 years of age who have failed to maintain their visual acuity under therapy with contact lenses or glasses. This procedure must be done under general anesthesia.

Size of Optical Zones for Myopia and Hyperopia

Maria Clara Arbelaez, M.D., has pointed out that the limitation of LASIK beyond -10D is because with scanning lasers it is important not to use optical zones smaller in diameter than the size of the pupil in the dark. In both myopia and hyperopia we need to work with optical zones larger than the size of the pupil at night. This limits the upper range of myopic and hyperopic correction we can prudently obtain with LASIK because the larger the optical zone, the lower the correction that can be attained with scanning lasers.

For corrections larger than -10 D, we have better options available now, namely phakic intraocular lenses (Fig. 24).

2) PRK (Fig. 22-B) - Performed with Excimer Laser - Indications:

a) Myopia: from -1.00 D to -5.00 D.
b) Hyperopia: from +1.00 D to +4.00 D.
c) Astigmatism: from 1.00 D to 3.00 D.

According to **Richard Lindstrom, M.D., the best operation in most cases is LASIK.** For the surgeon who can manage the microkeratome well and can, therefore, perform LASIK, the indications for PRK outlined above are really a second or third choice. Even though PRK is safe and effective, it has a fairly large incidence of postoperative corneal haze.

According to **Lindstrom, PRK is indicated as the procedure of choice,** as follows:

1) Superficial scar with myopia.
2) Basement membrane dystrophy with myopia.
3) Myopia when unable to use a microkeratome because of a high brow or tight lid with narrow palpebral fissures.

Comparison Between LASIK and PRK

Howard Gimbel, M.D., and **Simon Levy, M.D.,** find that LASIK has been used with very encouraging results in the treatment of both myopia and hyperopia. The place of LASIK alongside photorefractive keratectomy (PRK) is in flux but LASIK appears to be the better technique in correcting higher degrees of myopia and low and moderate hyperopia. In some centers such as their own (as well as Waring in Atlanta and Lindstrom in Minneapolis), LASIK is also routinely used to treat low myopia. LASIK is superior to PRK in causing minimal postoperative discomfort, in the rapid recovery of clear vision and stabilization of refractive change, and in the infrequent occurrence of haze. However, LASIK is the much more surgically demanding of the two techniques.

3) Non-Contact Laser Thermal Keratoplasty (LTK) - (Fig. 23-D) - Indications

This operation is performed with an **infrared Holmium:YAG laser** using a non-contact slit-lamp delivery system, as developed by Sunrise Technologies in the U.S.

a) Low Hyperopia: (+1.00 D to + 2.50 D). This constitutes the majority of patients with hyperopia. **Douglas D. Koch, M.D.,** Associate Professor of Ophthalmology at Baylor University in Houston and **Peter McDonnell, M.D.,** Chairman of the Department at the University of California at Irvine and Professor of Ophthalmology at the University of Southern California (Doheny Eye Institute) have found in a joint study that there was only 0.4 diopters average regression between 6 months and 2 years and almost no regression between 1 and 3 years. Regression had been the problem with several techniques previously used with Holmium:YAG laser.

b) Presbyopia: Treated with LTK through a monovision approach by inducing some myopia in one eye and emmetropia in the other.

c) Overcorrection after LASIK or PRK

4) Excimer Laser Sculpting to Produce a Multifocal Cornea - (Fig. 23-E)

Indications: Simultaneously performed for correction of refractive error for distance and near (presbyopia) (Fig. 19). Presumably this is a custom-made ablation for each different cornea and refractive error. It works in some cases, but it is still quite risky in most patients because they may end up with decreased quality and comfort of vision.

Changing the Corneal Curvature with Surgical Instruments

1) Radial Keratotomy - (Fig. 22-C): **Juan Murube, M.D.,** Professor of Ophthalmology at the University of Alcala (Ramon y Cajal Medical Center) in Madrid, Spain considers that RK continues to be valid in the correction of **myopia** even though it is being replaced by LASIK.

Murube is a top refractive surgeon who can utilize the highest technology available (LASIK, etc.) but he is also fully aware of the needs and limitations of well trained clinical ophthalmologists who practice in rural

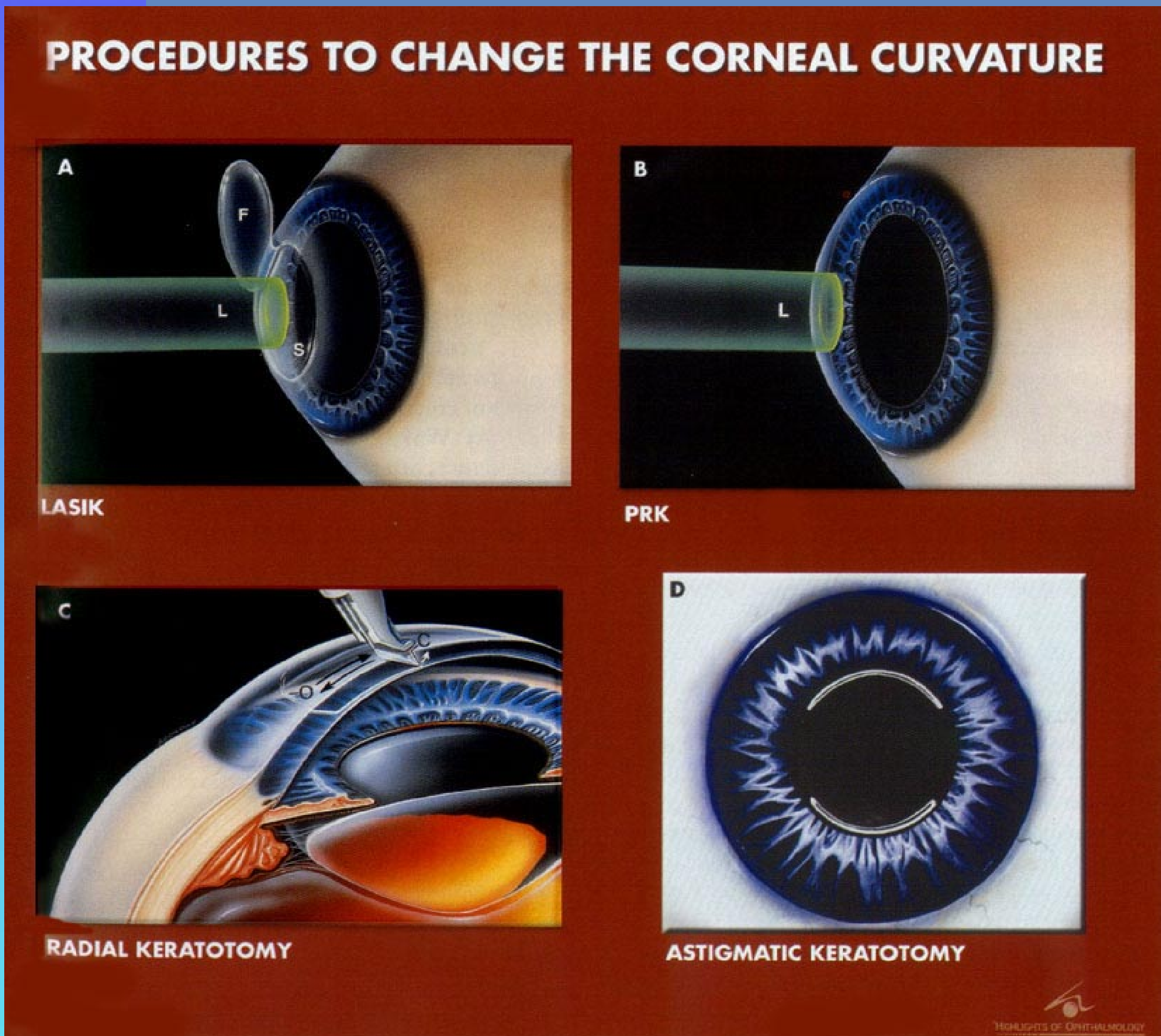


Figure 22: Correcting Ametropia by Changing the Corneal Curvature

The miotic cornea can be sculpted with an excimer laser, either under a corneal flap (LASIK) (A) or directly (PRK (B). Stromal incisions can be made to weaken the cornea, radially for myopia (C), or arcuately for astigmatism (D).

areas of the many countries he has visited. Many surgeons do not have an excimer laser available, and still perform RK.

Indications for Myopia: a) Classical 8 incisions: from -2.50 D to -5.00 D. b) 4 incisions: from -1.50 D to -2.50 D. **Lindstrom** uses RK only in selected cases of low myopia and as an enhancement following cataract surgery (-1.00 D to -3.00 D). **Lindstrom** never performs more than 4 cuts and in selected cases of very low myopia may do a MINI-RK (Fig. 3).

Waring at the Refractive Surgery Center in Atlanta (Emory University) offers RK for patients with very low myopia of -1.00 D to -2.00 D, especially for those without the financial resources to afford excimer laser surgery.

Harold Stein, M.D., in Toronto, Canada, a prestigious surgeon with a very large refractive surgery practice uses RK in cases under -2.5 diopters with astigmatism less than -2 D. He has rarely seen any haze or other complication and almost zero retreatments are needed.

Two of the most prestigious ophthalmic surgeons in Asia are **Arthur Lim, M.D.,** Chief of Singapore's Eye Institute, who also has extensive experience in the rural areas of China and **Pran Nagpal, M.D.,** head of a large and progressive Ophthalmic Institute in India. They note that most medical centers in larger cities in Asia already have the excimer laser technology available but that RK is still used in many rural areas.

We all know, of course, that while RK remains an effective and relatively economical refractive option for up to 4 or 5 diopters of **myopia,** the reduction in the corneal integrity and stability leads to long term changes in the refractive error when corrected with this procedure. These considerations have led to the increasing preference for excimer techniques, particularly LASIK.

2) Astigmatic Keratotomy - (Fig. 22-D) - Indications

This procedure, also known as refractive keratotomy, is still widely used. It consists of two techniques: the arcuate keratotomy shown in Fig. 22-D and the transverse keratotomy (also known as T-cuts). **Lindstrom** uses this technique to correct the following refractive errors:

a) Post-keratoplasty astigmatism.

b) Refractive cataract surgery (Fig. 23-A): the cataract patient with astigmatism.

c) Mixed astigmatism as for example, -1.00 +2.00 x 90 (Refer to Fig. 12).

d) When excimer laser is not available: astigmatic keratotomy may correct up to 2.5 to 3 diopters of astigmatism.

A **combined procedure of excimer and astigmatic keratotomy** is used only if the excimer laser is not capable of correcting the astigmatism present.

At **Waring's** center in Atlanta astigmatic keratotomy is offered for patients with **complex astigmatism** that cannot be resolved with the laser and for patients with residual astigmatism after intraocular lens implant surgery.

Changing the Corneal Curvature with Corneal Implants and Injected Synthetic Substances

Intrastromal Corneal Ring (Fig. 23-B): Intrastromal segments of a synthetic material are placed in patients with low myopia up to -3.50 D who do not want a microkeratome flap or laser treatment and who prefer the potential **reversibility** of the intracorneal ring procedure. It is an effective technique for low levels of spherical myopia. This procedure is discussed in chapter 5.

Gel Injection Adjustable Keratoplasty - (Fig. 23-C). As outlined by **Douglas Koch, M.D.,** the method involves injecting gel in the paracentral corneal stroma in order to flatten the central cornea and reduce myopia. This procedure is discussed in Chapter 5.

Indications: Correction of up to 5 or 6 diopters of myopia.

Particular Benefits: It is **reversible** and **adjustable.** Gel can be added or removed as needed, making

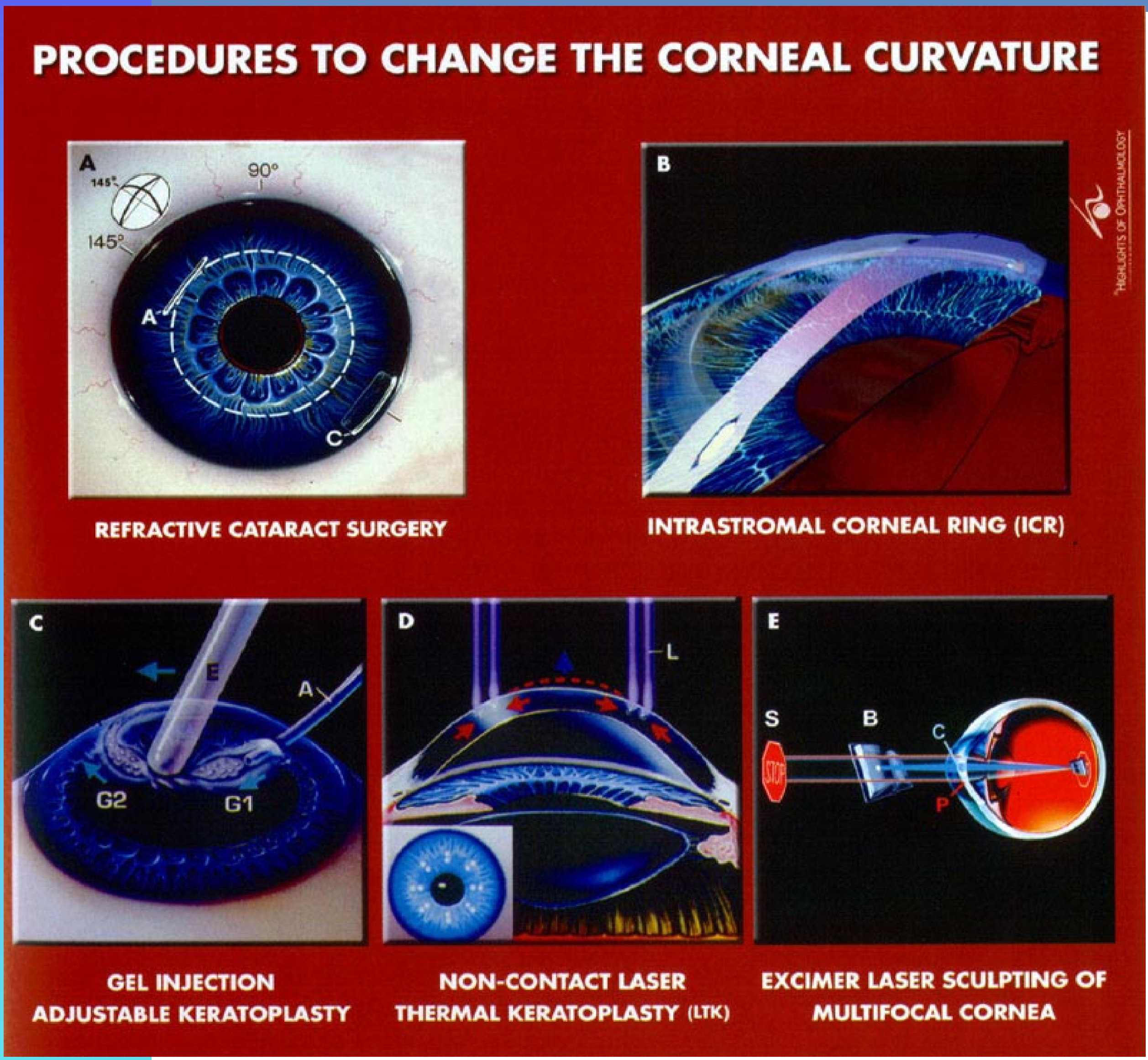


Figure 23: Correcting Ametropia by Changing the Corneal Curvature

(A) A transverse incision of the cornea can also be used to correct astigmatism when performing cataract surgery. Implantation of an intrastromal corneal ring (B), or injection of gel into a peripheral, circular track (C), forces the peripheral cornea to bulge, flattening the central cornea for correction of myopia. Mid-peripheral stromal laser coagulation (thermal keratoplasty, or LTK) (D) causes this tissue to shrink and the central cornea to bulge for the correction of hyperopia. A scanning excimer laser beam might sculpt a multifocal cornea (E) for the correction of hyperopia and presbyopia.

it possible to adjust patients' refractive errors throughout their lives.

Limitations: It is still in the early stage of evaluation in human patients. **Douglas Koch, M.D.,** (Houston), **Juan Murube, M.D.,** (Madrid) and **Gabriel Simon, M.D.,** are the pioneers in the research and clinical investigation of this procedure.

The sequence in which these techniques are presented in Figs. 22 and 23 is partly related to the nature of the procedure, in part to the present acceptance they have among ophthalmic surgeons, and the stage of evaluation of each technique.

II. INTRAOCULAR LENS IMPLANTATION IN PHAKIC EYES

The different lens types are shown in Fig. 24. Compared with the techniques utilized to modify the corneal curvature (Figs. 22 and 23), of which LASIK is the procedure of choice in most cases, phakic IOL styles and designs are capable of providing the patient with the best visual acuity, quality of vision and quality of image. While offering their own challenges, the techniques and instrumentation for phakic lens implantation are adapted from the standard cataract surgery already performed by most surgeons. The **parameters** for LASIK and its upper limits of correction as previously outlined as a guide, will serve to provide a better orientation as to when to use phakic lenses. Although there is some overlap of refractive error correction with each procedure, usually the best indications for phakic IOL's start when LASIK ends. They are grouped as follows:

1) Phakic IOL's in the Anterior Chamber (Fig. 24):

A) The Artisan (Iris Claw) Lens designed by **Jan Worst, M.D.** from Holland over 10 years ago (Fig. 24-D). This lens is now gaining very much popularity because of improvements in the design and instrumentation, making it a more "friendly" surgical procedure but still requiring much skill. Technically, it is a more demanding procedure than the Nu-Vita lens. It also provides very good results. It is fixated on the peripheral iris tissue (Fig. 24-D). (See Chapter 6.) It is manufactured by Ophtec. There are more years of experience using this as a phakic lens than there are with the Nu-Vita lens.

Indications: **High myopia** in the range of -11 to -22 D and **high hyperopia** in the range of +6.00 to +10 diopters.

B) The Multiflex Nu Vita Lens, with fixation in the anterior chamber angle. This is a less skill-demanding procedure **(Fig. 24-C)** but has the disadvantage of the precision needed to calculate the size of the lens (from white to white at the limbus +1 mm).

The main experience with this type of lens is with **Kelman's** Multiflex design in aphakic eyes. Bausch & Lomb manufactures this re-designed lens for phakic eyes under the trade name of Multiflex Nu-Vita. The reports on its use are enheartening.

Indications: **High myopia** in the range of -11 to -22 D. The step by step technique on the implantation of these lenses is presented in Chapter 6.

2) Lenses Implanted in the Posterior Chamber, Between the Anterior Capsule and the Posterior Iris Surface (Fig. 24)

A) The Pre-Crystalline PMMA IOL (Fig. 24-A): This lens was designed and created by Professor **Joaquin Barraquer, M.D.,** of Barcelona, Spain. It is implanted between the posterior surface of the iris and the anterior capsule of the crystalline lens and fixated in the sulcus.

Indications: **High myopia** in the range of -11 to -22 D.

Benefits: Contributes significantly to correct vision in patients where LASIK is contraindicated. Be

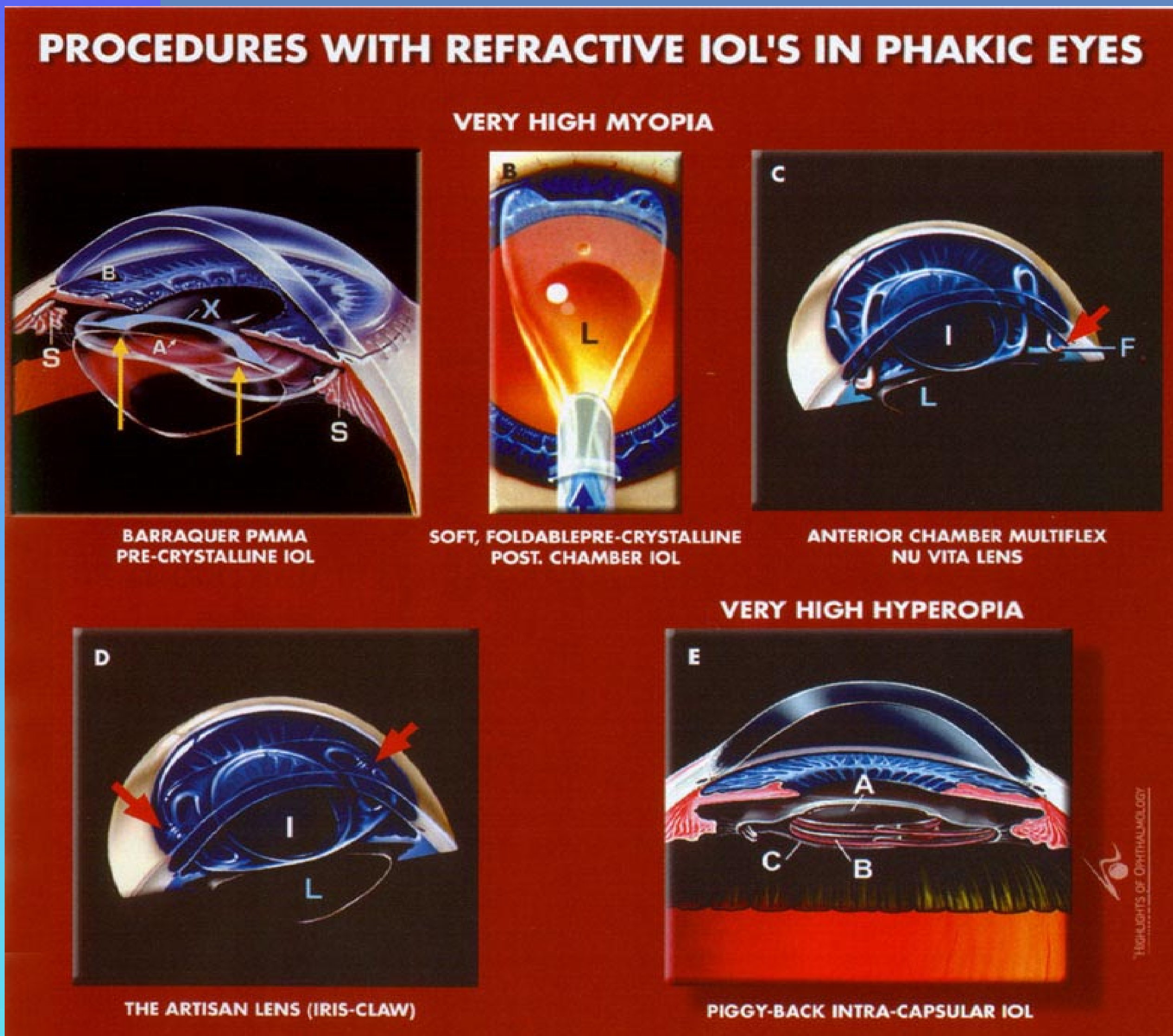


Figure 24: Procedures with Refractive IOL's to Correct Very High Myopia and Very High Hyperopia

Very high myopia is best managed with phakic intraocular lenses. They can be placed in the posterior chamber between the iris and the normal lens (A, B); or in the anterior chamber, supported by the chamber angle (C) or the peripheral iris (D).

For very high hyperopia, a lensectomy can be done and **two** aphakic intraocular lenses implanted on top of each other (E).

cause of its larger optical zone, it is particularly helpful to people with large pupils at night, so often present in high myopes.

Limitations: It requires a corneo-scleral incision of 7 mm for insertion (non-foldable, made of PMMA).

B) The Intraocular Contact Lens (Fig. 24-B): This is a soft, foldable, small incision **posterior chamber plate lens** designed by **Guimaraes** (Brazil) and **Roberto Zaldivar** (Argentina). This lens is also implanted in the posterior chamber between the posterior surface of the iris and the anterior capsule of the crystalline lens, and fixated in the sulcus.

Indications: **High myopia** over -10 D and high hyperopia over +3 D.

Limitations: The reduced size of the optical zone needed to create a very high correction within a very thin foldable lens may give rise to uncomfortable vision at night in some patients.

3) Clear Lens Extraction: with corrective intraocular lens implantation. Especially useful in presbyopic hyperopes greater than +3 diopters.

4) Piggyback Intracapsular IOL's (Fig. 24-E): Inserted inside the capsular bag after clear lensectomy to correct very high hyperopia when the latter is so high that no one intraocular lens may be easily available with such high power. For this procedure, it is best to use PMMA IOL's.

III. INTRAOCULAR LENS SYSTEMS OF PARTICULAR NEW INTEREST FOR THE CORRECTION OF APHAKIA

There is a wide variety of intraocular lenses either available or in the stage of development to correct aphakia at the time of cataract surgery. The lenses are from traditional as well as new designs and materials. Alcon has a one-piece acrylic lens. Graham Barrett has designed a one-piece hydrogel lens. Allergan has a new acrylic lens currently under investigation. Storz, now a division of Bausch & Lomb, has manufactured a lens that has a hydrogel acrylic optic fused to PMMA haptics; this lens has been approved and is being used widely throughout Europe. Using an interesting technology, Mentor has developed the Memory Lens, a hydrogel acrylic that comes pre-rolled. Although it must be kept chilled, it can be taken from the case and inserted into the eye without being folded or requiring any other manipulation.

New IOL Systems of Particular Interest

There are three designs and systems that have created particular new interest because they each provide a significant contribution of a different nature. They are:

1) Allergan's Array Multifocal Foldable IOL (Fig,. 25 A-B): At present, this is the only foldable **multifocal** intraocular lens that has been approved by the FDA. **Virgilio Centurion, M.D.** recommends its use for surgeons who are confident with phacoemulsification and small incision techniques. This lens is made with a silicone optic and PMMA haptics.

Having used different kinds of multifocal IOL's in the past, **Centurion** is familiar with the deficiencies in clinical results inherent in some designs. This new multifocal lens, however, is a refractive molded lens instead of a diffractive lens, which were the ones that gave rise to visual difficulties in the past.

Douglas Koch, M.D., points out that studies conducted using this lens show very high levels of vision with little evidence of contrast sensitivity loss. A case-control study conducted by **Jonathan Javits, M.D.** comparing patients who received monofocal IOL´s with patients who had the Array multifocal IOL,s showed clearly that patients with multifocal IOLs, were functionally better and happier with their vision. This is the first study that has shown these results so convincingly.

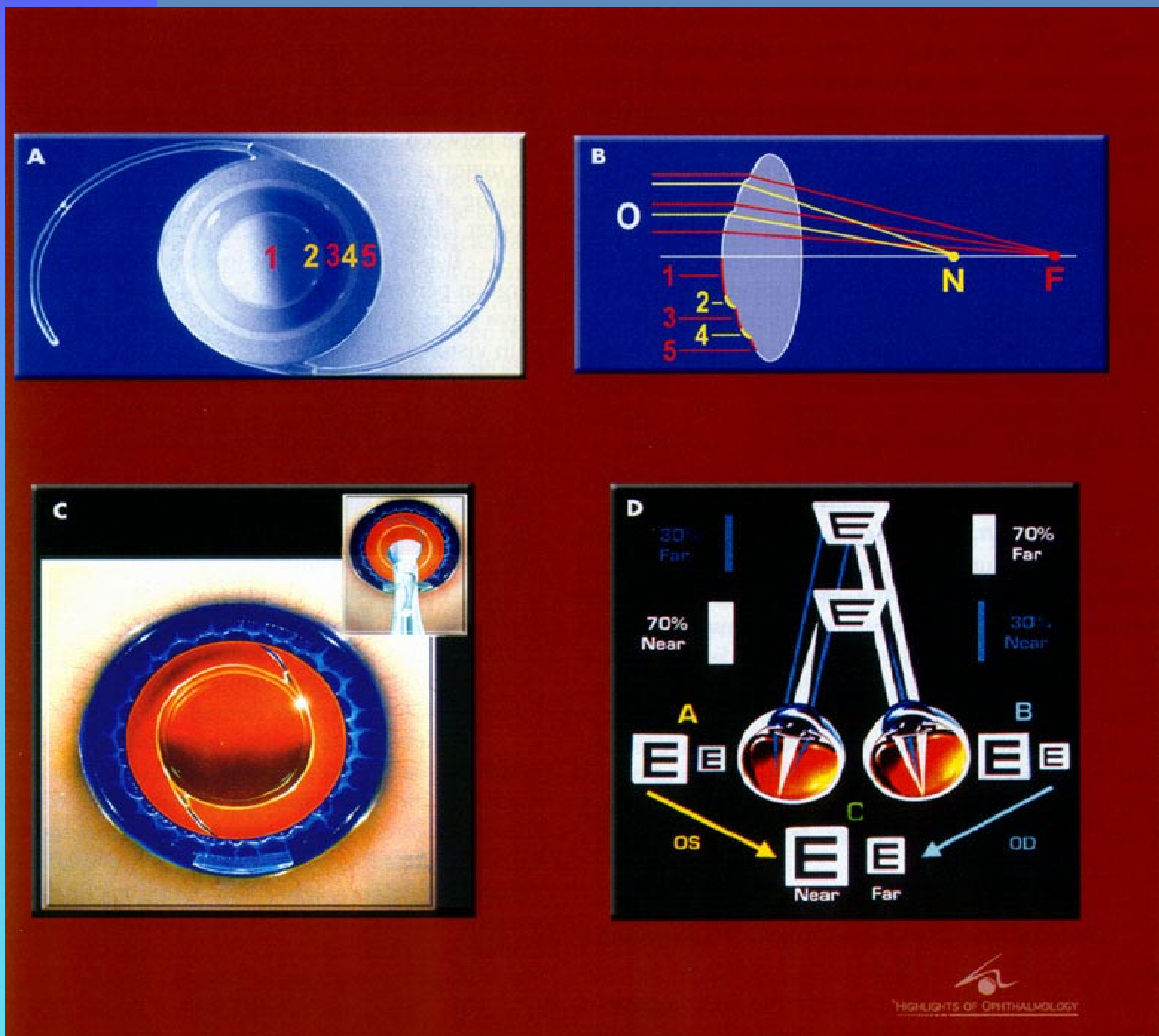


Figure 25: IOL Systems of Particular New Interest for Correction of Aphakia

The Allergan Array foldable multifocal lens is implanted in normal fashion (A, B). The Alcon AcrySof lens provides a very high quality image from a foldable lens, with less posterior capsule opacification (C). The Jacobi assymetrical lenses (D) are multifocal but provide emphasis for distance for one eye and for near for the other.

Studies in various parts of the world seem to reveal that more than 85% of patients have 20/40 or better vision without correction after implantation with this lens. All of the 456 patients in the US Clinical Study had J3 or better, and more than 60% were J2 or J1 without correction. About half were 20/20 without correction.

Researchers working with this lens have the clinical impression that depth of focus and quality of vision are improved if the surgeon implants the second eye within 4 weeks of the first implantation. Patient satisfaction is higher if there is a very short interval between the first and second eye. (A short interval between surgeries is usually the case when modern small incision cataract surgery is performed, if the cataract merits removal in both eyes. - Editor).

***2) Alcon's AcrySof Lens* (Fig. 25-C):** The long-sought solution to prevent opacification of the posterior capsule following extracapsular extraction seems to be partly attained through the implantation of the AcrySof lens. Recently published studies and extensive experience of prestigious ophthalmic surgeons reveal that IOL's made from polyacrylic material (such as the AcrySof lens manufactured by ALCON) **are associated with a significantly reduced incidence of posterior capsular opacification and consequent much lower YAG capsulotomy rates. It is not indicated for "piggyback" use.**

Special Features About AcrySof´s Implantation

At the present time this is the only approved acrylic lens in the United States. There are other acrylic lenses currently being produced in Europe.

Upon **handling** the lens, it is important to keep in mind that especially in high powers up to 30 diopters this is a thick lens. This makes folding more difficult. **Jack Dodick, M.D.,** has found that pre-warming the lens dramatically facilitates the ease of the fold. This is done at his institution by placing it in a warm environment such as on top of a sterilizer that has an ambient temperature between 100 and 105 degrees. This seems to soften the material and facilitates the gentle folding of the lens, making it much easier to implant especially for high diopter lenses which are more difficult to fold.

It is also important to keep in mind that if the surgeon performs rapid folding of a **cold** lens, this may leave striae in the lens that could conceivably interfere with visual acuity.

A second measure taken by **Dodick** to facilitate this lens' entry into the wound after folding and holding it with forceps is to pinch the lead edge of the lens with a second forceps, to make the "nose" conform into a bullet or missile shape. This facilitates entry into the eye. Once the nose enters into the eye, the rest of the lens follows with great facility.

Dodick does not use an injector, although that is another modality. He uses folding and insertion forceps to insert the lens. They must be very fine folding forceps so as to add very little bulk to the combination of lens and forceps that have to enter through the small wound.

Dodick likes to divide the implantation of the lens into three stages once it is in the anterior chamber. First, when the lead haptic is in the capsular bag, the lens is allowed to unfold. Stage two is the implantation only of the optic. Stage three once the optic is implanted is to implant the superior haptic by rotating it with the Lester hook or placing it with a Kelman-McPherson forceps. **Dodick** considers that a common mistake when implanting an AcrySof or any soft IOL, is to implant it in only two stages. Once the inferior haptic is placed into the capsular bag, some surgeons proceed immediately to try to place the optic and the superior haptic in one second stage. His experience has taught him that implantation becomes simpler and more controlled by dividing it into the three stages described.

3) The Asymmetrical Multifocal IOL (Fig. 25-D): **Professor Karl Jacobi, M.D., and Felix Jacobi, M.D.,** in Germany have introduced a new feature to multifocal IOL implantation. The idea of asymmetrical bilateral multifocal IOL implantation was first advanced in 1993. It came from the realization that a reduction in contrast sensitivity is inherent in the optical design. This reduction may be clinically significant and disturbing; it can especially interfere with night driving.

Karl Jacobi devised the concept of splitting light distribution for the far and near focus between both eyes. The concept requires bilateral cataract surgery with implantation of two different types of multifocal IOL,s. One eye receives a multifocal IOL that is dominant for distance with a light distribution of 70% for the far and 30% for the near focus. The fellow eye receives a multifocal IOL that is dominant for near and has a light distribution of 30% for the far and 70% for the near focus. The idea is to provide an improved binocular contrast sensitivity and better distance and near visual acuity than can be provided by bilateral multifocal IOL,s with symmetrical light distribution. The method essentially combines the two ways of correcting presbyopia after cataract surgery: monovision and multifocal IOL implantation. However, while patients with monovision see a blurred, out-of-focus image, patients with this lens combination see a distinct and clear image in each eye, although there is a low image contrast in the eye with the non-dominant focus.

Foldable Diffractive Multifocal Lens

Another important new development in this concept is the third generation, foldable diffractive three piece silicone multifocal lens with asymmetrical light distribution developed by **Felix Jacobi, M.D.** The advantage of this diffractive lens is that it is independent of pupil size and not subject to optical decentration problems.

This diffractive three piece silicone lens can be folded and implanted through a 3.5 mm self-sealing clear-corneal incision, thus reducing wound induced astigmatism to nearly zero. The lens optic is biconvex and also aspheric, thereby providing good optical performance similar to a monofocal IOL. This lens system is available through **Acritech,** Germany.

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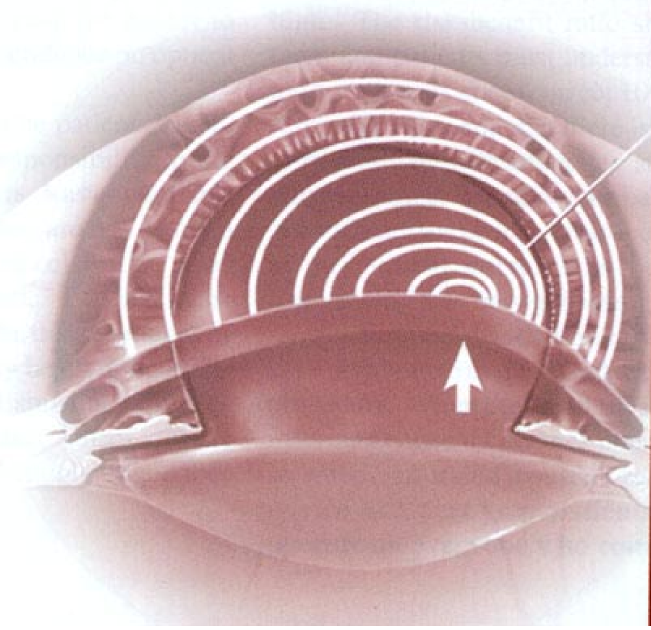
Preoperative Evaluations and Considerations

CHAPTER 3

HIGHLIGHTS OF OPHTHALMOLOGY



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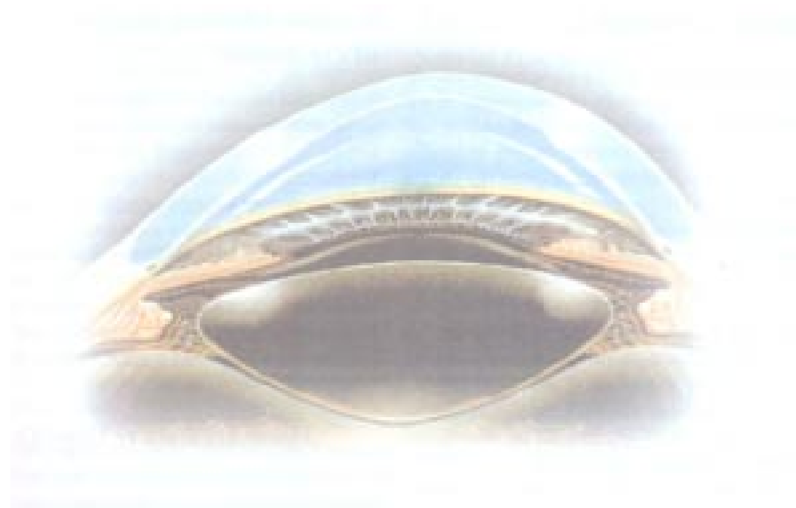


The Refractive Surgery Patient

George Waring, M.D., has observed that there are two important factors about patients seeking refractive surgery. First, surgery is often patient-driven; they are very interested in seeing well without glasses or contact lenses, and they sometimes push the doctor to provide surgical relief from their dependence on optical devices.

Second, because surgery can be patient-driven, the ophthalmologist has a special responsibility to the patient, to **be sure that patients have realistic expectations about surgery:** that they are not deluded by their own wishes, enthusiastic media claims, or good results their friends might have had. Patients must understand both the advantages and the disadvantages of the surgery and accept that there may be complications from any surgical procedure. Advertising that promises total freedom from glasses or contact lenses does a disservice to patients and becomes a double-edged tool for the physician.

The needs of these patients are markedly different from those more traditional ones seen in the clinical ophthalmologist's office. These refractive surgery patients require more information, generally have more questions, and must be told of the risk that may be involved even though the percentage of success may be high. The risk-benefit ratio should be analyzed with them and patients must understand that the purpose of the operation is not to correct 100 percent of the existing refractive error and that there is at present no technique available that will guarantee such results. Therefore, what we aim at is to allow the patient to liberate himself/herself from the need to wear spectacles or contact lenses as permanent corrections because the ametropic abnormality can be significantly reduced.

Similarly, obtaining informed consent from patients about to undergo refractive surgery is a different procedure. When the result is very good to excellent, the informed consent becomes unnecessary. When it is not so good, informed consent becomes essential. **Our advice is: Select your patients carefully, and do not operate on everyone who comes into your office.**

Preoperative Counseling

Buratto, Brint and **Ferrari** emphasize that the patient should have a thorough understanding of the surgical technique, obtained by brochures, videos, and personal consultation (first with the surgery counselor and finally with the surgeon). When given the choice between PRK and LASIK, patients most often choose to have LASIK when they understand its advantages, specifically the rapid visual rehabilitation and minimal postoperative pain and lack of long-term use of eye drops.

If LASIK is the procedure to be performed, all potential complications, both the more common ones (such as a period of glare, halos and night driving difficulties), and the more rare complications (such as flap problems and infections), should be thoroughly discussed and understood by the patient.

In **Buratto's** extensive experience, it is also important that the patient understand that LASIK **involves a series of steps** and there is a possibility that the operation may be interrupted following any of these steps, such as problems with the microkeratome, incomplete cut, poor flap, or malfunction of the laser. Patients understand this better if it is explained to them that each step builds on the previous step and that each "measurement" must be perfect for the surgeon to proceed onto the next step.

The possibility of undercorrection and overcorrection must be understood as well as the possibility for the need of enhancement, especially with higher myopia.

Be very cautious with those close to presbyopia. They often have the impression that they will never need spectacles again. They should accept the possibility of having a period of temporary hyperopia, which may require either temporary or permanent reading glasses. Myopes are used to reading without spectacles. If this is no longer possible following refractive surgery, they may be unhappy with what the surgeon might consider a perfect result.

Factors Affecting the Surgeon's Choice of Operation

In Chapter 2, we identified each of the procedures and discussed their indications, advantages, limitations and disadvantages. You have observed by now that there is significant overlap in the indications of many procedures and the range of refractive error they correct. Which, then, is the most appropriate?

Pallikaris emphasizes that when there is an overlap of indications of two or more procedures, knowing the advantages and disadvantages of each, the next most important parameters in selecting the appropriate procedure are the patient's age, life-style, and needs (i.e., occupation).

Vision Accuracy vs Visual Quality

In judging what procedure to select for a specific patient, keep in mind that, depending upon their occupation, for many patients **visual quality without** halos, glare, prismatic effect, interface striae and metamorphoptic images, and also **without** impaired binocular fusion, and maintaining good contrast sensitivity are more important than a 20/20 uncorrected visual acuity.

For instance, as **Pallikaris** has pointed out, people with myopia working as watchmakers and computer users need to work for long periods with very accurate near vision. Their efficiency depends on visual detail. They need to be slightly undercorrected by procedures that do not produce or that have the minimum incidence of haze, decrease in contrast sensitivity, and metamorphoptic effects.

Patients who need to drive at night, sometimes for long times, need very clear vision. Consequently, they must have an operation that permits wider, very well-centered optical zones. In these patients, if highly myopic, do not perform LASIK over 10 diopters because there is the risk of ending up with a rather small optical zone. Small and eccentric ablation zones lead to glare, causing the biggest problem in this category of patients. A similar consideration applies to **very** high myopes treated with phakic IOL's. Be cautious in implanting soft, foldable posterior chamber **phakic** IOL's in them because the IOL's optical zone may be smaller than these patients need and they may have visual problems at night. In other, less highly myopic patients, these IOL's are quite successful (Fig. 24).

Elements Not Related to Refractive Errors

1. Orbit Configuration: Patients with small or deep-set orbits and narrow palpebral fissures should be discouraged from having LASIK because the micro-keratome suction ring cannot be well-positioned and may interfere with passage of the microkeratome itself. PRK as advised by Lindstrom or RK are the procedures of choice in these cases.

2. Autoimmune Diseases and Collagen Vascular Diseases: PRK is absolutely contraindicated because of the risk of stromal melt with an exposed stromal surface. LASIK might be performed but make your decision with particular caution.

3. Glaucoma: LASIK may be preferable in patients in whom intraoperative pressure rises with steroids or who have a strong family history of glaucoma since a steroid-induced pressure rise may seriously complicate the postoperative course or result in visual field loss.

Patients with glaucomatous field loss should be avoided. The brief intraoperative rise in intraocular pressure (IOP) from the suction during LASIK may theoretically do further damage and cause further field loss.

It is also important to consider that measuring intraocular pressure with the applanation tonometer following excimer laser surgery may provide erroneous results, usually with a tendency to give readings on the low side, that is, less than the real pressure. Of course, the usual tendency of glaucoma to get progressively worse may be masked by this situation or may give rise to a pseudo low tension glaucoma.

Absolute and Relative Contraindications - Special Precautions

1. Monocular Patients: As emphasized by **Machat**, they are always a contraindication since this is an elective surgical procedure.

2. Keratoconus and Sub-Clinical Keratoconus (Fig. 26): They are both contraindications for any refractive surgery. We must always be alert to detect a sub-clinical keratoconus. They are more definitively diagnosed through corneal topography, as presented later in this chapter. If not detected, a refractive surgery procedure may result in the development of ectasia because corneal stability has been affected. By all means, be on the lookout for these patients because, in addition to the possible development of ectasia, the results are unpredictable.

3. Healed Corneal Scars from Herpes Simplex: It is best not to perform refractive surgery in these patients. Reactivation may occur. Also avoid doing this surgery in patients with history of kerato- uveitis or ophthalmic herpes zoster.

4. Retinal Pathology: ***a) Retinal Tear:*** All candidates for refractive surgery must have a detailed fundus examination with the binocular stereoscopic ophthalmoscope and the pupil dilated. **If a retinal tear is present,** even if asymptomatic, it should be sealed with adequate laser before any refractive surgery is performed **(Fig. 27).** If undetected or not adequately treated and if a postoperative retinal detachment develops needing a buckling procedure, this may alter the refractive result, which may at times be significant. Patients with a retinal hole or lattice degeneration merit evaluation by a retina specialist.

A history of retinal detachment or retinal tears is not an absolute contraindication, but in these patients we must be quite cautious and have a detailed fundus

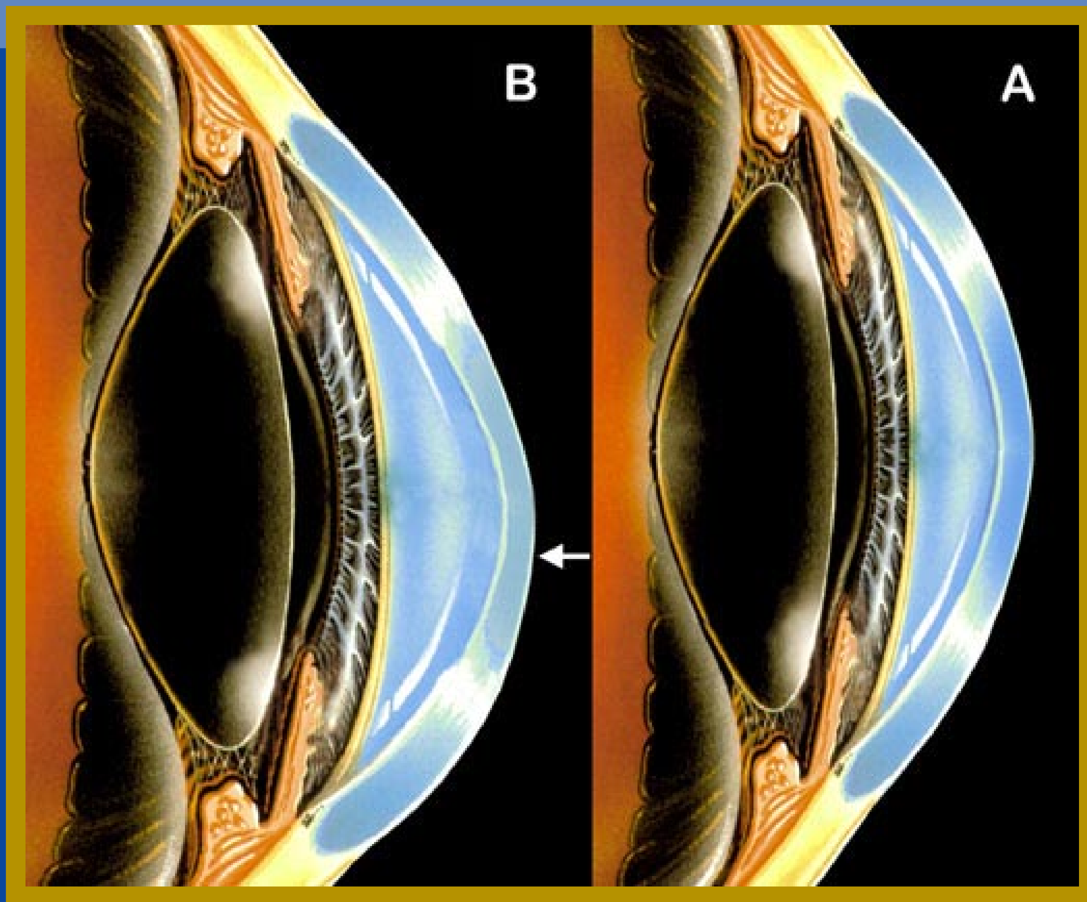
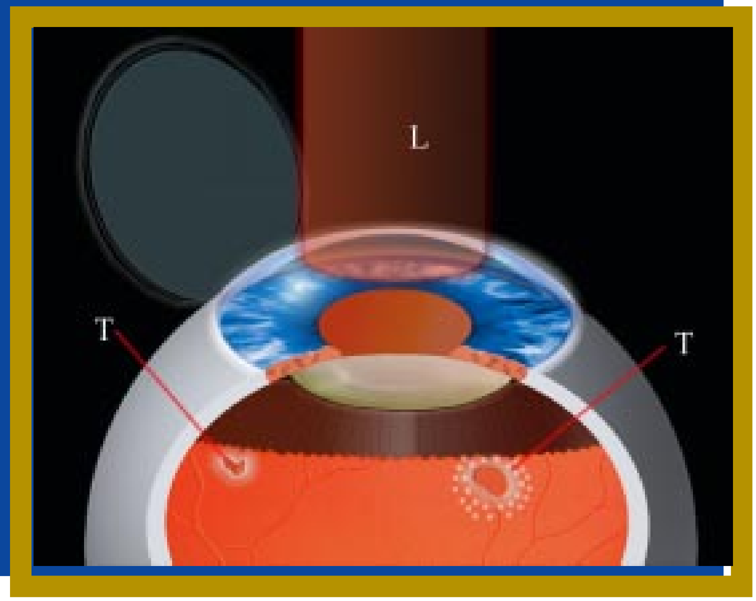


Figure 26: Preoperative Evaluation - Importance of Diagnosing Keratoconus and Sub-Clinical Keratoconus

This view shows a comparison of the profiles of normal corneal curvature and thickness (A) ideal for any refractive procedure, and typical keratoconus (B). Keratoconus can be detected by abnormal keratometric readings, topographic alterations or, when marked, by clinically abnormal corneal curvature (arrow) and the typical striae. The detection of sub-clinical keratoconus during the preoperative evaluation is also essential. Sub-clinical keratoconus can be detected only with computerized corneal topography (Fig. 40). Any refractive surgery procedure is absolutely contraindicated. Otherwise, the patient may develop progressive corneal ectasia with an unexpected, bad visual and refractive result.

Figure 27: Preoperative Evaluation - Importance of Examining the Fundus with Dilated Pupil and Indirect Binocular Ophthalmoscope - Observe the Presence of Retinal Tear

This cross section shows the presence of several retinal tears in a patient who was to have a LASIK procedure (L- Excimer laser). It is important to detect the presence of asymptomatic holes or small tears (T) preoperatively, especially in myopic retinas. It is wise to examine the fundus (retina and vitreous) with the indirect ophthalmoscope before any refractive surgery procedure. It is important to have any retinal lesion treated first by a retinal surgeon and proceed with the refractive surgery technique later. This is an important part of informed consent and good patient care, and can avoid surprises, complications and misunderstandings sometimes not related to the refractive operation.



examination preferably by a retinal specialist before undertaking refractive surgery.

b) Retinitis Pigmentosa: it is preferable to not do refractive surgery in these patients who already suffer from a serious, progressive, non-treatable disease. Night vision may be further affected.

c) Myopic Macular Degeneration and Posterior Staphylomas: it is important to document these changes because postoperative deterioration of vision may be independent of the procedure.

5. Diabetes Mellitus: Again, we are dealing with a patient who might have a progressive disease. Although diabetes is not a contraindication per se, it does require much caution and the patient must understand his/her future limitations so as to not relate them to refractive surgery performed perhaps years before retinal complications arise.

The Fundamental Role of Assessing Corneal Thickness

Study of the central cornea with **ultrasound pachymetry** is fundamental (Fig. 28). The surface of the **ultrasonic pachymeter** probe (Fig. 28) is wiped with alcohol and does not need to be sterilized. This instrument is used to take a very careful and accurate reading of the thickness of the central cornea. The pachymeter probe (P) is placed on the center of the cornea, perpendicularly as shown, to determine corneal thickness. The pachymeter has a console displaying the corneal thickness reading.

Clinical Importance

Ideally, we must preserve a **minimum** of 250 microns in the posterior stromal bed. Other investigators consider that preservation of a minimum of 50% of the preoperative central pachymetry is essential **(Fig. 28).** This is referred to as the **Barraquer "Law" of Corneal Thickness".** This is particularly important in the treatment of high refractive errors with the excimer laser and in "enhancement" procedures.

Unless sufficient corneal stroma remains, as determined by **Barraquer's** basic principle ("law"), there is an increased risk of developing corneal ectasia.

Determining the Amount of Correction to be Attained (Fig. 28)

The most important clinical application of assessment of corneal thickness is that the depth of the ablation determines the amount of correction that may be attained and the depth of the ablation must be within the parameters determined by Barraquer's thickness "law". The surgeon should not create a deeper ablation than that permitted by this "law", simply in an attempt to obtain more correction. If he/she does, it may lead to risks, particularly ectasia and keratoconus.

How to Calculate the Correct Amount of Ablation

If, for example, the central cornea has a total thickness of 560 microns, as shown in Fig. 28, and the thickness of the corneal flap in LASIK is 160 microns, and we allow 10 microns for Descemet's and the endothelium, there is a remaining stromal thickness of 390 microns. (560 – 160 - 10 = 390.) If we leave the required 250 microns of stromal bed untouched in order to respect Barraquer's law, the surgeon has a maximum allowed stromal ablation of 140 microns. (390 – 250 = 140.) It is generally estimated that 10 microns of ablation corrects one diopter of myopia. In this particular case, the surgeon could be allowed to ablate 14 diopters of myopia. (140/10 = 14.) This much correction, of course, is not recommended, as discussed in Chapter 2. The maximum recommended amount of myopic to be corrected by excimer is -10 D.

The planning as outlined here, beginning with a mandatory preoperative **Ultrasonic Pachymetry**, is essential for success when making calculations for: 1) the first operation, and 2) "enhancements". An absolute minimum total corneal thickness of 360 microns, ideally 380 to 400 microns, should remain postoperatively. This includes the corneal stroma, the LASIK flap and the very thin Descemet's and endothelial layer. The pachymetry should be performed both centrally and at 3.0, 5.0 and 7.0 mm paracentrally.

This planning must take into consideration the following factors:

1) Thickness of Corneal Flap: (average of 160 microns).

2) Diameter of Ablation: minimum of 6 mm in order to end with a functional postoperative optical zone of 4 mm. A 6 mm optical zone diameter provides the best quality of vision.

3) Amount of Residual Stroma.

4) Total Depth of Ablation.

Other Important Preoperative Assessments

In addition to the features already discussed, the other important measures in the preoperative evaluation are: unaided and aided visual acuity, autorefraction, manifest and cycloplegic refractions, keratometry, computerized corneal topography and endothelial cell count.

Endothelial changes should be assessed, since Fuchs' endothelial dystrophy, traumatic breaks in Descemet's membrane, and other causes of endothelial dysfunction may preclude stromal ablation.

Pupil size measured in different degrees of illumination is essential. Young patients with large pupils should be advised of potential glare, halo and night driving problems following refractive surgery. One has to weigh the benefits versus these difficulties in highly myopic patients requiring small optic zones to correct that much myopia. With low myopic patients in whom larger optic zones may be achieved with the more modern lasers, this becomes less of a problem.

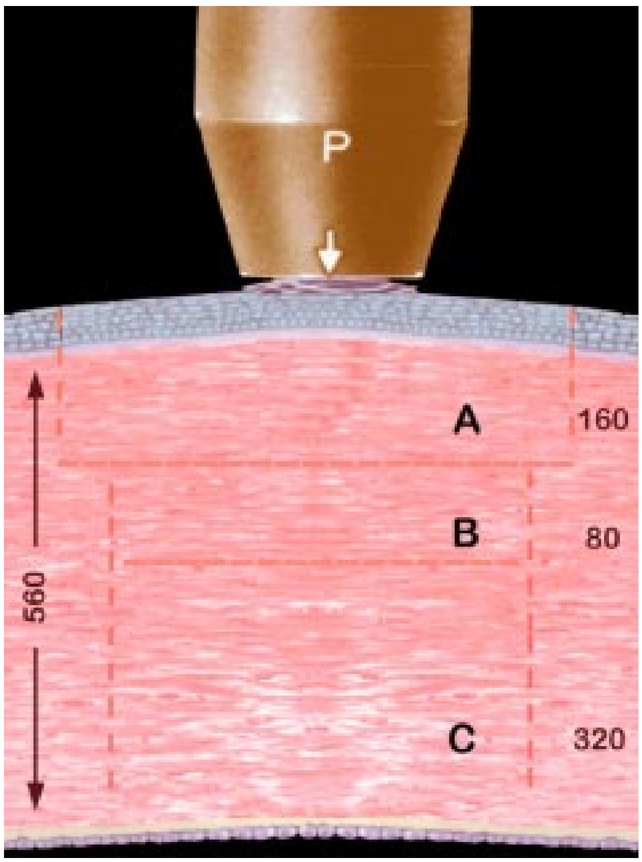


Figure 28: Corneal Tissue Ablation - How Much Ablation is Recommended Using LASIK Treatment of Myopia

This cross-section view shows the different layers of the cornea and the amount of tissue ablated (variable from case to case) in excimer laser treatment with the LASIK technique for myopia. The total corneal pachymetry is 560 microns (P). The "A" zone shows the average thickness of the corneal flap in LASIK (130 - 180 microns). This is related to the type of microkeratome used. The "B" zone shows the depth of tissue ablated from the stroma. This is varies with the amount of myopic correction the surgeon needs to attain and the type of excimer laser system utilized. In this case we present the parameters of a patient with -8.00 D of myopia with a stromal ablation of 80 microns. The "C" zone shows the amount of remaining corneal tissue not treated during the excimer laser procedure. In this particular case it amounts to 320 microns.

It is important to assess these measurements in detail and to keep in mind that the recommended remaining corneal tissue in every case should be at least 250 microns, to avoid complications like postoperative corneal ectasia.

As emphasized in Chapter 2, LASIK in patients with myopia over –10 D and large pupils may give rise to visual discomfort. The same applies to phakic IOL implantation when using very thin, foldable lenses with a small diameter optic.

Visual Acuity

When planning any refractive procedure, measurement of visual acuity with and without spectacle correction or contact lenses and best corrected visual acuity (BCVA) is essential.

High myopia is associated with reduced BCVA, which may differ between spectacle correction and contact lens correction. Higher myopes and patients with high astigmatism may have a level of visual acuity with rigid gas permeable contact lenses that may be impossible to replicate with refractive surgery. When considering a refractive surgery procedure in these patients, it is important that the patient be aware of these limitations in order to achieve high levels of patient satisfaction.

Refraction

A manifest and cycloplegic refraction is standard. The vertex distance in cases of high myopia is measured. In cases of very high myopia, a disposable contact lens of -7 D or -8 D may be fitted and the patient over-refracted over this contact lens.

Buratto recommends that the manifest refraction be the one selected for the refractive surgery correction. It must therefore be carefully performed using the correction that provides the best visual acuity with the least amount of minus correction. It is important not to over minus the patient.

The importance of the **vertex distance measurement**, particularly as the amount of myopia increases, is that with most modern lasers, the vertex distance is required for accurate calibration by the laser software.

The cycloplegic refraction is important in order to prevent overcorrecting the patient. It should be done with retinoscopy followed by subjective refinement.

Biomicroscopy

As emphasized by **Buratto,** the presence and quality of the tear film should be evaluated and specific tests, such as Schirmer's and tear film breakup time (BUT) done. Corneal clarity, and absence of conjunctival pathology which could perhaps cause difficulty with fixation of the suction ring in LASIK, should be noted. Tonometry is necessary to exclude undiagnosed ocular hypertension or glaucoma and to establish a preoperative intraocular pressure (IOP) level.

The examination of the anterior segment for lens changes, such as early posterior subcapsular cataract, should be done both to document its existence prior to surgery from a medical/legal point of view, and to suggest the possibility of lens extraction by phacoemulsification, with (or without) implantation of an intraocular lens (IOL), as an alternative method of refractive correction.

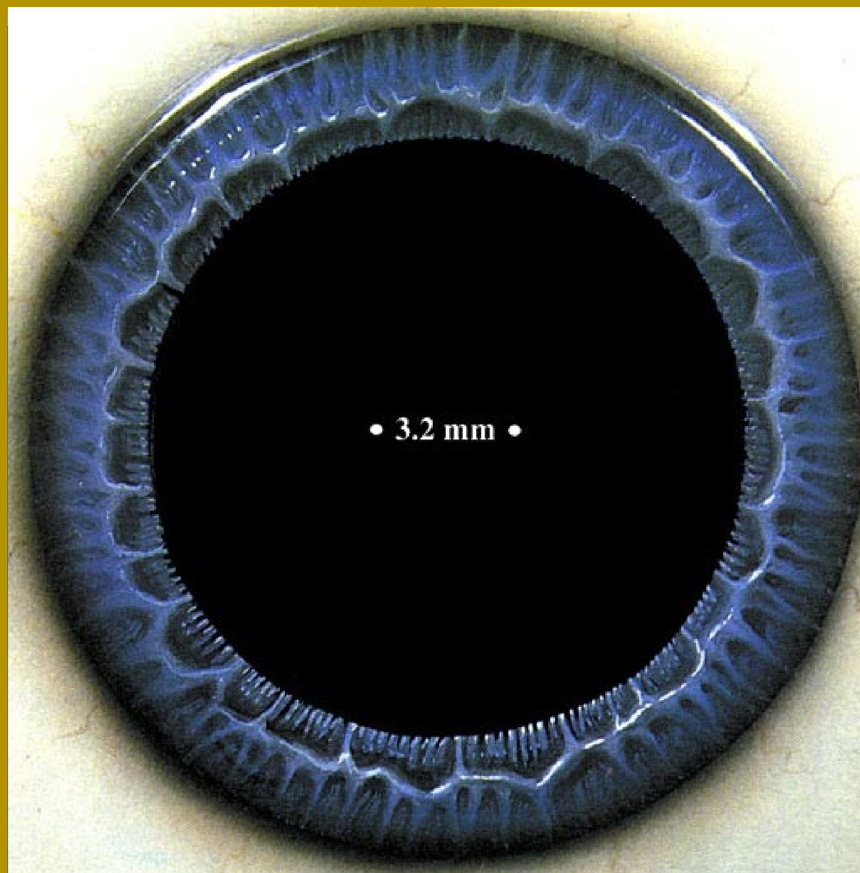


Figure 29: Limited Assessment with the Standard Keratometer

The standard keratometer takes only two small, 50 micron samples 3 to 4 mm apart to determine the central curvature and dioptric power of the cornea. It completely misses aspheric or irregular surfaces anywhere else on the cornea.

Keratoscopy

The standard clinical and surgical keratometer that we had used for many years to measure the power of the cornea, particularly for contact lens fitting, is not reliable for refractive surgery. It measures the curvature of the cornea, only along the two principal meridians, at points 3 mm to 4 mm apart on the central cornea **(Fig. 29),** and assumes that the remainder of the cornea, both peripheral and central, is perfectly sphero-cylindrical.

On a spherical surface, such as a steel ball, two small samples are sufficient to determine the curvature and power of that surface. However, as the cornea becomes less like a steel ball and more aspheric or irregular, the two measurements that the standard keratometer makes are not sufficient to describe the

central and pericentral corneal power. These are areas of the cornea where refractive surgery is mostly performed although the center is the location of important changes in LASIK, PRK and RK. To add information to the corneal curvature obtained with clinical keratometers, **photokeratoscopes** were developed that enable the photographic capture of Placido Disk mires reflected from the surface of the cornea (Figs. 30, 31, 32).

Figures 30 and 31 show the Placido disk mires reflected from the normal cornea. With this instrument, clinicians are able to appreciate, on a qualitative basis, distortions inherent in individual corneal shapes. For example, severe cylinder and irregular astigmatism (Figs. 10 and 11, Chapter 1 and Fig. 32, Chapter 3), as well as moderately advanced keratoconus (Fig. 33) can all be appreciated from simple visual inspection of

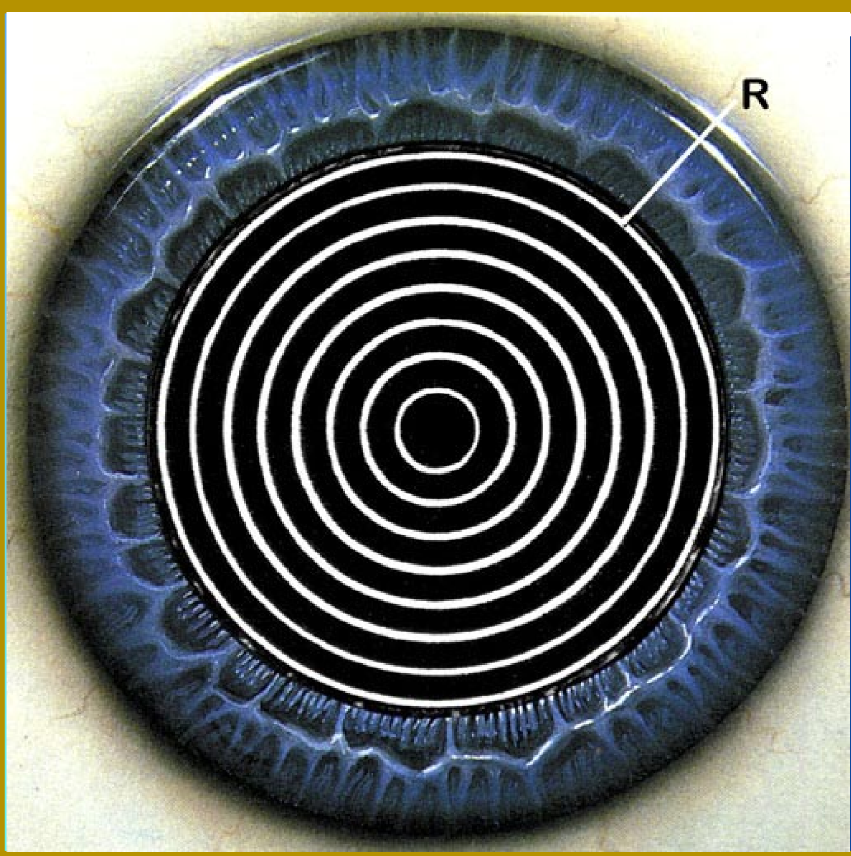


Figure 30: Placido Disk - Reflected Pattern - Normal Cornea

The reflected rings (R) from the photokeratoscope are seen on a normal cornea. Note the regular circular pattern of the 12 rings, which are evenly spaced on this normal surface. There is no distortion of the rings.

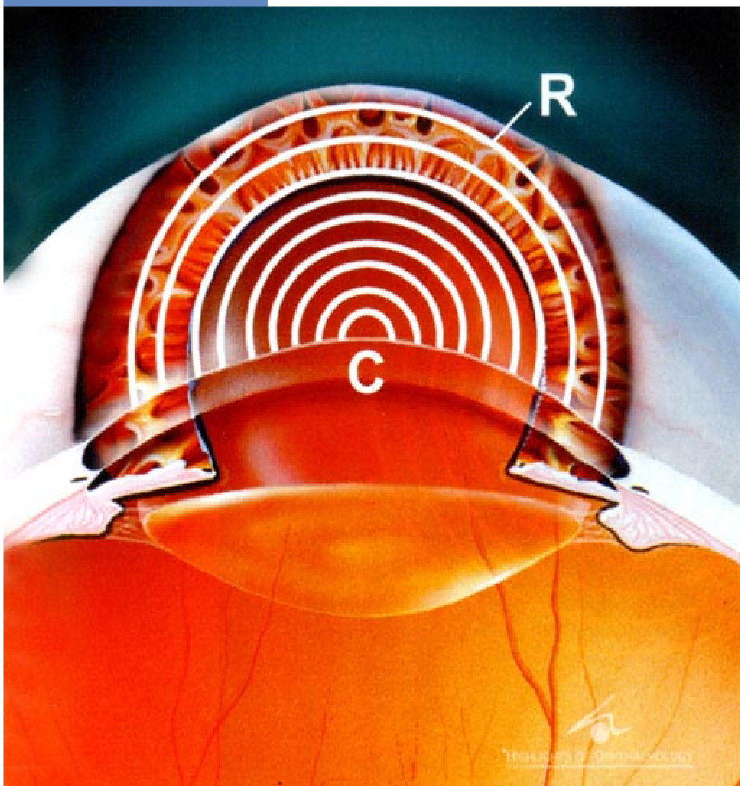


Figure 31 - Placido Disk - Reflected Pattern - Normal Cornea in 3 Dimensions

This oblique cross section shows a cornea (C) of normal curvature. Notice that the reflective light images (R) on the surface of the cornea produce a nearly perfect, concentric, circular pattern from the Placido disk positioned in front of the cornea.

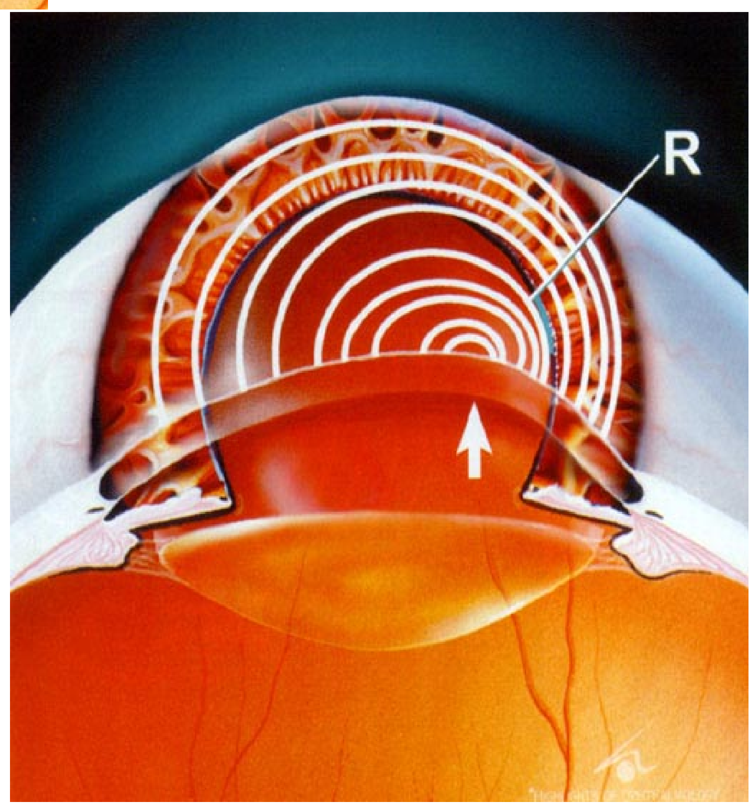


Figure 32 - Placido Disk - Reflected Pattern - Abnormal Cornea

In a cornea with abnormal curvature (note high spot in corneal cross section - arrow), the reflected pattern of the Placido disk shows distortion of the rings. The steeper portion of the cornea reflects the rings in a pattern in which they appear closer together (R). Familiarity with the types of reflective distortions produced by the cornea can be used to note the location of steep, flat and asymmetric areas, for the purpose of devising a proper treatment approach.

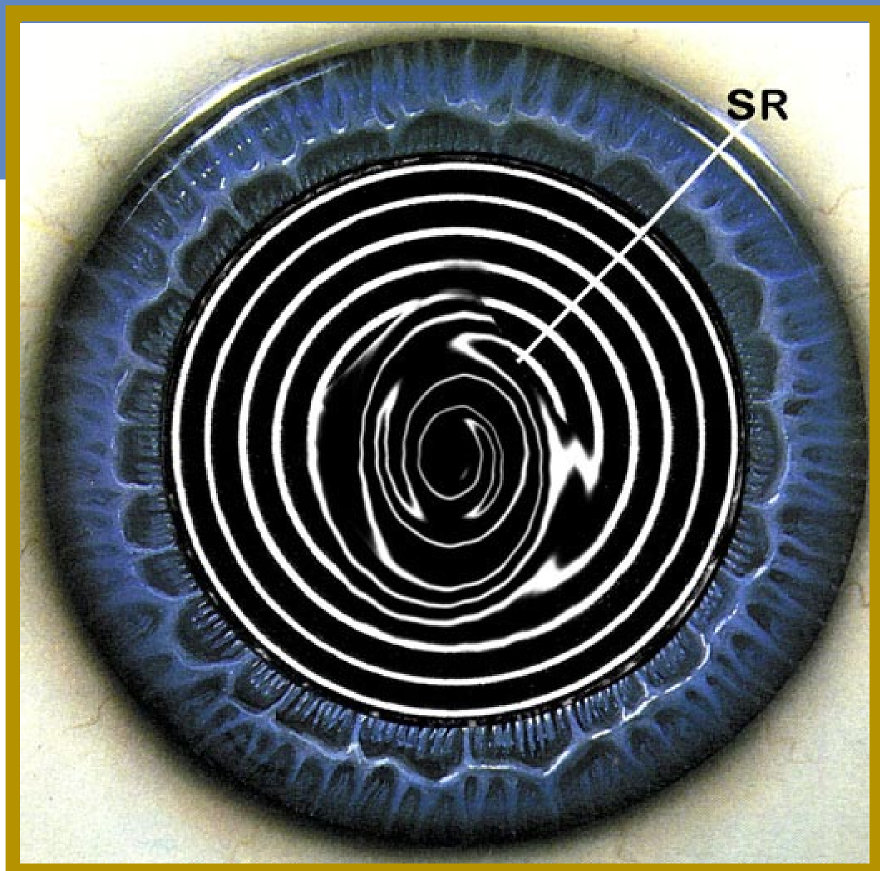


Figure 33: Placido Disk Image in Keratoconus

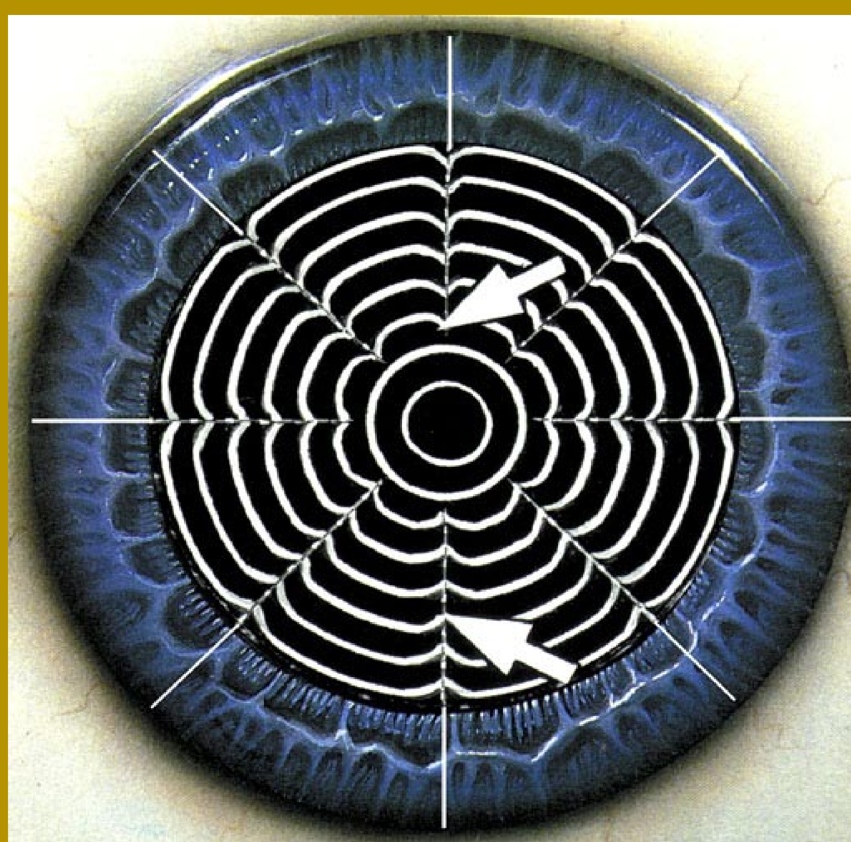
In this case the central and inferior rings (SR) show the advanced, central steepening (SR) pattern seen in keratoconus. There is a characteristic distortion in the pattern of the rings. For a clinical picture of this abnormality, see Fig. 26. For computerized corneal topography of keratoconus and sub-clinical keratoconus, which are essential to detect in the preoperative evaluation, see Fig. 40.

keratoscope Placido disk mires (Figs. 32 and 33). This is done using simple guidelines. Mires larger in diameter, broader in width or more widely separated than normal are an indication of low power of the underlying cornea. The steeper portion of the cornea reflects the rings in a pattern in which they appear closer together (R - Fig. 32). Figure 34 shows the irregularities in the Placido disk image following radial keratotomy. A similar visual inspection approach is used with intraoperative keratoscopes to reduce the amount of postoperative astigmatism following corneal transplantation. The current goal for an expert corneal surgeon is to reduce the average amount of regular corneal cylinder obtained with corneal transplantation to approximately 3 D to 4 D. Unfortunately, keratoscopy alone does not identify corneal cylinder in amounts less than about 3 D.

In spite of its limitations, **keratometry is needed and very useful** even by itself. **The possibility of a free cap increases greatly if the K-readings are flat, for example.** Keratometry assumes even greater importance when combined with the findings from corneal topography.

Figure 34: Placido Disk Image After RK

This photokeratoscope picture shows distortion of the paracentral and peripheral Placido rings (arrows) following radial keratotomy. Please observe the irregular shape of the rings.



COMPUTERIZED CORNEAL TOPOGRAPHY

The Important Contributions of Videokeratography

Because clinically significant amounts of distortion in corneal shape can remain undetected by photokeratoscopy (Figs. 30-34), **videokeratoscopes** (Fig. 35) have been developed that use **computerized methods** to capture the keratoscopic image information. They reconstruct the original corneal surface through a digitizing process to graphically portray the shape of the cornea in a way that is meaningful to the clinician (Fig. 35). **The end result is a color coded map.**

Computerized Corneal Topography is one of the most important developments in diagnostic instrumentation for the study of corneal diseases, particularly as applied to refractive surgery. **Rowsey** initiated the use of the Placido image to obtain qualitative measurement of corneal topography. The pioneer in this area is **Dr. Stephen Klyce, Ph.D.,** who in 1987 converted the digitized numerical values provided by a computer (Fig. 35) into color-coded maps of the different curvatures of the cornea with keratometer readings at various points. In addition to measuring the central cornea, this procedure provides additional information about the intermediate and peripheral areas which had always been poor in the past. These maps have become the practice standard because they present videokeratoscopic information in a form that is easy to use.

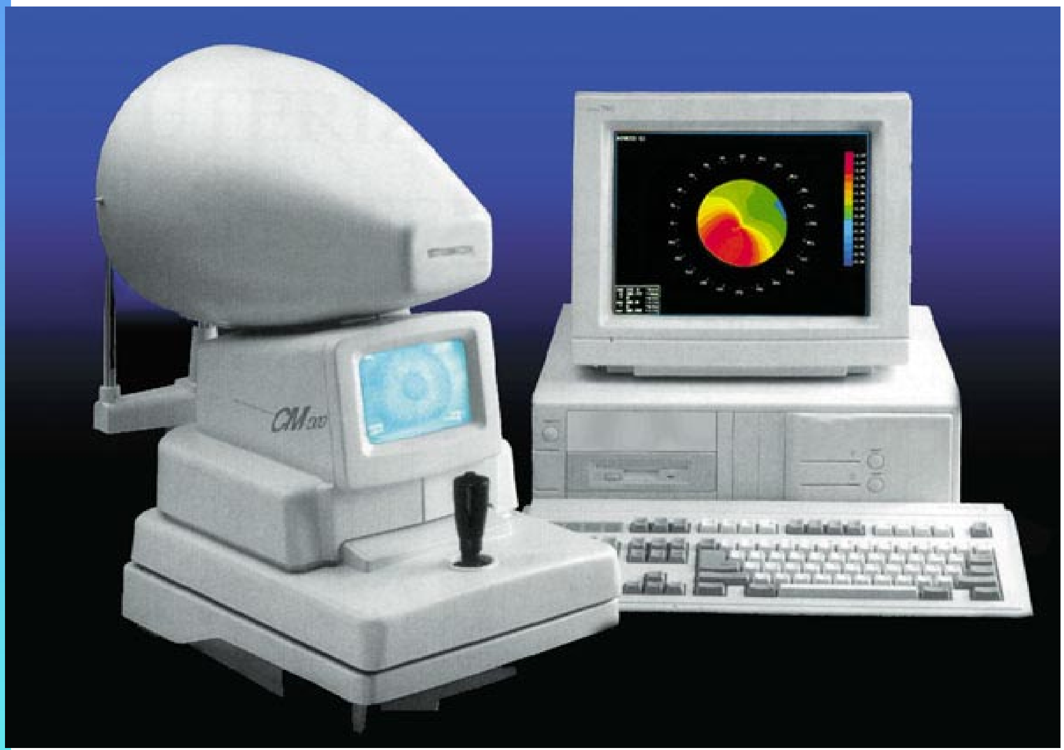


Figure 35: The Computerized Videokeratoscope

This state of the art equipment combines a series of illuminated rings, a digital camera, and a computer. The rings are reflected from a normal cornea as circular and equally spaced, as shown in Figs. 30 and 31. This image of the Placido disk rings is digitized by the computer shown in this figure and viewed by the physician on the computer monitor as a digitized color corneal map - a practical and clinically interpretable system.

How Computerized Corneal Topography Works

Klyce has demonstrated the usefulness of color-coded maps of the corneal surface, in which the cooler colors, such as blue, represent flatter areas of the cornea and the warmer colors, such as red, represent steeper areas (Figs. 10 and 11, Chapter 1 and Figs. 36 and 37).

The corneal map obtained through computed corneal topography covers the entire corneal surface: not only the center, but the mid-periphery and periphery where many of the abnormalities are present as well as the changes that occur from refractive surgery. The instruments traditionally utilized for computerized corneal topography to provide this information look at the reflection of an illuminated Placido disk from the cornea

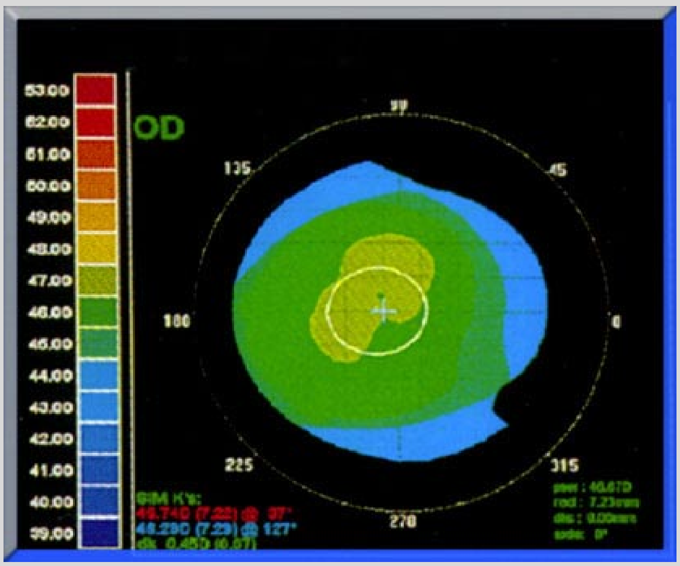


Figure 36: Topographical Corneal Map of a Normal Eye (Based on a Placido Disk System)

A normal cornea is aspheric with greater curvature towards its center. This can be seen in the full color corneal map. The colors are essential for its interpretation. The blue and green colors are characteristic of the degree of normal curvature (44 D) in the paracentral and peripheral areas. The slightly steeper curvature in the center is depicted by a **subtle** yellow color. The dioptric equivalents can be instantly interpreted by comparing the colors of the corneal images with the numeric table and color scale to the left of the map. (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art,* published by **Slack Inc.**)

Figure 37: Topographical Corneal Map of an Eye with Moderate Astigmatism (Based on a Placido Disk System)

This figure depicts a certain level of against-the-rule astigmatism on the 180° meridian in this otherwise normal cornea. This appears as an orange and red area where the 180° meridian is steeper than the 90° meridian. **Virtually no cornea is totally spherical.** The astigmatic component is not considered to be significant if it is 1.25 D or less, as is the case in this figure and the majority of eyes. (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art,* published by **Slack Inc.**)

(Figs. 30-34). The patient fixates the center of the disc (Figs. 30-34) **and the equipment's computer transforms the Placido disk image into a digitized** map (Fig. 35). Recent developments have resulted in **more sophisticated targets than the Placido disc.** Most refractive surgeons, however, still prefer equipment based on the Placido disc.

The Color Map Process in the Making

A video camera takes an image of what is being reflected by the cornea. This image can be transmitted to the screen of a video monitor. When satisfactory, we can freeze the image shown on the video screen. Immediately, by means of a digitized computer system within the instrument, the numbers read by the computer from various areas of the surface of the cornea are transcribed into an already existing software program that translates these into local corneal curvatures. The computer assigns different colors to this numerical, digitized information of the various corneal curvatures: **red to the steeper curves, blue to the flatter zones. The color that is assigned to each curvature** is shown on the vertical color bar present on the side of the topographic map (Figs. 36 and 37).

Interpreting the Color Maps

The computer returns the image to the video screen in colors instead of numbers **(Fig. 38).** The video image in the computer screen provides a **relative** color scale at the edge, which is expanded or contracted depending on the range of curvatures in the cornea being measured. For instance, if the flattest zone of a specific cornea is 37 diopters and the steepest zone is 45 diopters, the relative color scale assigned by the computer would be dark blue for the 37 diopter areas and dark red for the 45 diopter areas. The in-between colors are distributed between these two parameters **(Fig. 39).**

When you are making a comparative analysis of different cases, or the same case over time, it is of more value to ask the instrument to provide you with an **absolute** color scale in which a given color represents the same curvature in each map. This eliminates the confusion that may occur if the user fails to pay attention to the color scale. An absolute color scale is also useful in pathological corneas . The color scale shown in Figs. 36-39 has 15 color zones. Reddish colors represent steep curvatures and bluish colors represent flatter curvatures, with yellows and greens in between.

When using the absolute color scale, each color represents a 1.0-D range. This means that the patient may have up to 0.9 D of astigmatism (43.00 x 43.90) and theoretically have a uniform pattern. Ideally there should be relatively uniform local curvature over the pupil.

Accuracy of computerized topographic data depends upon proper acquisition of good images. Poor focusing, decentration, and shadows can all adversely affect the image.

Gills, Mandell, and **Horner** have emphasized that correct alignment for videokeratography is a critical requirement for high accuracy and precision, although its importance is frequently underestimated in a clinical setting. The **corneal sighting center (CSC)** is the point where the line of sight intersects the corneal surface. Light rays entering the eye are centered about the CSC, are refracted by the ocular interfaces, and ultimately form the foveal image. The CSC is the **primary reference point** for refractive surgery in that it usually represents the center of the area to be ablated in photorefractive keratectomy, and the center of the area to be spared in radial keratotomy.

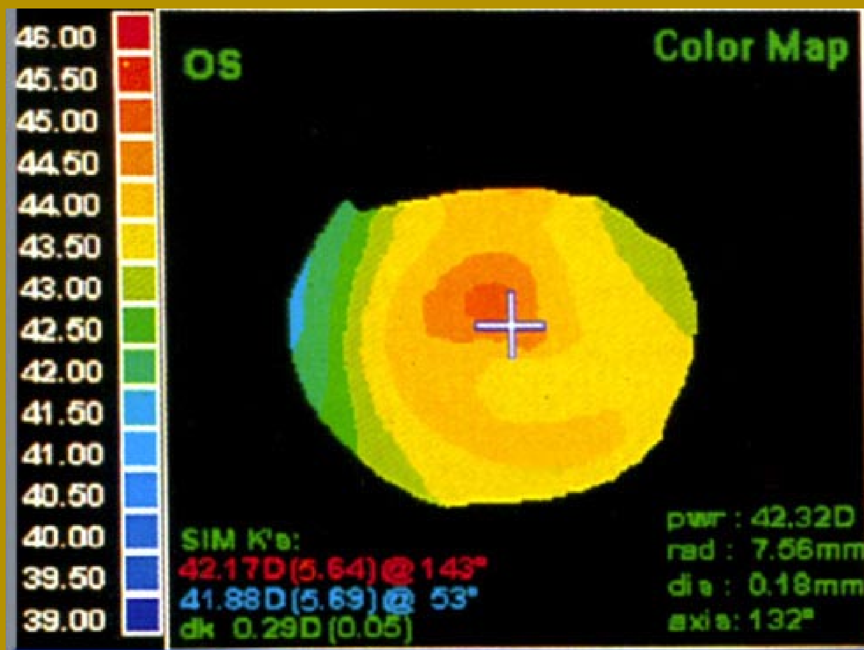


Figure 38: Topographical Corneal Map of a Slightly Myopic Eye (Based on a Placido Disk System)

This cornea, seen in some myopes, shows a greater and more pronounced level of corneal steepness than those in Figures 36 and 37. This can be interpreted using the colors on the map as a key and converting them to diopters with the help of the numeric table on the left. The map also illustrates how the cornea becomes less curved towards the periphery, where the colors are green or blue . (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art,* published by **Slack Inc.**)

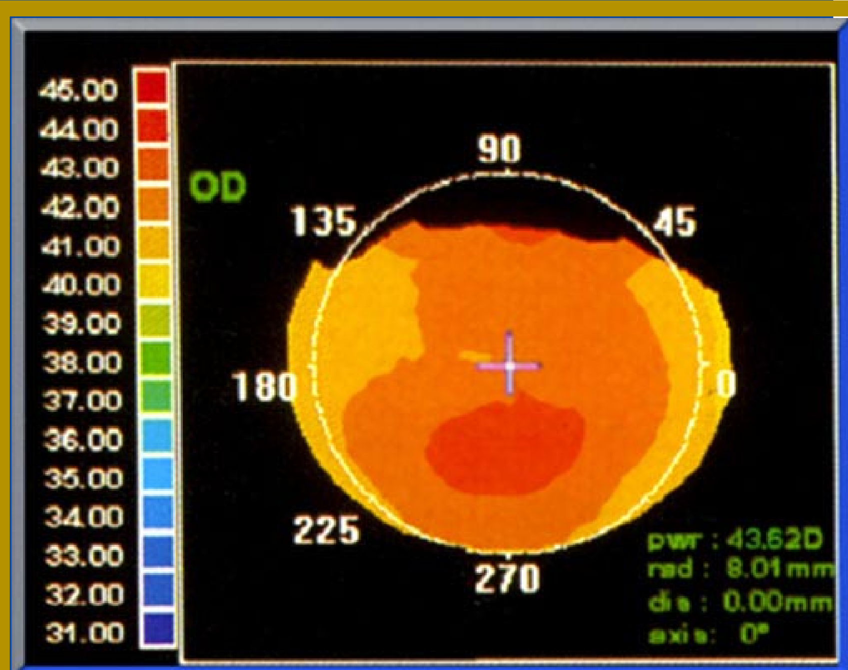


Figure 39: Topographical Corneal Map of a Moderately Myopic Eye (Based on a Placido Disk System)

In contrast with figure 38, this figure shows two shades of orange in the central area, documenting a greater degree of corneal curvature. The numeric data in diopters depicted on the bar illustrate the degree of corneal curvature in the exact area of the cornea where the image has been taken. Note that in this case, the cross pointing to the area where the measurement was taken, and guided by the "computer mouse," lies on the central cornea. (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art,* published by **Slack Inc.**)

Unfortunately, in order to simplify their design, most present videokeratographs do not align on the CSC. This, fortunately, is usually of little clinical consequence in most cases. However, knowledge of the alignment process is necessary in order to properly interpret more complex corneas.

In essence, the **map** provides a close estimate of the shape and refractive power of the cornea. The data is used to calculate the ablation needed in each area, but keep in mind that the data obtained is not perfect. In interpreting color maps, one must particularly observe whether the pattern is irregular enough to cause concern about the reliability of the map, and to determine what the position of the pupil is relative to the curvature pattern displayed in the map. The only way to become adept at reading and evaluating maps is through study and practice.

Importance of the Tear Film During Computerized Corneal Topography

Leo J. Maguire, M.D., has pointed out that keratoscope images are formed by reflection, which occurs at the tear film layer. Tear film may not be problematic if it is uniform over the entire corneal surface, but it can cause problems if the patient is tearing sufficiently to cause lacrimal lakes at the upper or lower lid margins or if focal tear film breakup distorts keratoscope mires and leads to digitizing errors. Artificial tears can alter the results of videokeratoscopy; for most preparations, he recommends waiting at least 5 minutes between applying the drops and performing the keratoscope exam.

Both **screening topography** and postoperative topography should be done when the patient is able to maintain good fixation and a good tear film and double checked if the reliability is questionable.

The Role of Contact Lenses

Raymond Stein, M.D., Co-Director of the Bochner Eye Institute and Assistant Professor of Ophthalmology at the University of Toronto, Canada, emphasizes that if the patients are contact lens wearers, he will do serial refractions and serial topography to make sure that their corneas are stable. For soft lenses, he generally prefers to have the patients out of their lenses for a minimum of 3 days, and for rigid gas-permeable lenses, a minimum of 3 weeks. But this may vary widely.

For those patients who are currently wearing rigid gas-permeable lenses and may not have worn glasses in years, **Stein** considers it is sometimes helpful to give them the option of being fit with soft lenses that they can wear up until a few days prior to surgery. **Stein** is an expert on contact lenses with a large refractive surgery practice.

The concept of how to manage contact lens wearers is not unanimous. **Buratto** recommends the use of corneal topography to monitor the cornea following contact lens removal. He recommends that soft contact lenses be discontinued for 2 weeks and rigid or gas permeable contact lenses for 4 weeks prior to consideration of refractive surgery. He has pointed out that this period of contact lens discontinuation may even be two to three times longer if corneal molding is detected, and that continued monitoring is required to allow stabilization of the anterior corneal surface until reliable keratometric and topographic readings are obtained.

Different Types of Computerized Videokeratography Systems

There are three different systems: 1) **Placido disk imaging**, which is an extension of the single mire used in the keratometer. This type of imaging has the potential for excellent accuracy and reproducibility. A series of rings is reflected by the cornea, and the reflected images are detected by a video camera. Curvature data are derived from the measured distances between rings (See Figs. 30-33).

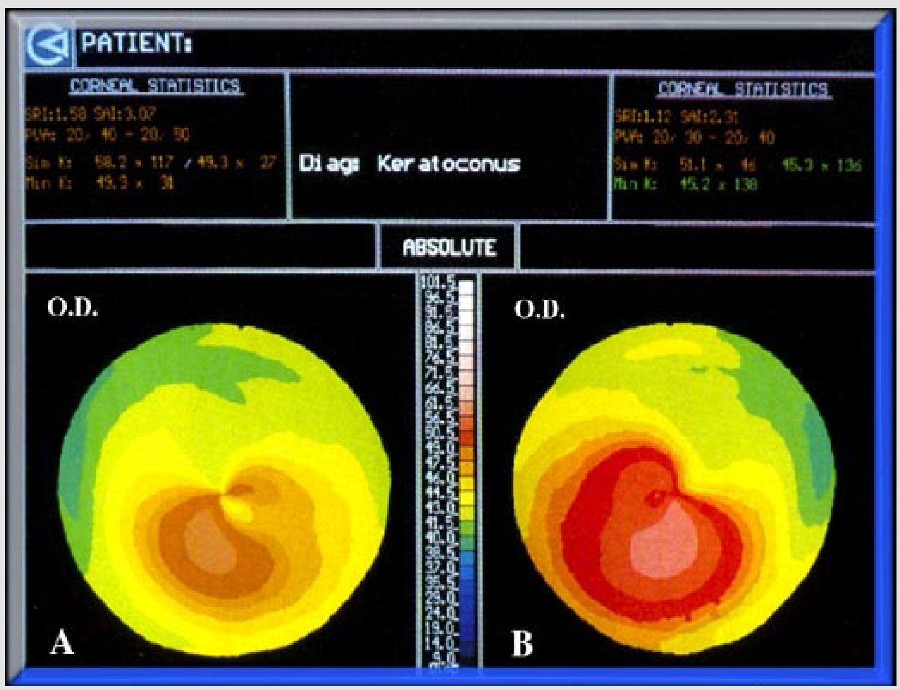


Figure 40: Subclinical Vs Clinical Stage Keratoconus (Based on a Placido Disk System) – Preoperative Evaluation

Computerized corneal topography is an essential diagnostic method in the detection of corneal pathologies such as subclinical keratoconus. It is important to make this diagnosis before refractive surgery. In figure "A" we observe a slight alteration of curvatures in the central and inferior zones (orange-brown), which indicates locally increased curvature due to subclinical keratoconus. These patients are asymptomatic, and this condition is not detectable in the clinical exam or using a standard keratometer (Fig. 29). In contrast to what we have observed in Fig. "A", Figure "B" depicts a clinical, symptomatic keratoconus, with high keratometry values and a greatly pronounced inferior corneal curvature plotted by the computer in red and orange. (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art*, published by **Slack Inc**.)

2) The PAR Corneal Topography System (CTS) (PAR Technology Corporation) that uses **rasterphotogrammetry**, in which a two-dimensional **grid** pattern is projected onto the cornea and then imaged from a different orientation (See Fig. 41).

3) The ORBSCAN offered by ORBTEK, which uses a projected **slit** rather than Placido rings (Fig. 42).

Videokeratography Systems of Choice

Steven E. Wilson, M.D., Professor and Chairman, Department of Ophthalmology at the University of Washington in Seattle, is an authority of worldwide prestige on corneal topography and refractive surgery. **Dr. Wilson's** thoughts, at present, on the various systems are:

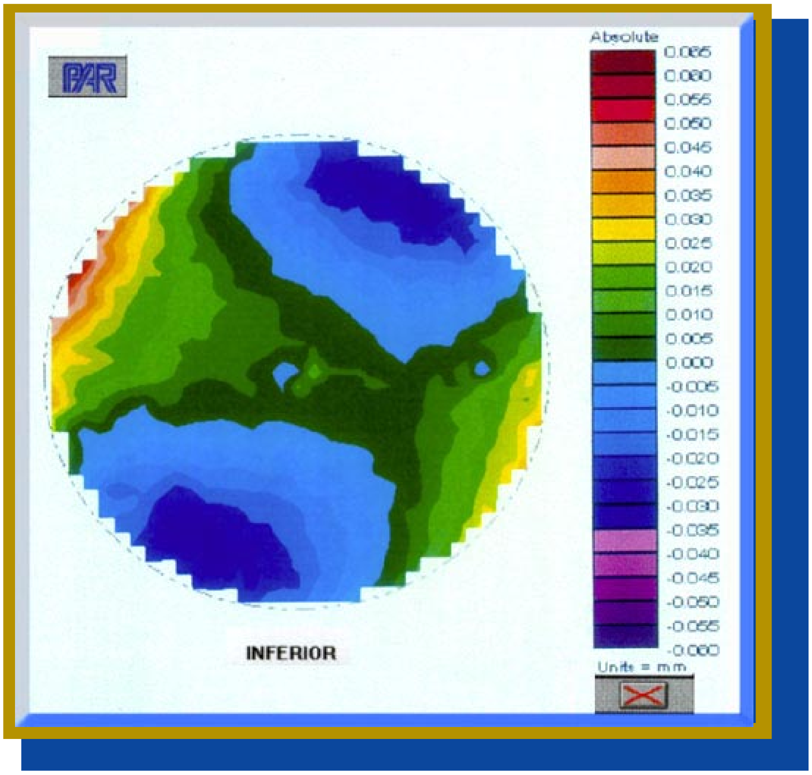


Fig. 41: Computerized Corneal Topography Using the PAR System in Normal Cornea

This is an elevation type topography map of a normal cornea. Thinking of the cornea like a mountain, elevation is defined as the "height" above the limbus or base of the cornea. In contrast to Placido disk based systems, this grid based system allows the creation of elevation maps with which we can presumably diagnose such pathologies as keratoconus more efficiently. In addition to maps showing elevation, three-dimensional and dioptric topographical maps may be obtained which permit very sophisticated evaluation of the corneal surface. (Artistically modified by HIGHLIGHTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art,* published by **Slack Inc.**)

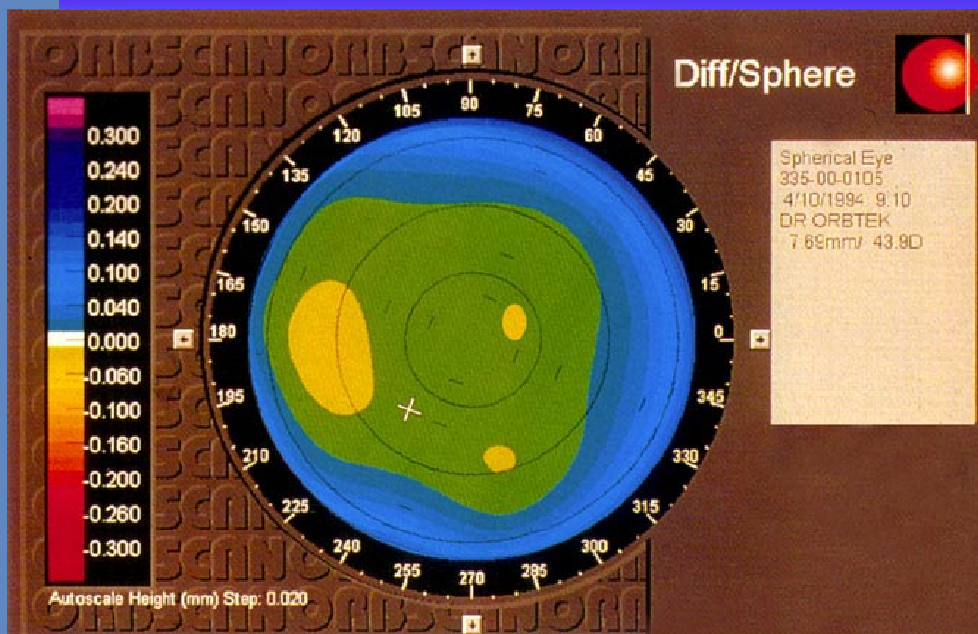


Figure 42: Computerized Corneal Topography Using the ORBSCAN System in Normal Cornea

This system constructs a topographical map from multiple, parallel slices of a slit lamp light. It is able to display the posterior, in addition to the anterior, corneal curvature. According to **Professor Murube**, this permits a greater understanding of the cornea's optical properties, its curvatures, and its thickness. This figure depicts a normal central corneal curvature illustrated by the typical green and yellow colors for 43.5 D. (Artistically modified by HIGHLIG HTS with permission, from **James P. Gills et al** classic text: *Corneal Topography: The State of the Art*, published by **Slack Inc**.)

Videokeratography based on computerized analysis of the **Placido disc remains the most widely used method for analysis of corneal topography.** Alcon, Humphrey, EyeSys, and Tomey produce widely used instruments. There are a number of other companies that are also involved in Placido disc-based technology. One of the advantages of this technology is that it has had far more validation, so the strengths and weaknesses of the maps are understood by clinicians.

Rasterstereography is a technique pioneered by **PAR** Technology and still remains relatively unused. It has gained little acceptance in the clinical community. This technology could have utility for monitoring corneal topography **intermittently** during refractive surgical procedures designed to reduce corneal irregularity, or in other situations where linking between corneal topography and excimer laser ablation are desirable. Efforts continue in this area, however this technology remains experimental.

The **Orbscan** corneal topography device uses **scanning slits** to monitor both the anterior and posterior surfaces of the cornea. Recently, Orbscan has incorporated Placido disc analysis with the scanning slit, presumably to provide an analysis of both the anterior and posterior corneal surfaces and, therefore, information about corneal thickness across the entire cornea.

Professor **Juan Murube, M.D.,** in Madrid, who has extensive experience with all three methods, describes the Orbscan system as providing 40 successive optical slits with a slit lamp using 45º of angulation, first

20 slits from right to left followed by 20 slits from left to right. By reflection of light from both the anterior and posterior corneal surfaces, you obtain simultaneous topography as well as the corneal pachymetry.

Murube considers that Orbscan technology, has now about 10% of the market. Both **Murube** and **Wilson** believe that its acceptance is slowly increasing.

Wilson considers that the main problem with the Orbscan scanning slit technology is that it has not been validated in studies published in peer reviewed journals. Thus, although the image provides analysis about corneal topography pre- and post-refractive surgery, clinicians are left wondering about the accuracy of this information since no independent verification has been forthcoming. Just recently, **Bausch & Lomb Surgical acquired Orbtech, for linking corneal topographical analysis with excimer laser ablation**. Further investigation will be required and there are some accuracy-related issues that need to be resolved.

The Most Important Developments

In **Wilson's** judgment, **the most important developments** in clinical applications of corneal topography **are linkage of corneal topographic analysis with excimer laser ablation.** This has long been a dream of refractive surgeons and efforts have been increasing in this area over the past two years. Currently, this linkage is confined to what may be called "snapshot linkage" in which the initial corneal topography is utilized in programming an excimer laser. Presumably this would need to be a laser with scanning capacity. This remains problematic, since it is not clear that the information provided by any current topographic instrument is sufficiently reliable to allow precise ablation such that central islands or decentered ablations can be corrected.

Additionally, **Wilson** believes that it is unclear whether the information provided by these different topographic technologies is sufficiently reliable to allow even normal corneas to be corrected so that aberrations interfering with "perfect" vision can be eliminated.

What We Need for the Future

Peter McDonnell, M.D., considers that even though computerized corneal topography has been essential to advances in refractive surgery, the changes in technology during the past years have not been dramatic; they have been small, incremental changes or improvements in software (Figs. 30-35). In general, existing devices still rely on reflective ring images, or Placido ring technology (Figs. 31 and 35). **McDonnell** considers that this technology has definite limitations. The mathematical assumptions used to generate maps depend upon the quality of the corneal surface. They estimate the curvature of the cornea based on reflected images, for which a good tear film is necessary. Because a tear film may not be present on the cornea during surgery, these devices have limited applicability for **intraoperative monitoring.**

New Generation of Devices

Several investigators are exploring what will possibly be a new generation of devices using laser interferometry, or laser holography. **McDonnell** believes that a new breakthrough approach may be what is needed for measuring with the precision of a micron or less the height of different areas of the cornea. A new generation of devices may not require a tear film and may facilitate topographically directed ablation. Such advances may dramatically decrease the problems of undercorrection and induced overcorrection. Significant changes in corneal topography will probably require a technological leap into some other area than Placido ring technology.

Leo J. Maguire, M.D., at the Mayo Clinic considers that we need better **instruments** that can provide more precise quantitative measurements of both the surface and optical quality of the cornea. We need better **methods** that can accurately analyze complex surfaces and peripheral cornea, as well as differentiate between artifact and real corneal distortion. New instruments will be introduced over the next few years that he hopes will more closely approximate the perfect corneal topography system.

Refinements in videokeratography are expected. Some units will be able to display results using more than one method for estimating curvature. Some will be more sensitive to local changes in corneal shape. Others will better estimate the cornea's refractive properties. Other techniques such as neural networking may allow more specific identification of sub-clinical keratoconus, contact lens-induced corneal warpage, and other distortions.

Maguire points out that positional measurement approaches (e,g., rasterphotography, and slit imaging or Orbscan) must sample more points on the corneal surface and be made even more sensitive at measuring corneal height.

It is still unclear whether videokeratoscopy is the best way to measure changes in optical performance induced by corneal surgery and disease. The answer will depend on the relative capability of videokeratoscopes and other competing instruments as they continue to develop. Videokeratoscopy will remain the technology of choice if improvements in both hardware and software enable it to perform better than it does now. The successful technology will be the one that is most accurate, produces information that is most understandable to the clinician, and is available at a cost acceptable to the eye care provider.

Real Time Corneal Topography

More advanced applications of the linkage of corneal topography to excimer laser would include intermittent monitoring during ablation and real time corneal topography-ablation. In the intermittent analysis, the excimer laser would treat based on initial topography and then, after a few moments of treatment, topography would be obtained once again. At this point, the excimer laser would incorporate this new information and continue intermittently scanning and obtaining topography in an attempt to refine an irregular cornea. Currently, this remains theoretical.

Wilson emphasizes that **real time corneal topography is the ultimate dream of refractive surgeons.** However, several major problems must be overcome. These include the speed with which topographical analysis must be performed as the cornea is ablated, acquisition and analysis of corneal topography on a rough surface while the excimer laser ablation is being performed, and the level of accuracy of the topographic measurements.

Topographic Assisted LASIK

Maria Clara Arbelaez, M.D., one of South America's most prestigious refractive surgeons, has been working with **Michael Knorz, M.D.,** in attempting to develop a method by which LASIK can be performed with a topographically assisted program. This is particularly important in the presence of the **irregular** astigmatism often found after penetrating keratoplasty, penetrating injuries, or peripheral corneal scars. While these irregular patterns are poorly treated by broad beam excimer lasers, a specific program designed to re-sculpture the corneal surface based on the preoperative refractive evaluation and corneal topography may provide the ultimate method of treating irregular corneal patterns. This is an attempt to create perfectly shaped corneas for these difficult cases.

It is important to keep in mind that the current excimer laser programs only allow the treatment of **regular** refractive patterns. **Irregular astigmatism is currently a contraindication for excimer laser refractive surgery,** as the treatment of this pattern with the current excimer lasers yields unpredictable results and visual distortion. **Arbelaez** has reported rather good results with high patient satisfaction following topography-assisted LASIK in irregular astigmatism post-keratoplasty, post-trauma, decentered ablations and central islands. This method is still pending refinements and further development.

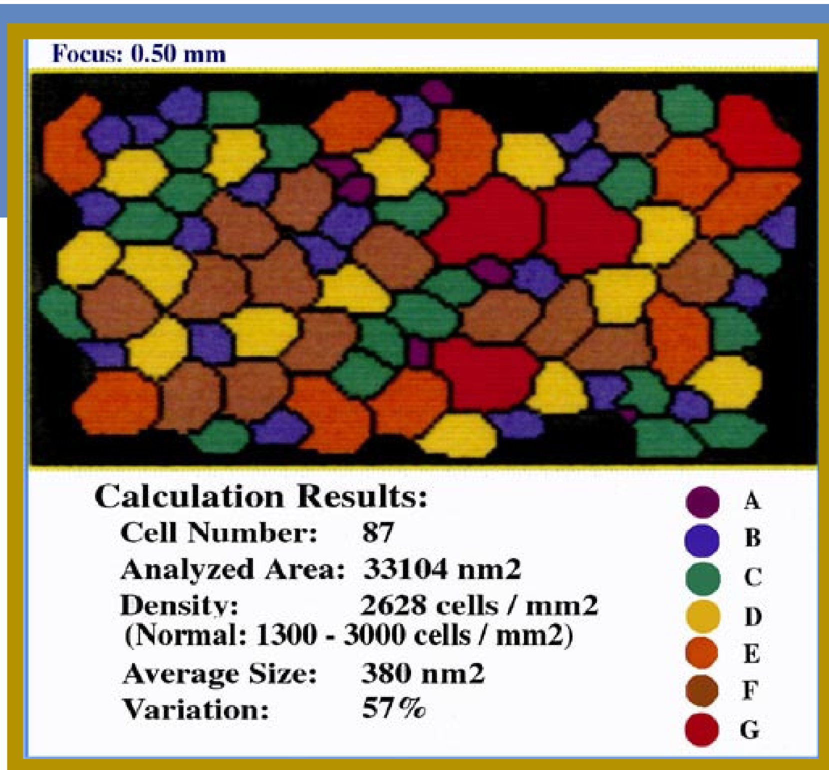


Figure 43: Preoperative Evaluation – Importance of Endothelial Cell Count Using a Specular Microscope

The potential decrease in number and the alteration in shape of the endothelial cells following a refractive procedure, especially with excimer laser, makes a preoperative study worthwhile. This figure illustrates the distinctive coloring of the cells, according to size or density, produced by computer analysis. The table below the figure lists the number of cells in the sample as well as the size of the analyzed area in microns and the average size of the cells studied. The values for a normal corneal sample are also included in the results. This study gives us an evaluation of the anatomical and morphological states of the endothelium before the surgery.

Specular Microscopy (Fig. 43)

This is an important part of the preoperative evaluation especially if corneal guttata or other signs of a low endothelial cell count are found. It is clinically and medical-legally important to document a low endothelial cell count before LASIK, rather than worry later whether LASIK caused it. It must be done before any examination that might roughen or dry the corneal surface. Although endothelial cell changes following lamellar surgery (including LASIK) have not been reported clinically, they have been seen **experimentally** when excimer ablation of greater than 90% depth was achieved. This depth of course is completely contraindicated in patients, but two cases of corneal perforation during LASIK have recently been reported, and other cases with deep ablation must also exist.

CHAPTER 3

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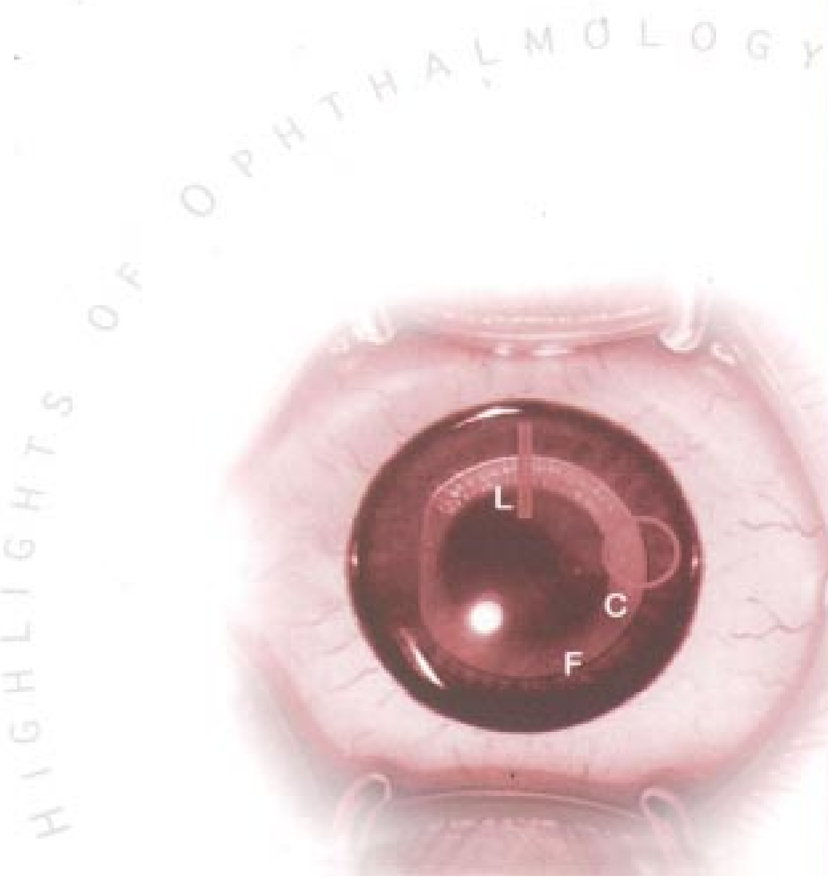
Surgical Techniques for Myopia

Low, Moderate and Moderately High (-1.00 D to -10 D)

CHAPTER 4



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LASIK

LASIK: THE DOMINANT PROCEDURE

Peter McDonnell, M.D. emphasizes that now that LASIK (laser in situ keratomileusis) is by far the predominant refractive surgical procedure, we are beginning to learn both its full potential and its limitations. This includes refining our knowledge about how much refractive error can be corrected with LASIK while maintaining a high quality of vision. (**Editor's Note:** In Chapter 2, we emphasized that the prudent cut-off for LASIK is -10 D. Higher myopia is best treated with phakic intraocular lenses). **McDonnell** points out that increased experience with LASIK will allow us to better determine answers to several important questions, such as how thick the cornea needs to be to avoid structural weakness, which in some cases has led to the complication of ectasia, a situation much like keratoconus (Fig. 28). (**Editor's Note:** This is clearly presented in Fig. 28, Chapter 3, and the text next to it titled "How Much Ablation to Perform").

Lindstrom prefers LASIK over all other procedures in low, and medium to high myopia up to -10 or -11 D, within the parameters and exceptions discussed in Chapter 2. For exceptions he occasionally performs PRK and RK.

Waring at the Emory Vision Correction Center in Atlanta offers LASIK for the majority of his patients because it is the preferred technique by surgeons at the Center. **Recovery is very rapid.** Further, enhancement procedures can be done to adjust the outcome.

Machat points out that visual recovery in LASIK is only 1 to 4 days. The most important factors for patients contemplating LASIK have been the speed of recovery and the lack of pain. Most people find it difficult to proceed with any procedure that produces a painful eye. Given the option, they choose the procedure that allows the most rapid return to full activity with the least pain.

Upper Refractive Limit

In determining the upper refractive limit in patients with high myopia who would be good candidates for LASIK, the key question is how flat the central cornea can be made, how well it can be shaped, and how thin the corneal bed can be. **Waring's** ideal cutoff might fall somewhere between -10D and -12D. At present **Waring** prefers to implant phakic intraocular lenses in patients with high myopia of greater than approximately -11 D. (**Editor's Note:** This is presented in Fig. 28, Chapter 3, and clearly outlined in Chapter 2 when discussing the **procedures of choice**).

Current Status of LASIK in the U.S. and other Continents

McDonnell points out that in the United States, although any new drug or device must be approved by the U.S. Food and Drug Administration (FDA), the FDA does not tell physicians how to take care of patients or how to perform surgery. Therefore, once a drug or device is approved for one purpose, it is legal for a physician to use it for another purpose as part of the practice of medicine. The microkeratome actually existed before the formation of the FDA because of the pioneering work of **Dr. Jose Ignacio Barraquer.** The Excimer laser is FDA-approved for the purpose of PRK. Therefore the laser and microkeratome can be used in combination to perform LASIK even though they are not specifically approved for this purpose (and cannot be advertised by the manufacturers as intended for the purpose of LASIK). Surgeons in the U.S., then, can use both the laser and microkeratome to perform LASIK in what is called an "off-label" use of the devices.

McDonnell estimates that in the U.S. at present, perhaps slightly more than 70% of excimer laser refractive surgery is LASIK, and only about 30% is PRK. In 1997, the predominant surgery was PRK, and PRK appears to remain an important refractive surgical procedure in Canada, but this is changing. **Harold Stein, M.D.,** and **Raymond Stein, M.D.,** in Toronto have an extensive refractive surgery practice and have shifted their preference from PRK to LASIK within the past two years, with some exceptions. In Mexico, Central America, South America and other continents, LASIK has been the dominant procedure for several years, well before it was popularized in the U.S. The recent movement from PRK to LASIK in the U.S. **has been driven by surgeon and patient appreciation of the extremely rapid visual rehabilitation offered by LASIK** compared to the several days required for healing of the epithelial defect after PRK. Although patient discomfort from PRK is mild in most cases, patients lose time from work. Many of these patients are very busy professionals whose time is quite valuable, and a rapid recovery is very appealing. When they have LASIK they praise how well it went to their friends, who then choose the same procedure.

LASIK - SURGICAL CONSIDERATIONS AND TECHNIQUE

Preparing the Patient for Surgery

In most cases, **oral sedation** of the surgeon's choice approximately 45 minutes prior to the procedure is advisable. The patient should be relaxed, but not overly sedated because the procedure requires patient cooperation for proper fixation. **Standard surgical** preparation of the eyelids and the periorbital skin is done with an iodine-based solution before entering the laser suite. **Antibiotic ointments are contraindicated** because they may affect the stromal interface postoperatively but **topical antibiotic drops** pre-op are indicated to reduce the bacterial load in the conjunctiva. The choice of antibiotics is far less important than with PRK, as the risk of infection is greatly reduced. **The epithelial toxicity of the antibiotic must be considered.** Topical gentamycin is quite epitheliotoxic and therefore should be avoided. Tobradex (tobramycin .3%-dexamethasone 1%, Alcon) and Ocuflox (floxacin 0.3% from Allergan) may be used safely. Fluoroquinolones are not toxic to the epithelium and provide excellent broad spectrum bacterial coverage and penetration; however, some surgeons have questioned their association with precipitates and interface opacities in some cases of LASIK.

An **eye wash solution** is irrigated into the conjunctival fornices to remove any meibomian secretions or the tear film debris which is present in many patients. The patient is made comfortable in supine position under the laser with the surface of the cornea perpendicular to the laser beam .

A topical nonsteroidal antiinflammatory **(NSAID)** drop may be instilled preoperatively to help reduce any discomfort or inflammatory reaction.

Anesthesia and Adequate Lid Speculum

McDonnell has found that patients generally tolerate surgery very well using the minimal amount of topical anesthetic needed. He often uses unpreserved anesthetic agents to avoid toxicity to the epithelium. **Machat** has observed that when both eyes are treated in the same session, the second eye is more sensitive when the operation is started. This is commonly referred to as "second eye syndrome". There appear to be multiple factors for increased sensitivity, including a heightened awareness of what will transpire and tachyphylaxis of the eye to repeated applications of proparacaine. Therefore in bilaterally treated patients, **it is best to apply the topical anesthesia to each eye only immediately before treatment. Machat** also recommends application of topical anesthesia with a soaked surgical spear to the upper and lower fornices. This is where most of the discomfort from LASIK occurs, because of its relation to the eyelid speculum. The vacuum from the suction ring creates a well tolerated mild pressure sensation. The lamellar incision itself is virtually painless. Therefore, by anesthetizing the fornices well, especially the upper fornix, patient comfort and cooperation are greatly enhanced. Applying the anesthetic immediately preoperatively also reduces epithelial toxicity. Patients should keep their eyes closed once anesthetized, as the blink reflex is diminished and the corneal surface may be damaged by the drying effect with the eye open.

LASIK is performed as an outpatient procedure, without a lid block. At first it seems difficult operating on patients without a lid block, although it is becoming a routine procedure in small incision cataract surgery. Lid blocks are unnecessary and inconvenient because many of the patients are more comfortable without a patch postoperatively. With a lid block if the patient leaves the clinic without a patch or removes it, they would have lagophthalmos, their flaccid orbicularis muscle will prevent them from spreading tears properly across the cornea, and they may develop an epithelial erosion from drying.

Most surgeons recommend using a lid speculum that has very little metal along the upper and lower lid margins, such as the Barraquer light weight wire speculum.

Operating Room - Cleaning and Sterile Precautions

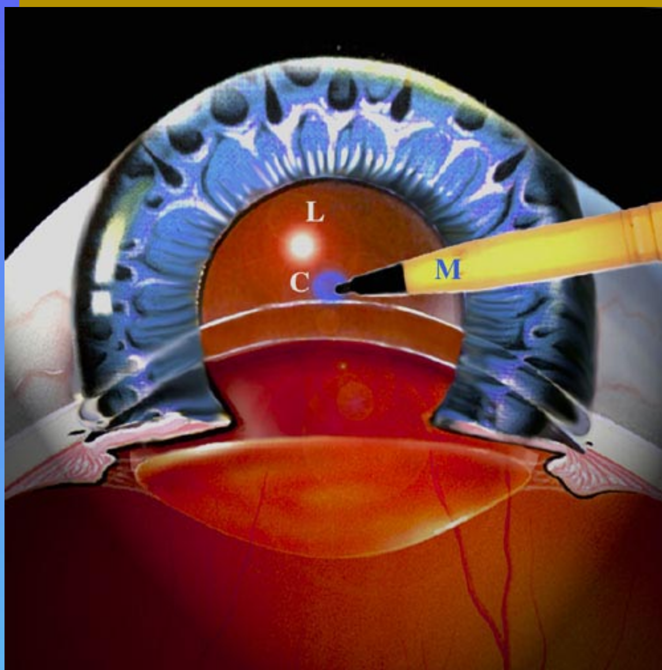
All personnel and the patients themselves must wear caps and shoe covers. For the most part this is an extraocular operation, but you never know when it could become an intraocular procedure because of a potential complication with the microkeratome. For this reason, all sterile precautions must be maintained. The surgeon must scrub and put on gloves. A sterile cover for the Mayo stand is utilized and the scrub (surgical) nurse is required to use sterile gloves when placing the instruments on the stand.

Ocular Fixation

Patient self-fixation on a coaxial target is the best method to use for ocular fixation. Patients can accurately fixate on a target for the several minutes that may be needed for the photoablation. Consequently, self-fixation can be more accurate than fixation provided by the surgeon.

Preoperative Corneal Markings

Marking Technique for the Line of Sight (Fig. 44)



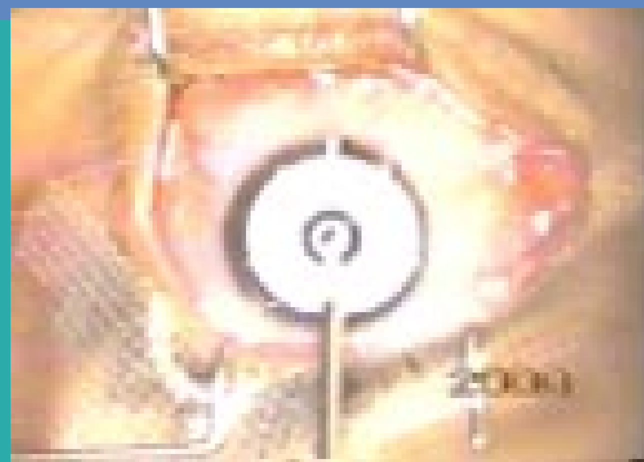


Figure 44: LASIK Technique – Marking the Pupillary Center **(Click over Videoclip)**

The marks are intended to predetermine perfect centering at the time of the cutting of the corneal flap with the microkeratome or, in PRK, the laser ablation. Note how the surgeon marks the central point on the pupil (C) with a genitian violet pencil. The surgeon ignores the light reflected by the cornea (L), as he is using the center of the pupil as a guide.

The marking technique for the line of sight or "entrance pupil" recommended by **Buratto** is the marking of the **center of the pupil on the surface of the cornea (Fig. 44).** It has the highest degree of reliability and is used in all types of keratorefractive surgery. This is an easy technique to perform. The patient is placed beneath the co-axial operating microscope and asked to stare at the central light with the eye to be operated (the other is occluded). The light of the microscope is dimmed so that it does not "blind" the patient making it easier for him to fixate. The surgeon marks the center of the pupil (Fig. 44). If the procedure is performed under the microscope of an excimer laser, the patient is asked to stare at the green or red target with the eye to be operated. (Again, the other is occluded).

Most experienced refractive surgeons agree that for best centration of the ablation it is necessary to mark the cornea directly over the underlying center of the pupil. This is done using an epithelial marking pen. This marking should not be done with needles, hooks, or cannulas, to avoid traumatizing the central cornea.

Light passing through the center of the pupil is more effective in stimulating the photoreceptors than light passing through the peripheral pupil because photoreceptors are aimed toward or oriented to the center of the pupil. Studies on eccentric pupils have demonstrated that photoreceptors actively orient themselves toward the center of an eccentric pupil. Therefore, as illustrated in Fig. 44, you actually ignore the corneal light reflex. Errors may arise from the use of the corneal light reflex as the sighting and marking point instead of the center of the pupil.

Other Important Markings of the Cornea (Fig. 45)

Assuring Correct Realignment of the LASIK Cap

Prior to any lamellar refractive procedure, **Buratto** recommends that the corneal surface should be marked with several other reference points. In addition to having topographic and geometric importance, these points **are useful as reference and orientation points for the correct centration of the suction ring, but more importantly, for the correct replacement and realignment of the flap, especially in the case of a free cap.**

With a free cap, the pararadial mark shown in Fig. 45 not only allows the initial realignment of the cap, but more importantly, it assures that the cap is placed correctly and not upside down. This can be extremely difficult to judge without the benefit of the pararadial mark. Marking of the cornea at the limbus is also of great assistance in evaluating cyclotorsion of the eye when doing cylindrical ablations **(Fig. 45).**

PREPARING THE EQUIPMENT AND INSTRUMENTS FOR SURGERY

THE EXCIMER LASER

The surgical success of LASIK requires proper cleaning, assembly, and testing of the microkeratome, as well as calibration and set-up of the laser. **Slade** recommends that each member of the surgical team should be responsible for every aspect of the procedure by doing multiple checks along the way. Appropriate humidity, temperature, and air purification should be present in the laser room at all times. The laser should be turned on and calibrated exactly according to the manufacturer's recommendations. The laser cutting rate or fluence and the beam quality (homogeneity) should meet acceptable operating standards. We refer you to Figs. 15, 16, 17, 18 in Chapter 1, for qualities of modern lasers.

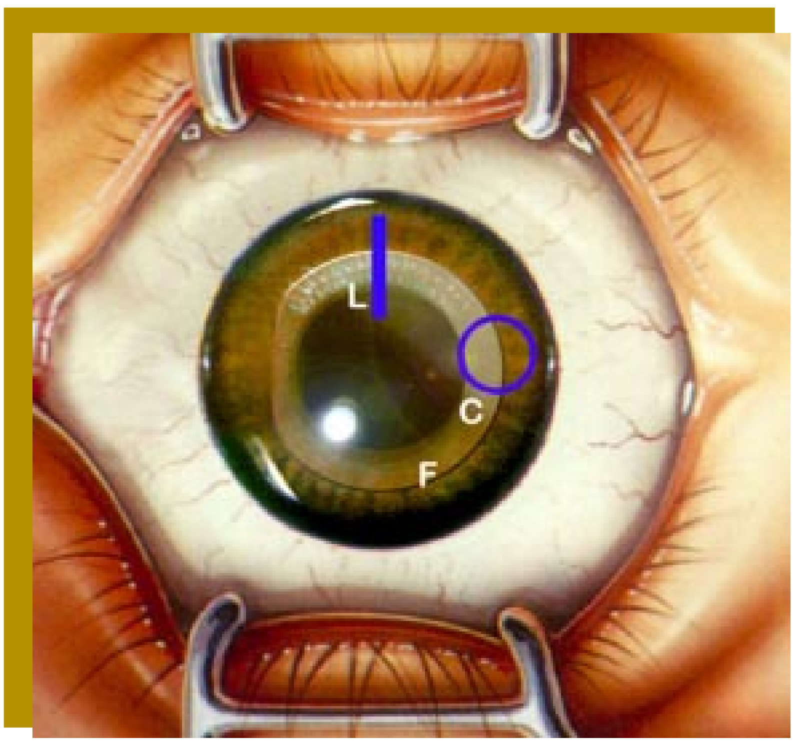


Figure 45: LASIK Technique – Marking the Edge of the Corneal Flap to Assure Proper Realignment

The area where the corneal flap will be cut with the microkeratome is marked in order to assure proper realignment in cases where a free cap is formed. Depending on the surgeon, 1 or 2 marks are made. A circular mark (C) assures good alignment of the flap and a linear mark (L) makes identification easier in the case of a free cap as a complication by making sure that the cap is properly oriented and is not upside down.

If the operation is complicated by the excision of a free cap instead of a hinged flap, place the cap over a corneal transplant dish with the epithelial surface down and the stromal surface upwards and do not irrigate. Within a very short time, the cap will recover its original shape on its own.

Excimer Laser Calibration

The only important differences in the laser calibration technique required for LASIK compared to that for PRK, lie in the **software** utilized and the target correction attempted.

Consideration of Optical Zone Size and Depth of Ablation

The laser must also be calibrated for the **optical zone size and depth of ablation (Fig. 28).** These become critical factors to consider in the correction of high myopia. Specifically, **optical zones of at least 6 mm are required to avoid significant glare (Fig. 59).** It is impossible to use single zone techniques for high myopes greater than -10 D because of the significant depth of ablation required (Fig. 28). We have previously emphasized that myopes over -10 D must be treated with phakic intraocular lenses, and **not** with LASIK. The size of the optical zone and the thickness of the remaining stroma cannot be sacrificed just to obtain a larger correction. The **strong tendency** now is to use larger optical zones. These also help to reduce regression and night glare, but limit the maximum correction obtainable.

Excimer Laser Maintenance and Recalibration

Machat points out that like all precise instruments, excimer lasers require continued and increased maintenance as the number of procedures increases. Broad beam delivery systems (Fig. 15) require greater maintenance than scanning systems (Figs. 16, 17, 18). Broad beam delivery systems have greater energy requirements and a more complex optical pathway, both of which result in greater maintenance demands. Optic degradation is a natural event that occurs as the laser energy damages the lens and mirror coatings and decreases beam quality.

Scanning lasers (Figs. 16-18) have a reduced need for complex optics and are less affected by degraded beam quality. Although scanning and flying spot lasers contain fewer optical components, each procedure requires more pulses, which may still lead to optic degradation and require frequent replacement. All optics require replacement at variable intervals. Likewise, the number of procedures performed per month and the efficiency of laser usage will determine how long a gas cylinder will last. **It is more efficient to perform multiple procedures on any particular day rather than a few procedures on multiple days.**

Our clinical and surgical results depend a great deal upon the proper functioning of the excimer laser that we use. All of them are highly sensitive instruments. We must follow the manufacturer's instructions strictly for recalibration. The surgeon must test the laser prior to each case to examine the beam energy output both quantitatively and qualitatively.

Limitations of LASIK Related to High Cost

The LASIK equipment necessary to perform this operation has two major limitations and disadvantages. One is the significantly **high cost** of excimer lasers. This, by itself, limits their availability to advanced eye centers or to groups of ophthalmologists who can get together and carry the financial burden until the number of procedures performed eventually covers the initial as well as the high maintenance cost.

The other major limitation is the need to use a microkeratome, which is also an expensive piece of equipment. This may change in the future if the disposable microkeratomes which are now being developed (Fig. 47-D) become sufficiently reliable and able to make a highly satisfactory cut for the corneal flap. The problems for the surgeon related to the use of this instrument and the measures to take in order to prevent complications with its use are amply discussed in this chapter.

MICROKERATOMES

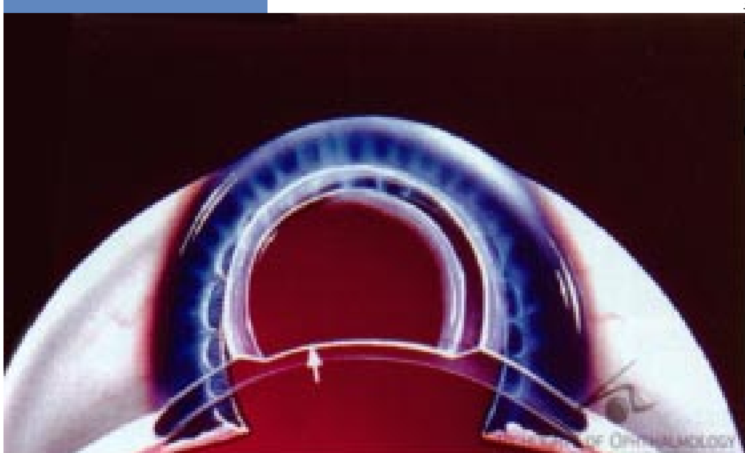
Just as LASIK has the unquestionable advantages of practically no pain postoperatively and very rapid visual rehabilitation, it has **one major limitation and problem** in performing the procedure: the need to use, at present, a **microkeratome** in order to do the operation. This, by itself, significantly limits the number of good ophthalmic surgeons who are fortunate enough to receive the necessary, highly specialized training to use this instrument **safely and effectively.**

Limitations and Complications

Jose Barraquer developed the first microkeratome; he first used it in a human case in 1963. Since then, it has become used worldwide in LASIK and other procedures. Therefore, microkeratome technology has been available for almost 37 years. **Carmen Barraquer, M.D.,** emphasizes that we all recognize that microkeratomes can be difficult to manage. During the past 10 years about 20 different models have been developed in an effort to design a model less likely to cause complications.

Many companies are working to improve microkeratomes, a certain indication that there is a problem with currently available technology. Generally, the devices have multiple parts and have been complicated to operate. If assembled or oriented incorrectly, they can cause complications such as perforation, which is disastrous with the very high intraocular pressure produced by the suction ring during LASIK.

The complication rate of free caps and irregularity of the surface **(Fig. 46)** caused by a less than perfect microkeratome section is the major barrier to the successful use of this most important instrument. The high intraocular pressure to which the eye must be subjected during LASIK in order to make the corneal flap with the microkeratome is a risk factor for several other complications as well. In addition to retinal artery occlusions,



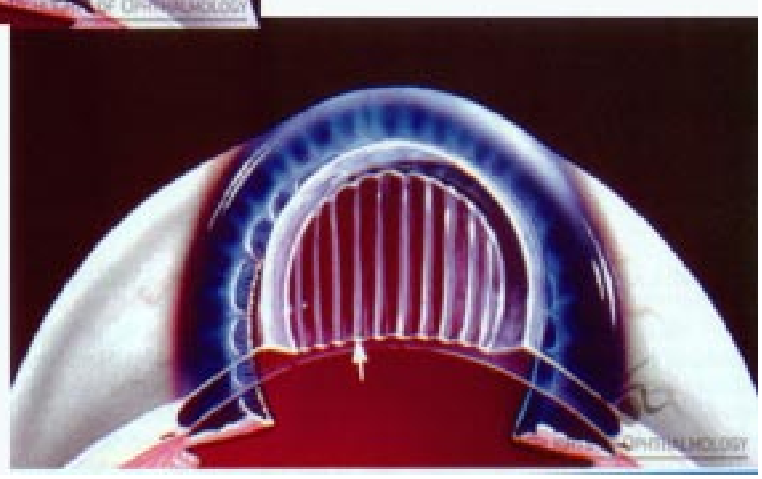


Figure 46: Smooth vs Irregular Lamellar Section with Microkeratome

A slow, even, controlled movement of the microkeratome is essential during sectioning for production of a smooth interface (top - arrow). Cutting too fast or using a less than perfect microkeratome blade can result in an deficient lamellar section inducing irregular astigmatism (below). Starting, stopping and restarting the cutting can result in a stepladder and irregular section (below - arrow).

in patients with high myopia these include submacular hemorrhages, possibly related to unrecognized subretinal neovascularization (Figs. 49, 50). The very high pressure and deformation of the globe have also led to the development of retinal tears and retinal dialyses although this is very infrequent.

Potential for Vision Loss

In **McDonnell's** extensive teaching experience, because of the learning curve, the patient's chance of losing two or more lines of vision may be on the order of 4% to 8% with a surgeon who is first performing LASIK. After the surgeon has performed 50 to 500 surgeries - surgeons argue about this number - the risk of loss of vision may drop to about 1%. Still, **obviously, this is a substantial risk.** Therefore, the prize will go to the company that develops a microkeratome that is less complicated, has a very high margin of safety, and that can be mastered more rapidly by surgeons.

New Approaches in Developing Microkeratomes

The newer microkeratomes have fewer interchangeable parts, making them easier to clean and assemble. Gears have more protection, so there is less chance of jamming and interruption during the creation of the flap.

Improvements in Design and Performance

Thanks to the research and teaching efforts of industry and ophthalmologists, improvements in design have occurred steadily, especially during the past 2 years. **Waring** points out that automated keratomes, such as the Innovatome and the Hansatome (Fig. 4 B) manufactured by Bausch and Lomb - Chiron , allow the microkeratome to move mechanically across the eye without requiring the surgeon's hand to push it. The ability of the microkeratome to make a very smooth incision, without chatter marks has also improved. The Innovatome, which has a blade 100 microns thick and 1 mm wide, can make an extremely smooth surface. A microkeratome preset to a cut a standard thickness such as the Chiron - Bausch & Lomb Automated Corneal Shaper (Fig. 47-A) or the Moria manually advanced microkeratome can now be used fairly safely.

The **Moria Company** also makes a new automated microkeratome that can create hinges with different orientations, either superior or nasal. Several of the new microkeratomes including the Eyetech and Mastel, use diamond blades or other gem blades in the hope of creating a much smoother surface (Fig. 46-A). Some, as the SCMD microkeratome (Fig. 47C), use a cable or a turbine to drive the blade across the surface, rather than gears. Advanced, automated microkeratomes have become very prevalent, and have the advantage of a consistently uniform performance (Fig. 47 A-B).

The instruments have also become less complex and the assembly simplified. There are now one-piece microkeratome heads. Several manufacturers, including Laser Sight, and Moria make plastic disposable microkeratomes that are driven by gears across the surface (Fig. 47-E). After a single use, they are discarded and replaced. Disposable microkeratomes, however, have not yet been proven advantageous in a published series of cases (Fig. 47).

Figure 47: LASIK – Main Types of Microkeratomes Now in Use (See next page)

The smoothness of the lamellar cut in LASIK depends greatly on the efficiency of the microkeratome used. **(A)** This side view of the Chiron Automated Corneal Shaper (ACS) depicts the movement on the tracks of the suction ring (G-gear driven) (red arrow) as it makes the lamellar cut. The instrument's head may be calibrated for different corneal thicknesses as well as various flap diameters (F). Motor (M). **(B)** The Hansatome was designed optimizing microkeratome technology by combining the original Automated Corneal Shaper and improving its capacity to pivot along a track (G) and post (P) in order to create superiorly- (F) and nasally-hinged cuts (See inset). It may also be adjusted to different depths, and diameters of up to 9.5 mm. **(C)** External view of the Turbokeratome from SCMD illustrating the concept of a manually controlled lenticular cut. The flap has a thickness of approximately 160 microns as well as a diameter of up to 10 mm (depending on the manufacturer). It is placed between the edges of the track of the

Figure 47: LASIK – Main Types of Microkeratomes Now in Use (Cont.)

suction ring (yellow arrows) and uses a turbine motor, which allows for high-speed cuts, producing very high-quality flaps. **(D)** The Chiron Hansatome Microkeratome is shown in place on the eye. The motor blade portion (M) is placed (red arrow) on the pivot post (P) of the fixation ring (R). Suction of the fixation ring to the eye is provided via a channel located within the handle (H) located nasally (N). The motorized oscillating blade advances across the cornea (blue arrow) by the motorized gear (G) moving along the elevated track (T) of the suction ring. In this way, the blade creates a lamellar corneal flap, hinged superiorly (S), as it pivots securely on the suction ring post (P). Blades are disposable. **(E)** This external view illustrates the use of the recently manufactured disposable microkeratome. It is made of plastic and its features are similar to the aforementioned. These disposable microkeratomes may be manual, or automaticly driven by a motor that moves the microkeratome along a track on the suction ring (yellow arrow). The depth of the cut is variable, according to the surgeon's previous calculations.

Confusion still exists because of the more than ten different styles of microkeratomes currently on the market. Data are not available to determine whether one or two of these styles are clinically better than the other ones. Most of the new designs have been available only 1 to 2 years, so there is limited clinical experience. During the next few years surgeons must carefully determine which of these instruments are safe and practical enough to use with LASIK, and which ones will turn out to be impractical and therefore disappear from the scene.

One new approach involves using a high speed, high pressure, thin stream of water to create the microkeratome section **(Fig. 48 A-B).** The potential advantage of this approach is that raising the eye pressure to extreme levels is unnecessary.

In addition, some investigators are exploring the possibility of using a solid state laser such as a picosecond laser to make the flap instead of doing it mechanically with the microkeratome. Many small pulses are applied at a specific depth within the cornea, so as to break the adhesions between the anterior flap and the deeper cornea. The laser-created flap is lifted up, the ablation is performed, and the flap is replaced (Figs. 56, 57, 58). Which of the many new approaches being developed by several different companies will prove to be the most effective over the next 2 to 3 years remains to be seen.

Carmen Barraquer's concept of the present status of this complex subject is that its evolution has provided us with two different kinds of instruments: those with the original lineal motion and new ones which have angular movement. In addition the surgeon can choose between manual or automatic displacement.

The blade has been maintained as it was originally developed, with an angled position and oscillatory movement. New blade materials have been developed, but in general metal blades are the ones most used.

The new generation of microkeratomes with angular motion allow the surgeon to change the position of the hinge either superiorly or nasally.

Since no one microkeratome may be best for all cases, ideally a refractive surgeon may want to master two or more microkeratomes, preferably incorporating both technologies, in order to be able to offer each patient the highest reliability that LASIK technique can attain.

Preventing Complications with Microkeratomes

Carmen Barraquer believes the best way to avoid complications with any microkeratome, which is a precise and delicate instrument, is to understand exactly how it works. **Barraquer** recommends that surgeons work with the instrument that they really know best.

Surgeon's Responsibility

Waring emphasizes that it is the responsibility of the surgeon to know the mechanism of operation, the procedure for safe clinical use, and the problems that can occur with whatever microkeratome he or she elects to use. **It is the responsibility of the surgeon to use the instrument correctly, and not the responsibility of the manufacturer to ensure that the surgeon does a good job.** As **Carmen Barraquer** emphasizes, the surgeon must work with the microkeratome he/she really knows.

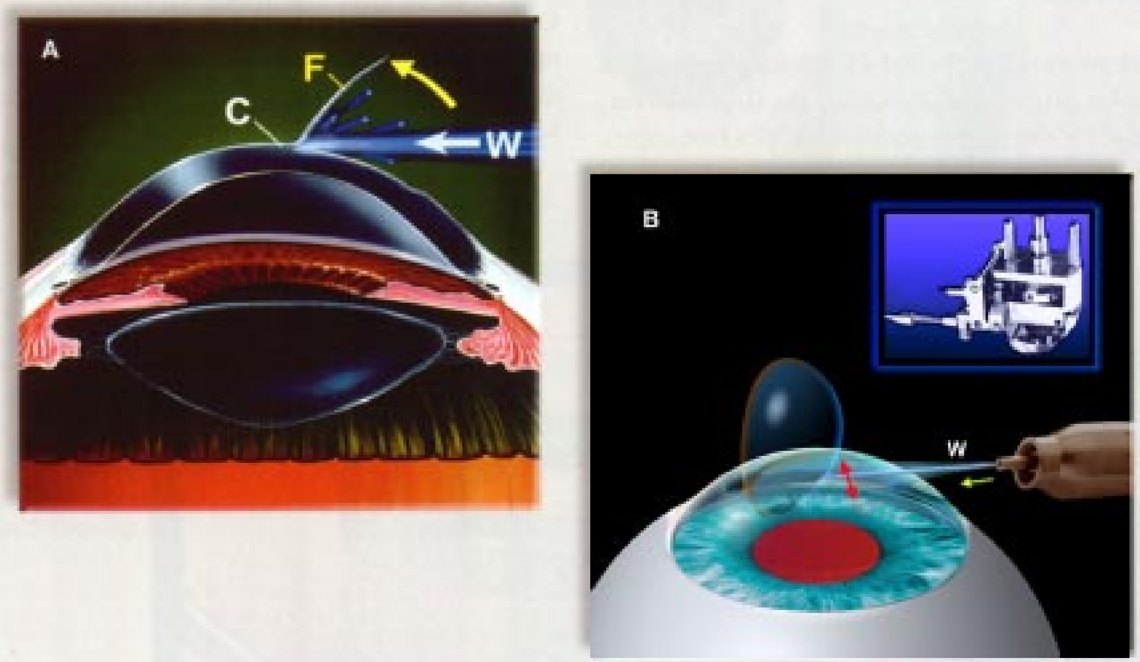


Figure 48 A-B: Concept of Possible Future Microkeratomes - The Water Jet

(Left) Exploration of other possible approaches to creating lamellar corneal flaps includes the use of a high speed, high pressure thin stream of water to create the section. Shown is a conceptual view of a thin stream of water (W) striking the cornea (C) in a controlled fashion, to section a flap (F). The potential advantage of this approach is that the raising of the intraocular pressure may be unnecessary as compared to the current blade type microkeratome approach. **(Right)** This is another view of the **hydrokeratome** (water jet) completing the dissection of the corneal flap. Water (W). The red arrows indicate the stream of water making the section, avoiding any possible surrounding tissue damage, as well as the formation of metal particles. It is capable of various section-depths as well as corneal diameters up to 10 mm. The inset shows the mechanical instrument that gives rise to the "water jet".

MAKING THE CORNEAL FLAP

Corneal Markings

As shown in Figs. 44 and 45, marks are placed on the cornea for proper realignment of the flap. Markers are essential for the proper positioning of a free cap.

Functions of the Suction Ring

The suction ring **(Fig. 49)** provides three functions: globe fixation, elevation of intraocular pressure to make possible a keratectomy of even thickness, and a dovetail track to guide the advancement of the micro-keratome head.

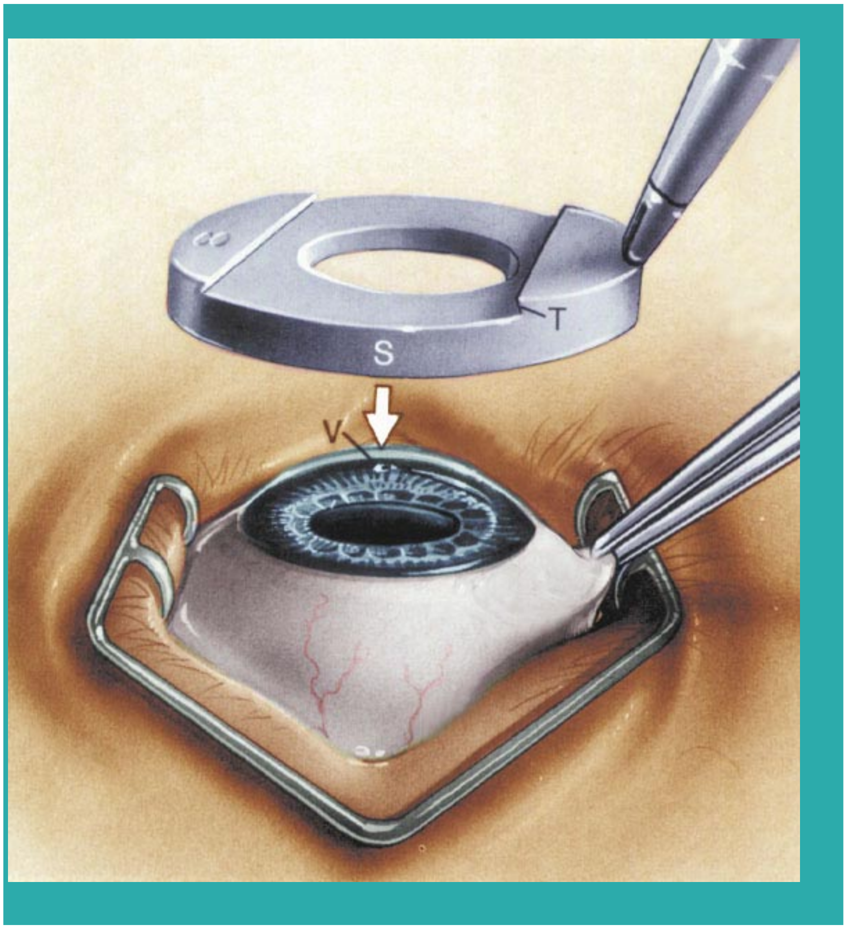
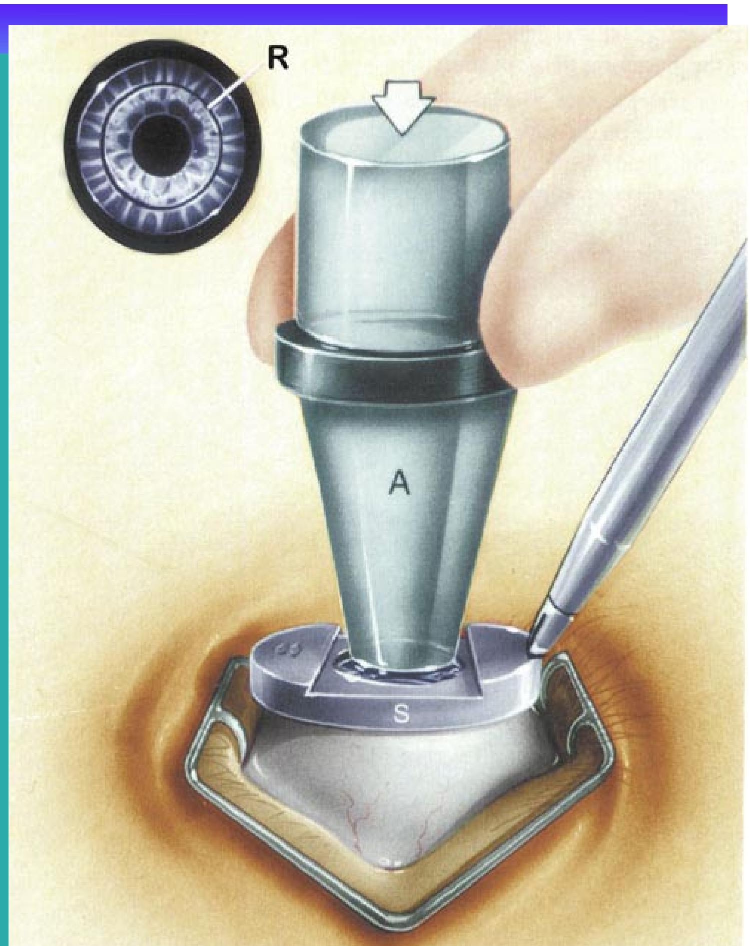


Figure 49*:* LASIK - First Steps - Placing the Suction Ring

The center of the pupillary area (V) has been marked with methylene blue (See Fig. 44). Peripheral markings here also been made (Fig. 45). These markings will permit perfect realignment of the corneal flap to its pre-op position. The LASIK pneumatic suction ring (S) is placed on the eye (arrow). With a suction pressure greater than 65 mm Hg, the instrument fixates the globe at the limbus and provides a dovetail track (T) for the microkeratome.

Figure 50*: Technique of LASIK - Preparing the Eye for the Microkeratome Pass - The Barraquer Tonometer*

The intraocular pressure is checked to ensure that it is appropriate (65 mm Hg or greater). This is required for an adequate microkeratome section. A clear, plexiglass applanation lens (A - Barraquer Tonometer) is placed on the cornea. Looking down thru it, the surgeon checks to be sure that the area of the cornea that it applanates is smaller than the calibration ring (R - Inset). The high pressure for 1-2 minutes ensures a uniform microkeratome section and is not dangerous to the eye. Suction ring (S).



Barraquer Tonometer in LASIK (Click over Videoclip)

The Need for Transient High Intraocular Pressure

After the vacuum to the pneumatic suction ring has been activated and prior to the passage of the microkeratome, the surgeon must verify that the intraocular pressure is sufficiently high (greater than 65 mm Hg) to perform a highly satisfactory microkeratome cut of the corneal flap. This is best confirmed with the Barraquer tonometer, which consists of a conical lens with a flat undersurface that is marked with a circle, and a convex upper surface that acts as a magnifier (Fig. 50).

How to Interpret the Tonometer's Marks and Readings

The lens is lowered directly onto the **relatively dry corneal surface.** If the applanated area is smaller than the circle (see inset in Fig. 50) the intraocular pressure is higher than 65 mm Hg and surgery can proceed. If the applanated area is larger than the circle, the pressure is too low and passage of the microkeratome could result in a thin, irregular keratectomy that is smaller than the desired diameter.

The importance of having the cornea relatively dry at this stage is that, if wet, the fluid meniscus can give a falsely low result.

Making the Microkeratome Cut

Once adequately high intraocular pressure is obtained, the corneal surface is irrigated with balanced salt solution (BSS) to minimize epithelial roughening as the microkeratome is passed. Moistening the cornea with BSS helps the microkeratome glide easily. Occasionally, a narrow palpebral aperture may necessitate a lateral canthotomy but usually gentle manipulation of the eye speculum to open the lids and expose the globe is sufficient. The microkeratome is loaded into the dovetailed groove on the suction ring (Figs. 49, 51). The gears

Figure 51: The Gears of the Microkeratome are Properly Engaged - Cross-Section View

This figure shows a general cross-section of a microkeratome loaded into the dovetailed groove on the suction ring. It also shows the instrument as it begins to create the lamellar corneal flap (F) while it moves across the cornea (arrow) on the suction ring (blue). The cutting blade (orange) is located beneath the blade guard (green). Microkeratome motor (red). Suction ring handle (purple). Because many of these components have adjustable parts, creation of a successful lamellar corneal flap depends on all of these complex components working both properly and in harmony.

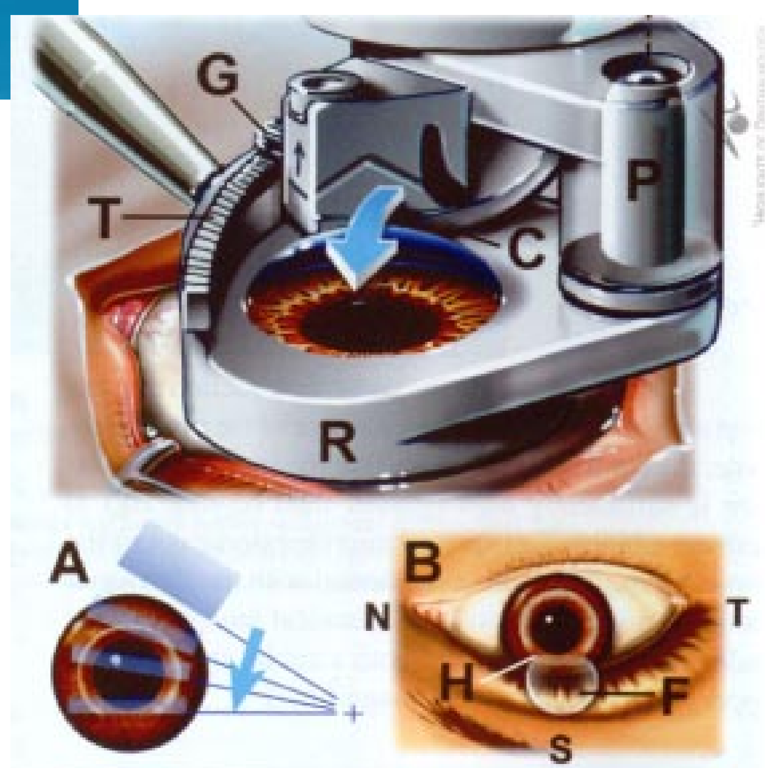


Figure 52: Concept of the New "Up Cutting" Microkeratome Systems

The latest microkeratome systems advance the motorized oscillating blade (C) in a circular direction (arrow) by pivoting on a fixed hinge post (P) located on the suction ring. A motorized gear (G) on the opposing side of the blade system moves accurately along a curved track on the suction ring (R). The motion of the advancing blade is shown in inset (A). Inset (B) shows how the system creates a flap (F) in the superior direction (S) by "up-cutting". The hinge (H) of the flap is located superiorly. Nasal (N) and temporal (T). This is a conceptual illustration.

of the microkeratome must be properly engaged prior to activation (Figs. 51, 52, 53, 54). In the case of automated microkeratomes such as the Automated Corneal Shaper or the Hansatome (both made by Chiron, but there are other effective ones), the instrument is advanced by activation of the surgeon-controlled foot pedal. It is advanced to the stopper mechanism. Upon completing the cut, the instrument is then reversed and removed. The vacuum is discontinued and the suction ring is removed.

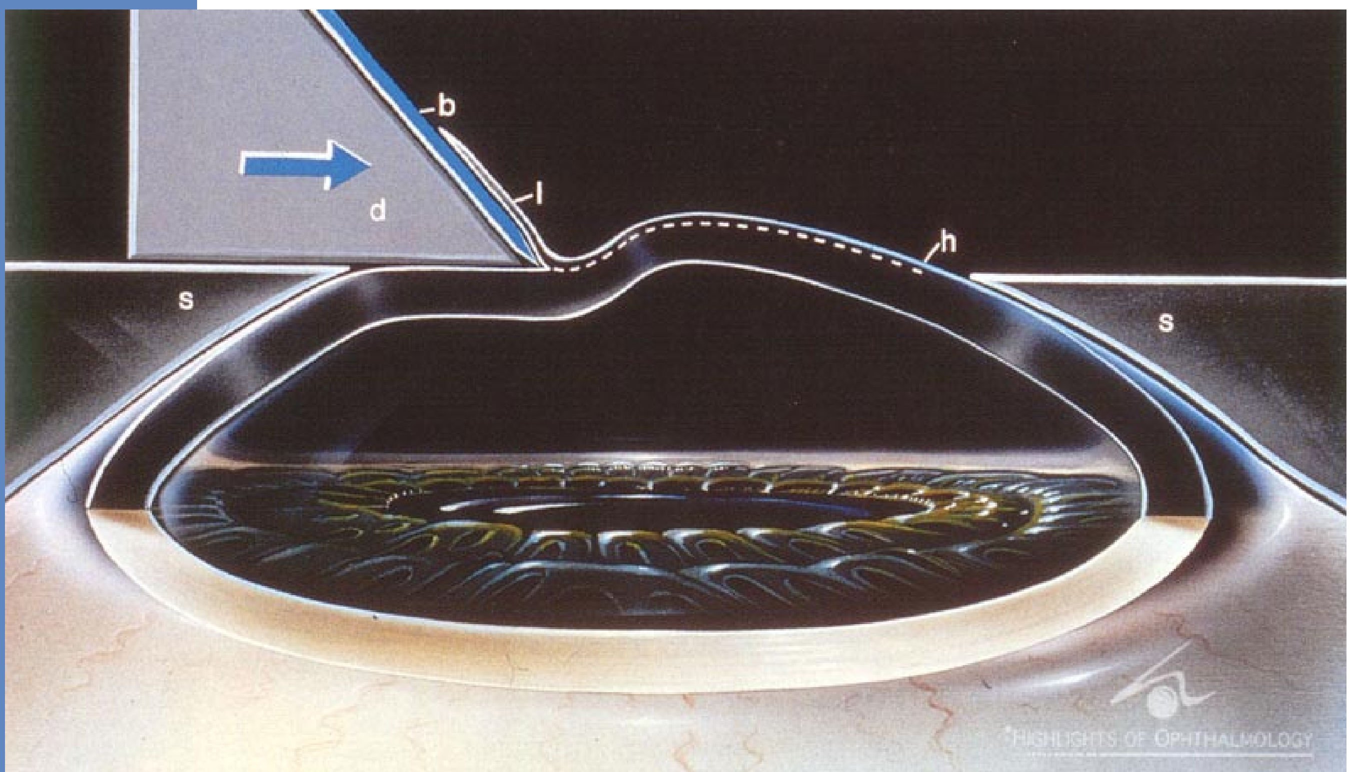


Figure 53: LASIK - The Microkeratome Instrument and Lamellar Section Technique

Shown is a conceptual cross-section view of the microkeratome instrument producing a lamellar corneal section. As the microkeratome is moved (arrow) across the cornea within the dovetail tracks of the suction ring (S) (Figs. 49, 51), the oscillating microkeratome blade (b) cuts the lamellar section (1). The depth of cut is determined by adjusting the shim, or spacing footplate (d), beneath the blade. The lamellar section will follow the dotted line shown. A "stop" device on the instrument will prevent a total excision of this lamellar section (free cap). Hence, the lamellar section becomes a hinged (h), disc-shaped flap which will be reflected either medially or superiorly to expose the corneal stromal bed beneath. It is this stromal bed which is treated and reshaped with the excimer laser.

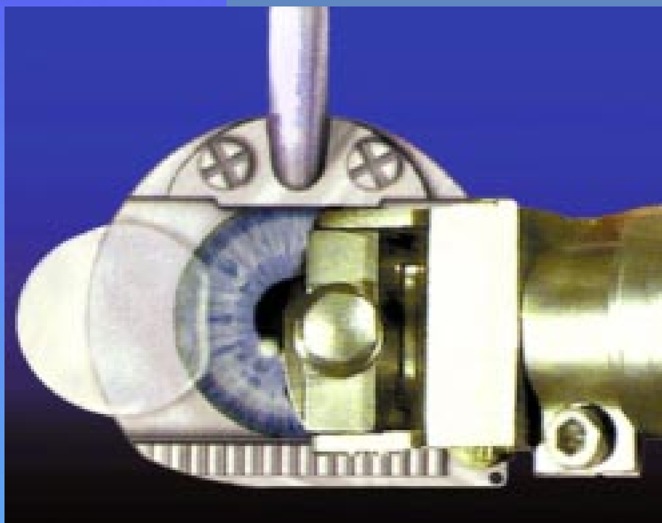
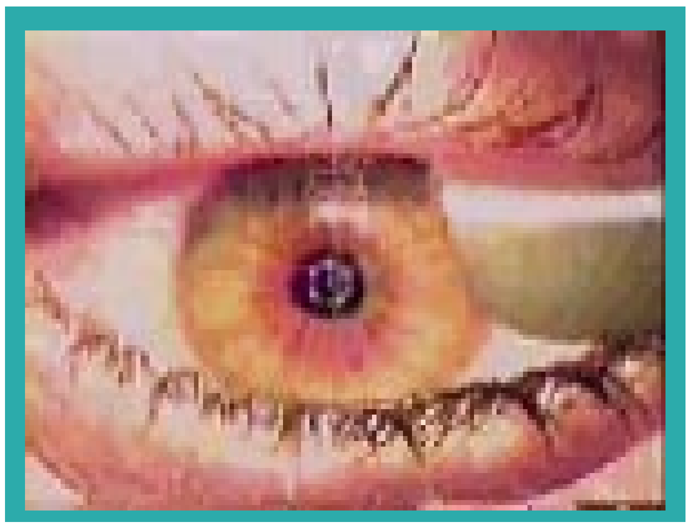


Figure 54: Hinged Corneal Flap Performed with the Automated Corneal Microkeratome

This surgeon's conceptual view shows the Automated Microkeratome made by Chiron already loaded into the dovetailed groove on the suction ring and activated by the surgeon's control-foot pedal. It is advanced to the stop mechanism. The flap is shown here hinged on the side (for better didactic purposes, although many flaps are now hinged superiorly as shown in the inset in Fig. 47-B). Upon completing the cut, the instrument is reversed. The vacuum is discontinued and the LASIK suction ring is removed. This procedure is done immediately before the application of the excimer laser ablation.

Performing
Myopic LASIK
(click over video clip)



Handling the Flap

Slade recommends that after positioning the patient's head so the corneal surface is perpendicular to the ablation beam, and prior to lifting the flap and beginning the excimer laser stromal ablation, the surgeon and staff should **reconfirm** the proper laser settings. **Gimbel** places a sponge around the limbus to absorb hemorrhage from limbal vessels. He then reflects the flap with a single motion using forceps (Fig. 55).

PERFORMING THE LASER ABLATION

After the corneal flap has been folded aside on its hinge either nasally or superiorly and, consequently, out of the ablation field (Figs. 55, 56) the surgeon proceeds with the stromal ablation, applying the excimer laser over the entrance pupil (Fig. 56). The ablation is based on the laser's computer calculations, programmed for the final desired refraction. As the ablation proceeds, the centration should be cautiously monitored. If significant movement occurs, the surgeon should stop the ablation, reorient the patient, and proceed when properly aligned. This is less of a problem if the surgeon is operating with the new eye-tracking laser systems which automatically follow the movement of the eye (pupil) (See Fig. 20).

During the ablation, fluid may accumulate on the corneal surface and should be **wiped dry.** A single pass

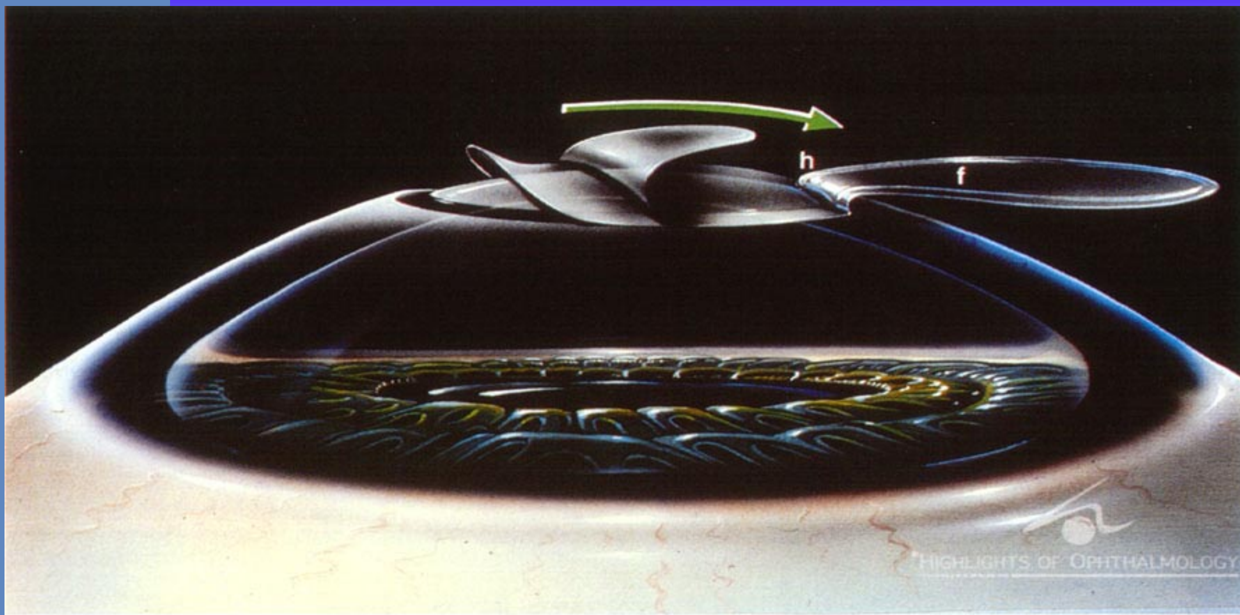


Figure 55: LASIK - Lamellar Corneal Flap Being Reflected - External View

This external view shows a lamellar corneal flap (f) as it is reflected (arrows) to expose the superficial corneal stroma. Notice the hinge (h) of the corneal flap. Creation of the lamellar section as a flap, rather than a totally excised disc, will allow easy replacement of the flap back to its original position following laser treatment. This ensures exact realignment of the flap and attempts to minimize postoperative astigmatism.

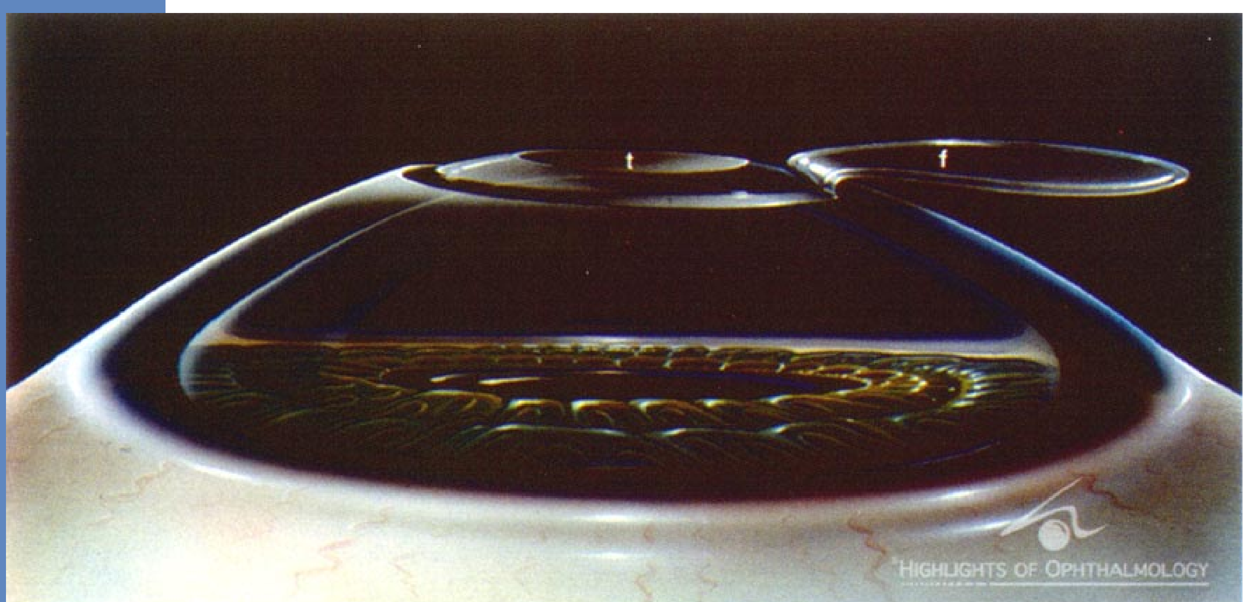


Figure 56: LASIK for Myopia - External View - Excimer Laser Ablation

Once the lamellar corneal flap (f) is reflected, the exposed stromal bed of the cornea (s) is ablated to a predetermined amount and shape with the excimer laser (I). The excimer laser beam (I) is shown here as applied to the corneal stroma centrally, which differs in the management of hyperopia (See Figs. 59 and 60). The pretreatment shape of the exposed corneal bed is shown here to compare with the following figures.

of a non-fragmenting cellulose sponge or blunt spatula is usually sufficient. When extending the stromal ablation to treatment zones with larger diameters, it is **important** to prevent ablation of the back surface of the corneal flap. This may be assured by covering the corneal hinge with a blunt instrument.

Figure 57 shows the corneal bed following the laser ablation **in myopia.** Note that the central corneal curvature has been **flattened (in the treatment of myopia).** At this stage, the posterior side of the flap and the stromal bed are irrigated with BSS using a syringe attached to a small-gauge cannula.

Myopic Scanning Ablation
(Click over Videoclip)

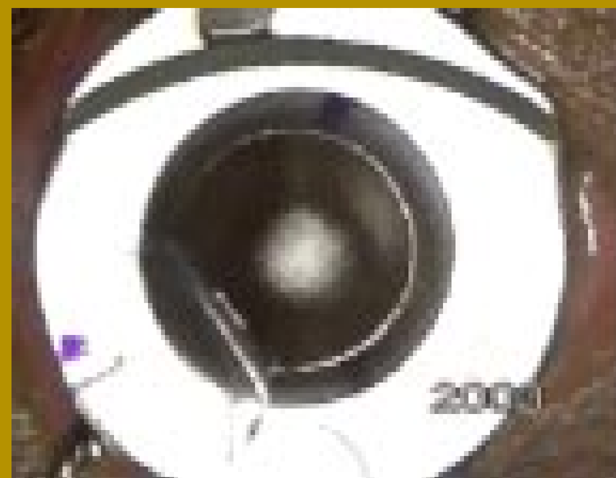
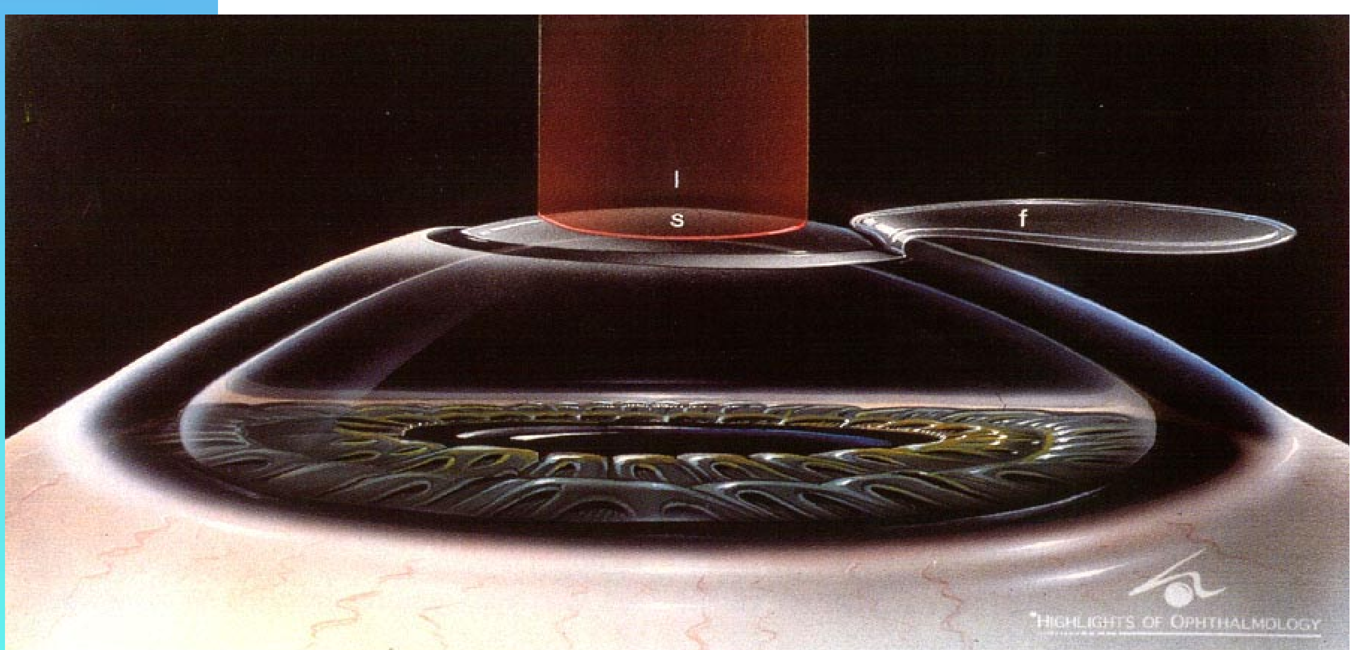


Figure 57: LASIK for Myopia - External View - Post-Laser Ablation Stage

Following laser treatment (ablation) of the corneal stromal bed (t), **the central corneal curvature** is seen to be effectively flattened by a predetermined amount (a minus refractive change shown here as a shallow cavity in the central cornea). The corneal flap (f) is shown with its proper hinge, which can be either nasal or superior. The flap is then replaced over the top of the treated area, and the change in curvature which was made to the corneal stromal bed will be translated to the anterior surface of the flap. The steeper, pre-op corneal curvature is shown in ghost view for comparison. (Note: the amount and shape of corneal tissue shown removed is exaggerated to highlight the concept of this procedure).



POST-LASER MANAGEMENT OF FLAP

The flap is gently swept forward and positioned back onto the stromal bed with a blunt-tipped instrument (Fig. 58). Irrigation **under the flap** proceeds from the hinge outwards, and is minimized so as not to cause too much stromal hydration, which can lead to poor flap adhesion. Irrigation is completed to clear any remaining debris from the interface. The flap is inspected to ensure proper position. Check with the previously made corneal mark to be sure the flap is in proper alignment (Fig. 44, 45). Avoid exerting too much pressure: that may stretch the flap and damage the epithelium. The interface is allowed to dry for several minutes. A slit beam is used at high magnification to search for debris trapped under the flap. If present it is gently irrigated out.

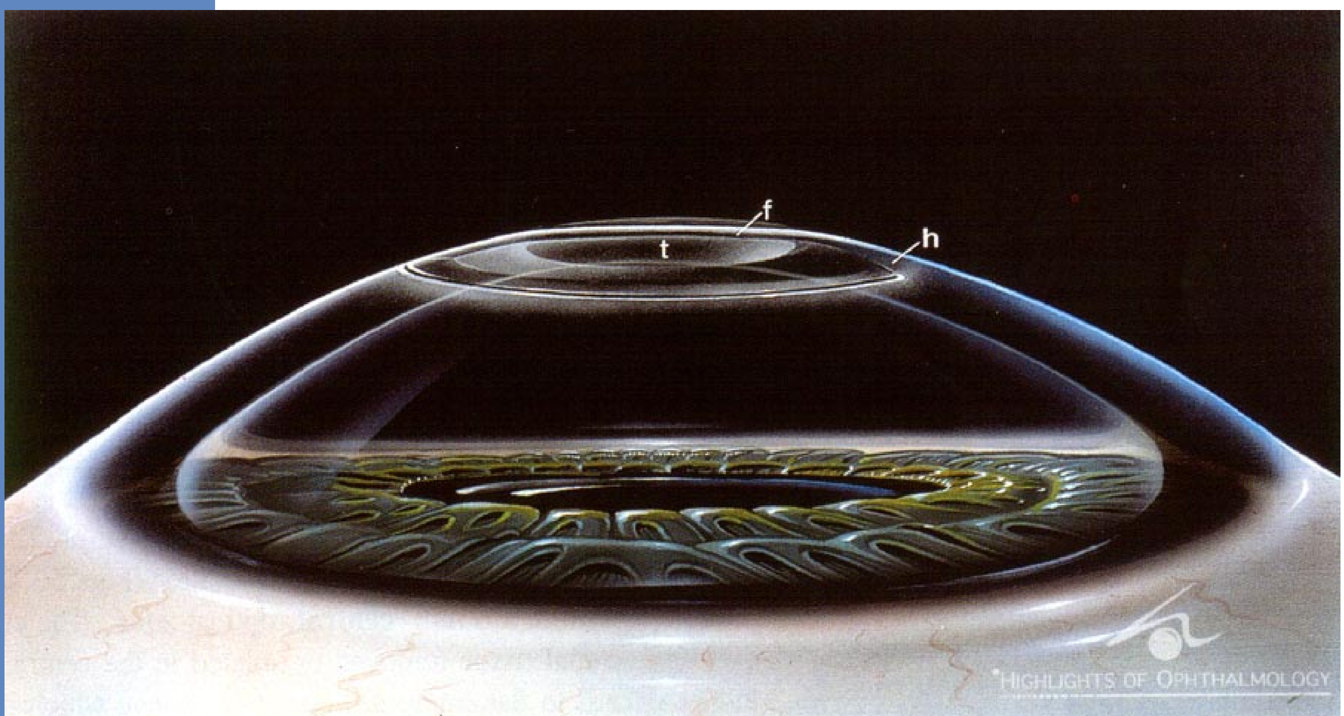


Figure 58: LASIK for Myopia - External View - Post-op

The lamellar corneal flap (f) is shown placed back onto the treated stromal bed (t). Notice that the curvature change made to the stromal bed beneath the flexible flap is now translated to the anterior surface of the flap. The central corneal curvature is now flatter than the pre-op curvature shown in ghost view. The hinge (h) of the corneal flap has allowed a direct reapposition of the flap to its original position on the cornea, minimizing any astigmatism from unwanted rotational misalignment. The lamellar corneal flap is not sutured.

COMPLETING THE LASIK OPERATION

The operation is completed by carefully removing the speculum and the drape. To prevent dislodging the flap, the patient is instructed to keep the eyelids open and look upward while the speculum is removed gently.

IMMEDIATE POST-OP MANAGEMENT

Immediately postoperatively, one drop each of antibiotic and nonsteroidal anti-inflammatory agent is instilled. The flap is checked at the slit lamp before the patient goes home.

Gimbel recommends using a moist chamber over the eye to assist in flap hydration and to reduce the incidence of flap displacement. This is especially important in the **immediate postoperative period** when the topical anesthetic is still acting and the patient may blink infrequently. He recommends use of this chamber for a week postoperatively **during sleep.** Otherwise, a shield is placed over the orbit, but no pressure patch is applied. Clinic follow-up is at 1 or 2 days, 1 week, monthly for 3 months, and then at 6 months.

Doane and Slade point out that on the first postoperative day, the uncorrected visual acuity should be 20/40 or better in the low and moderate myopia treatment ranges, which are the patients we are discussing in this chapter. Slit lamp examination should reveal a clear cornea with intact epithelium. Check proper flap apposition, stromal edema and interface debris. The patient should be placed on topical prophylactic antibiotics four times per day for the first week. Topical preservative-free lubricating drops are helpful in selected patients on an as-needed basis during the first several weeks after surgery. A short course of topical corticosteroids is prescribed. Systemic analgesics are rarely necessary with LASIK. The patient can resume regular daily activities after a normal 1-day postoperative examination but should be cautioned to avoid rubbing the cornea and participating in contact sports without wearing proper eye protection. Exposure to potentially contaminated moisture sources such as hot tubs, pools, and fresh water lakes should be avoided for at least 2 weeks. Full visual recovery can take several weeks or more and can be delayed if significant irregular astigmatism exists.

DIFFERENCES IN CORNEAL ABLATION BETWEEN MYOPIA AND HYPEROPIA (Figs. 59-60)

There are major differences in the strategy and technique of ablation with the excimer laser for myopia and/or astigmatism vs hyperopia. Although the subject of this chapter is myopia, it is appropriate to present these major differences now.

Characteristics and Technique of Excimer Ablation in Myopia and/or Astigmatism

In myopic and/or astigmatic patients, the corneal flap is made with an average diameter of 7.5 mm (Fig. 55) and the excimer laser ablation (Figs. 56, 57, 58) is within a 6 mm **central** optical zone. The corneal stromal tissue removed or ablated in the central zone leads to flattening of the central cornea, which in turn corrects in part or totally the myopic or astigmatic refractive error (see Fig. 59 for detailed explanation and view).

Figure 59: Characteristics and Diameter of a Central Excimer Ablation for Myopia and/or Astigmatism

This figure shows the type, characteristics and diameter (A) of an excimer laser ablation for the treatment of myopia and/or with astigmatism. This sculpting lessens the amount of central tissue (stroma) using an average central ablation optical zone of 6 mm. The diameter of the central ablation may vary, according to the type of excimer used, as well as the depth of treatment and the amount of intended correction in diopters for the myopia and/or astigmatism. The 6-mm central zone shown here as somewhat opaque or dim is where the laser beam is being applied and the central corneal stroma ablated. This is the surgeon's view through the microscope of the excimer. The corneal flap in the inferior part of the figure corresponds to the superior–hinged flap.

Making a Superior Flap (Click over Videoclip)

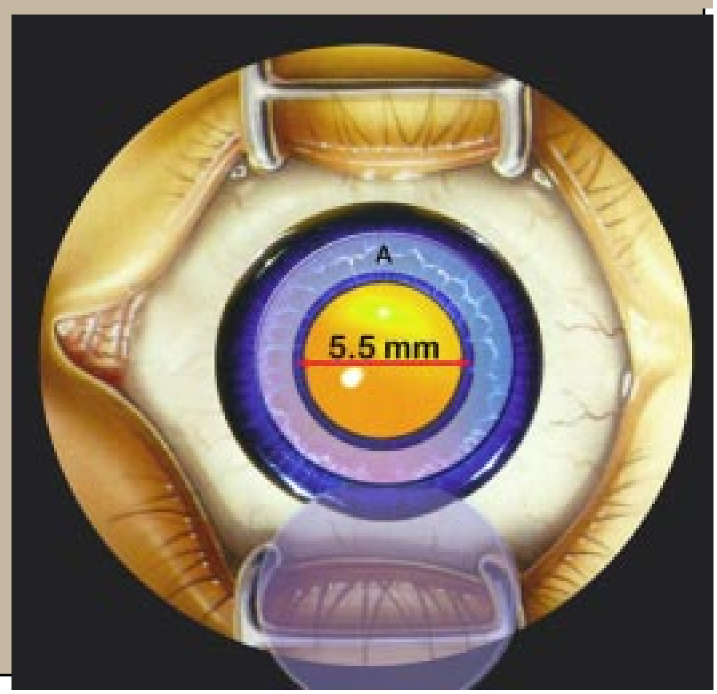


Figure 60: LASIK – Different Characteristics and Parameters in Hyperopia Vs Myopia – Peripheral Paracentral Excimer Laser Ablation

As opposed to the type and characteristics of the myopic eye, in the hyperopic, the ablation is intended to steepen the central corneal zone by performing a stromal ablation in the form of a lifesaver (A). This corrects or lessens the previous amount of hyperopia. In these cases, the average optical zone is approximately 5.5 mm or more depending on the type of excimer laser used. The central 5.5mm zone shown here in bright color is not ablated. The excimer laser beam is applied to the light bluish area shown here in the shape of a lifesaver. Since corneal tissue is ablated (removed) from this encircling zone, this zone is flattened, with resultant increased curving or steepening of the central cornea, thereby correcting the hypermetropia.

Characteristics and Technique of Excimer Laser Ablation in Hyperopia

In contrast with myopia or astigmatism, in hyperopia the **corneal flap is made larger**, up to 9.5 mm or 10.0 mm. The **central zone** has an average diameter of 5.5 mm, but **the central zone is not ablated. The excimer laser ablation is performed paracentrally,** in the shape of a life-saver, as clearly explained and illustrated in **Fig. 60.** Ablation of the corneal tissue in this encircling zone causes increased curving or steepening of the central zone, thereby correcting the previously existing hypermetropia.

In order to understand these essential differences between refractive surgical correction of myopia and/or astigmatism vs hyperopia, please refer to Figs. 59 and 60 and read the corresponding figure legends.

Whenever you flatten one part of the cornea, the other part steepens. This is called "coupling." To treat myopia you flatten the central cornea. The periphery steepens but, since you don't see clearly through the periphery anyway, it doesn't matter. To treat hyperopia you flatten the (mid) periphery, and the central cornea steepens: just what you want.

RK corrects myopia by weakening the peripheral cornea. The weakened periphery bulges (steepens), and the central cornea becomes flatter in response.

In treating astigmatism by excimer, when you flatten one sector, the sector at right angles to it steepens, augmenting the effect. With keratotomy, you weaken and thereby steepen one sector – and the opposite sector flattens. A tight limbal suture steepens the cornea in that meridian; the opposite meridian flattens. Removing the tight suture reverses both. These are all additional examples of "coupling."

COMPLICATIONS WITH LASIK

Preventing Complications

First and foremost, preventing complications is much more effective than managing them after they occur. **Gimbel** emphasizes that attention to every detail of the LASIK procedure is essential if the complication rate is to be minimized. An individual surgeon's complication rate drops rapidly when the learning curve is surmounted and the curve can be greatly foreshortened if one is fortunate enough to be assisted and supervised by a more experienced surgeon.

Waring advocates several strategies for preventing complications from LASIK. The **best way** to prevent complications with the flap, which is the most prevalent complication, is to use a meticulous preoperative checklist to ensure that the microkeratome is assembled and working properly. The Emory Vision Correction Center uses a very strict protocol for every eye. Both the surgeon and the technician are involved so that each item in the assembly and application of the microkeratome and the laser is checked in the same way that pilots and co-pilots complete a checklist before an airplane takes off. Going through this checklist virtually eliminates the chance of a technical error.

The **second** strategy in the priorities to prevent complications is to recognize in advance problems with particular patients. Patients with small palpebral fissures and small or steep corneas must be identified in advance, as well as those who have difficulty holding still, or who squeeze their eyes. If the surgeon decides to perform LASIK in spite of these limitations and disadvantages, adjustments must be made in advance in order for the instruments to work properly with these individual patients.

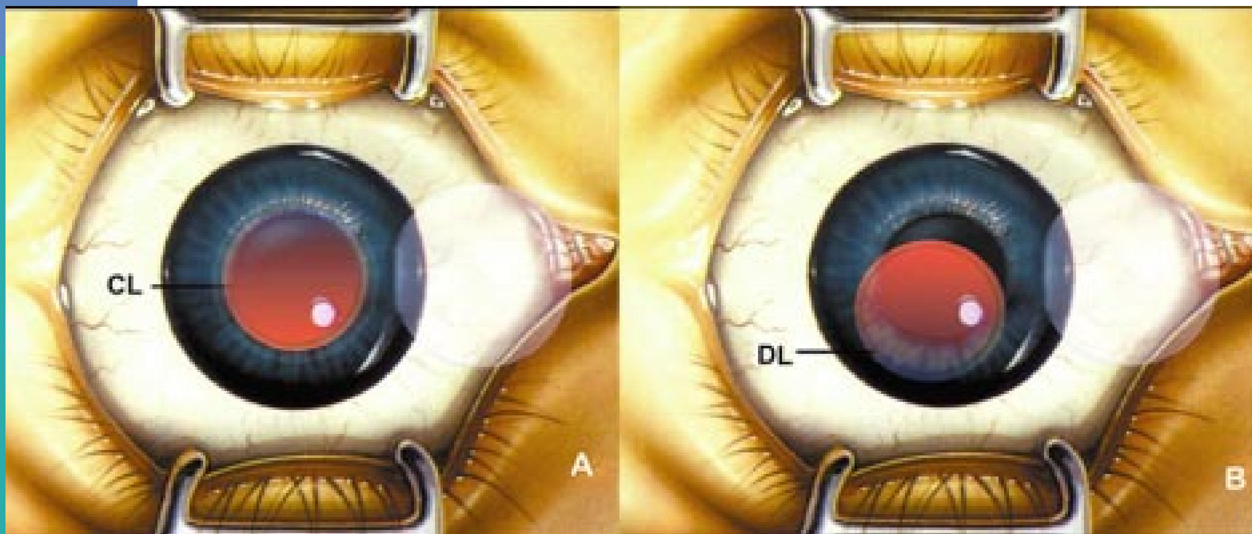


Figure 61: Well-Centered Myopic Ablation Vs a Superiorly Decentered Myopic Ablation

The goal is to produce a myopic ablation which is centered correctly over the pupil, as shown in figure "A". In figure "B", (surgeon's view) the ablation disc is decentered superior-temporally. Light enters the pupil from the ablated disc, the edge of the disc which has poor optical quality, and untreated cornea below the disc which produces an out-of-focus image. In addition, the decentration itself produces an irregular astigmatism. All of this results in an unhappy patient.

The **third** strategy is to become very familiar with the use of the instruments and what to do if difficulties arise, as emphasized by **Carmen Barraquer.** Typical problems occur if the microkeratome stops partway across the cornea, creates an incomplete flap (Fig. 63), damages or creates an irregular flap (Fif. 46), cuts a buttonhole in it (Fig. 64), or makes a complete disc with no hinge termed "free cap" (Fig. 65).

Other significant complications that are **very difficult** to manage but that **can be prevented** if careful precautions are taken are:

1) A Decentered Ablation (Fig. 61): This can occur if there is inadequate fixation of the eye during the procedure or the laser eye-tracking (Fig. 20) is inadequate. Self-fixation is better than surgeon-provided fixation.

Figure 61 shows the significant difference between a well-centered myopic ablation versus a superiorly decentered myopic ablation. This may happen when a good eye-tracking system is not available or when good eye fixation is not achieved during the procedure. In figure "A", we see a well-centered myopic ablation (CL). Note the relationship between the pupillary edge and the ablation edge. In order to avoid the occurrence of decentration, it is essential to maintain good fixation over the center of the pupil using the central cross hairs of the surgical microscope during the excimer laser application. In figure "B", we see an important decentration towards the superior and temporal sector (DL). This is the cause of double vision, shadows, glare and, in some cases, of the induction of irregular astigmatism. Many alternatives have been described to solve this complication. One of the most popular is retreatment with excimer laser on the opposite side of the decentration, guided always by the corneal topography. This procedure can smooth the ablation of the central optical zone, improve vision, and alleviate the patient's symptoms.

2) A Crescent-Shaped Second Image (Fig. 62): This is the result of performing a laser ablation smaller than the pupil diameter. When the pupil enlarges during darkness the patient gets a ghost image from the uncorrected paracentral cornea. This very bothersome complication can be prevented if we follow the basic principle: **do not** attempt to perform LASIK in patients with myopia greater than -10 D. In these patients the surgeon needs to create a deeper stromal ablation using a smaller diameter excimer laser ablation to provide a larger myopic correction. This is done respecting the strict protocol of **Jose Barraquer's law** (Fig. 28) regarding how deep within the stroma are we allowed to ablate.

If the diameter of the ablation is smaller than the diameter of the pupil, the retina receives a sharp and clear image from the ablated disc and, in addition, a second, out-of-focus, Crescent-shaped image from the surrounding, unablated cornea.

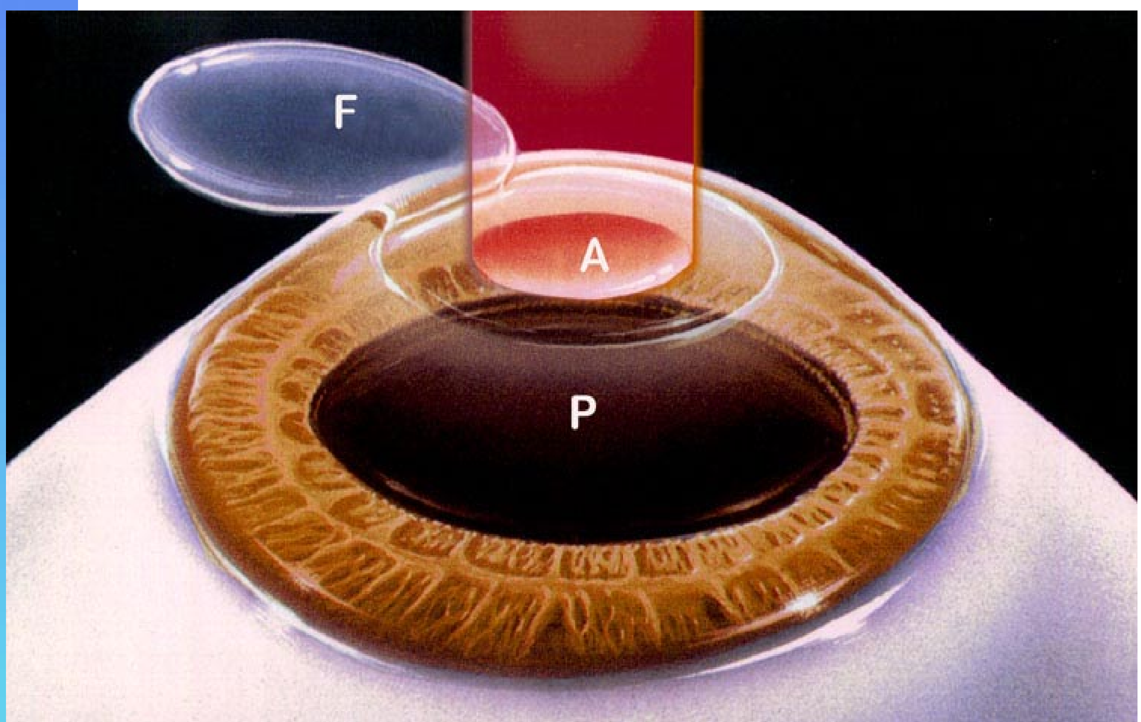


Figure 62: Crescent-Shaped Second Image

In this figure, we observe how the diameter of the ablation (A) is significantly smaller than the pupilar diameter (P) during dilation in the dark. This, in some cases, causes permanent glare, shadows and even double vision. It is recommended this disparity be avoided by making sure the ablation diameters are greater than 5.5 mm, especially in myopia greater than 6 diopters. It is also advisable to observe the approximate diameter of the pupillary opening by dimming the intensity of the slit lamp light before the procedure. Corneal flap (F).

Considerations of Intraoperative Flap Complications

Corneal Perforation

This is an infrequent but devastating complication, due to faulty assembly of the microkeratome. Most commonly, the depth plate is absent or not fully inserted. The design of the Chiron **Hansatome (Figs. 47-B and E) prevents this mistake** by incorporation of the depth plate into the blade. Because of the very high intraocular pressure produced by the suction ring, perforation is followed by immediate expulsion of intraocular structures and vitreous, necessitating major surgical intervention.

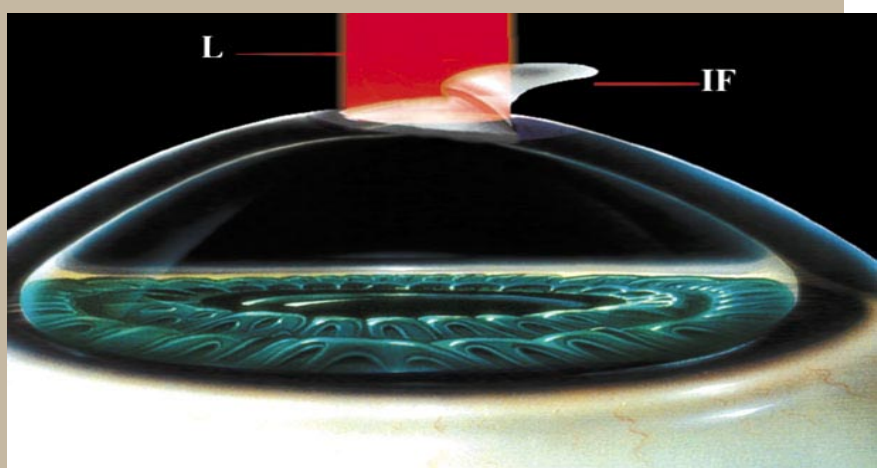
Incomplete Flaps

Incomplete flaps **(Fig. 63)** result from electrical failure, incorrect use of the automated microkeratome foot pedal control or microkeratome or gear obstruction by eyelids, lashes, speculum, drape, or loose epithelium. If the flap is nearly complete, the cut can sometimes be completed manually. In the presence of an incomplete flap, unless an **adequate** cut can be completed manually, it is best to abort the operation, put the flap back in place and repeat the procedure with a different depth plate at a later date. **Do not** continue the operation and **do not perform a laser ablation.** Be prudent: wait 3 months and make another attempt, this time with extreme caution.

Incomplete Flap in Myopic Ablation (Click over Videoclip)

Figure 63: Incomplete Flap in LASIK

It is important to maintain the microkeratome path free of obstacles at the time of the keratectomy. The ideal flap diameter for a good central myopic ablation should be greater than 4.5 mm. In cases where there is an incomplete cut (IF), with diameters smaller than expected it is recommended, only in low myopia, to reduce the optic treatment zone so as to be able to continue the procedure. If the keratectomy does not allow this, it is preferable to abort the procedure and not apply the laser (L). In the following intervention, 2 or 3 months afterwards, it is recommended that a new keratectomy is performed 10 – 20 microns deeper, if the pachymetry allows. Note in this illustration how, if the laser application is continued despite an incomplete cut (IF), ablation of the hinge may cause haze in this area, induce irregular astigmatism, and produce permanent glare and image distortion.



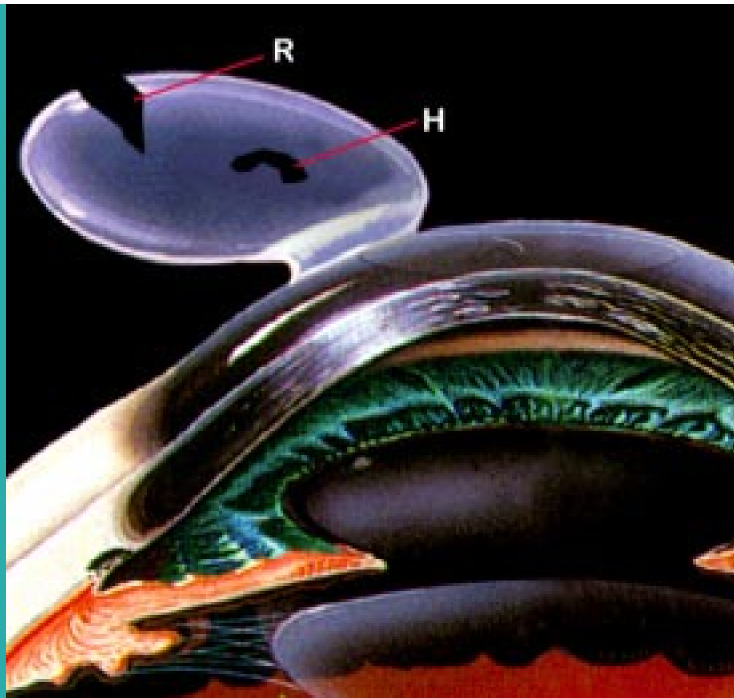


Figure 64: Large Flap Tears or Buttonholes

Major damage to the flap, either as a tear (R) or a buttonhole (H) will spoil the optical result. LASIK should be abandoned, and the flap cleaned and replaced.

(Click over Videoclip)

Buttonholed Flaps, Large Flap Tears and Irregular Flaps (Fig. 64)

Thin, irregular (Fig. 46) or buttonholed flaps result from inadequate suction with insufficiently high intraocular pressure, epithelial sloughing, or with excessively steep or flat corneal curvatures. It is important to put the flap back in place, **not to perform any laser** ablation, and repeat the LASIK procedure later. An unexpected pressure shift by the suction ring, a low intraocular pressure, foreign material in the microkeratome path during the keratectomy or a poorly-calibrated or assembled microkeratome are a few of the causes of flap damage. When the damage to the flap edge is slight, the planned procedure and the laser application may be continued. When there is considerable damage, such as a large flap tear (R) or a central hole (H), it is recommended that the laser not be applied, as this may induce important haze formation, as well as thickening of the edges of the flap tear and the consequent induction of irregular astigmatism and blurred vision. In these cases, once the procedure is aborted, it is recommended to clean the flap interface and replace the flap in its original position in order to avoid permanent damage.

Free Flaps or Caps (Fig. 65)

Free flaps or caps (Fig. 65) are caused by faulty microkeratome assembly, flat corneal curvature, and/or inadequate suction. If the flap has not become too edematous it may re-adhere spontaneously to the stroma. If a full disc is cut as shown in Fig. 65, it can simply be left in the microkeratome while the laser ablation is done in the bed. Then the disc is repositioned on the eye with or without suturing. If the cap is not in the microkeratome and the surgeon needs to obtain the correct orientation and be sure whether the cap is upside down, place the cap in a corneal transplant dish without irrigation and it should spontaneously recover its shape.

In order to reposition the flap correctly it is essential to follow the preoperative markings made as described in Fig. 45. If necessary the flap may be sutured in place.

Gimbel points out that if a free cap has been lost, there are two choices. The surgeon can allow the stroma to re-epithelialize. In this case, the refractive outcome may be satisfactory, but haze formation may be excessive. If the cornea has become too thin or its surface too irregular, another alternative is to perform a lamellar keratoplasty.

Poor Flap Adhesion

Poor flap adhesion may be a sequel to excessive irrigation during flap replacement or too much manipulation of the flap. The flap may re-adhere if gently stroked into place and given longer than the normal 4 minutes drying time to settle. If this is not sufficient, it should be sutured.

Trapped Debris

Trapped debris may originate from the tear film, unclean irrigating solutions, surgical instruments including sponges, or atmospheric pollution in the operating room. Although it often does not affect the visual outcome or healing of the flap, such debris should be irrigated from under the flap at the end of the procedure. Solutions for irrigation should never come from an open

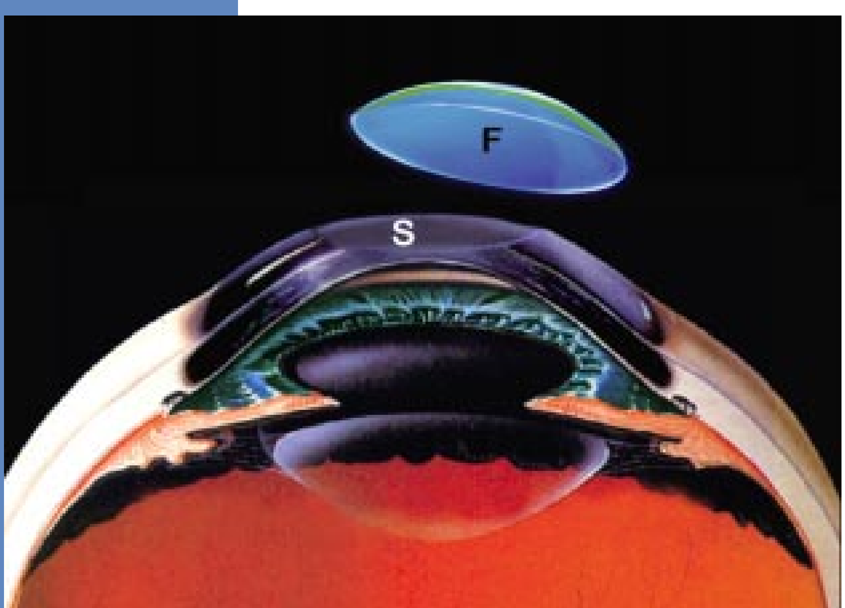


Figure 65: Free Cap in LASIK

The marking of the area where the keratectomy is to be performed is very helpful in this type of complication. One must remain calm and replace the flap (F) in its original place being careful to maintain its alignment, guided by the marks previously made on the cornea. It is also recommended that the flap be placed on a corneal dish (those commonly used in corneal transplants), so that it may recuperate its proper curvature. This way, we may be sure which side is epithelium and which is stroma and we may guarantee good placement on the stromal bed (S). In some cases, it is necessary to take a few sutures with 10-0 nylon with no traction. A free cap may occur in corneas with shallow keratometries, in eyes with low intraocular pressure or if the suction ring is disengaged prematurely. In cases where the flap is definitely lost, is it recommended to treat the case as if it were a PRK adding topical treatment with steroids for a few weeks.

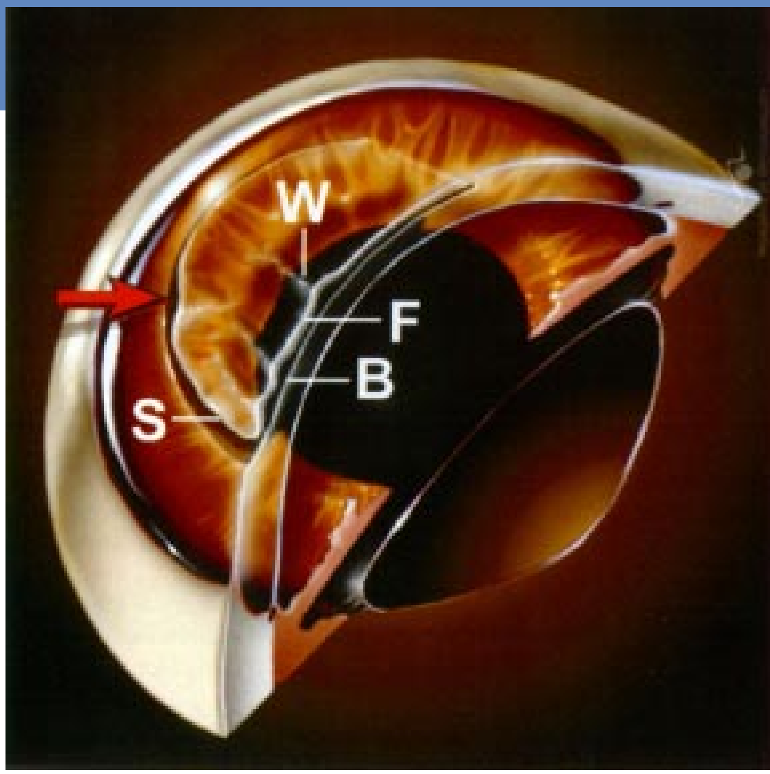


Figure 66: Problem of LASIK Flap Wrinkle and Slippage

The most common post-operative complication with corneal lamellar flaps is edge slippage or wrinkling of the flap. Note that the edge of the flap (S) has slipped slightly and there is some wrinkling (W) of the flap (F). Such a condition, if not corrected, could lead to epithelial ingrowth (arrow) between the flap (F) and the treated corneal bed (B) beneath. Proper operative technique can avoid this problem. Wrinkles across the center of the cornea can produce multiple images, glare and distorted images.

medicine glass or "clean" dish, only directly from the manufacturer's bottle.

Postoperative Flap Complications

Wrinkling

The most common postoperative complication with the flap is slippage or wrinkling (Fig. 66). The surgeon should inspect the eye shortly after surgery. If there is a wrinkle or a slip, the flap can be refloated, repositioned, and left to dry as usual. If a small edge slip is seen days to weeks postoperatively that does not affect visual acuity, no treatment is needed. If wrinkles of any sort are seen across the center of the flap (Fig. 66), the flap should be lifted, refloated, and sutured in position with a running eight-bite antitorque 10-0 nylon suture, which is left in place 5 to 7 days (Fig. 67). **Repositioning a wrinkled flap can be done a year or more after**

surgery. The wrinkles, which can produce multiple images, glare, and distorted vision, can be reduced or even eliminated.

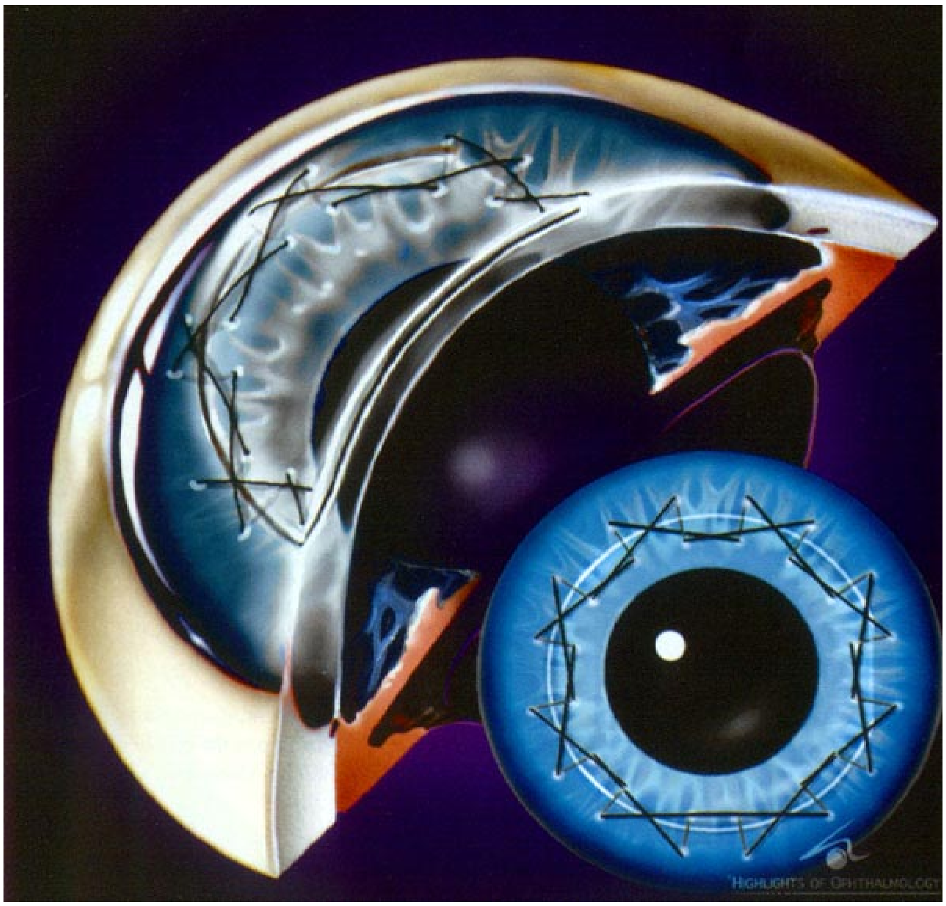
Dislocation and Flap Slippage

Another postoperative complication is **dislocation of the flap.** If this occurs, the flap must be repositioned after the bed and flap stromal surfaces are cleaned carefully. **Waring** sutures the flap back in position with an eight bite running antitorque 10-0 nylon suture. Although the flap can be repositioned without suturing, once the stroma is edematous, the flap can easily slip out of place again. Therefore, **Waring** believes suturing is the safest technique for securing the flap. From their experience with flap slippage at Emory, **Waring** and his colleagues have found that repositioning the flap does not affect the basic laser ablation. Very good vision can result even after a flap slip.

Prevention of slipped flaps postoperatively requires maintaining a moist, smooth epithelial surface so the lid does not push the flap out of place. The moist surface is maintained through frequent instillation of artificial tears postoperatively and through disrupting the epithelium as little as possible during surgery. In addition, the surgeon must ensure that the edge of the flap is flat and secure, with no areas of lifting or wrinkling, before the patient leaves the clinic. A therapeutic soft contact lens can be placed on the eye after surgery if there are epithelial abrasions, to decrease the roughness and consequent discomfort, and diminish the chance of flap slippage. This lens is left in place for 1 to 2 days and then removed. Flap slippage varies in frequency with different surgeons. **Waring** attributes this disparity to the lack of widespread dissemination of knowledge regarding the subtle techniques some surgeons have learned to decrease flap slippage.

Figure 67: Repair of Corneal Lamellar Flap with Slippage or Wrinkle

If there is a wrinkle or a slipped edge in a corneal flap postoperatively, the flap can be refloated, repositioned and left to dry as usual. If, however, wrinkles of any sort are seen across the center of the flap, days or weeks postoperatively, the flap should be lifted, refloated and sutured in position with an eight bite running antitorque 10-0 nylon suture as shown. The suture is left in place five to seven days.



Preventing Epithelial Ingrowth

The major technique for preventing epithelial ingrowth **from the edge of the flap** is to press down the edge of the flap at the end of surgery with a micro-sponge to decrease the space between the flap and the bed epithelium **(Fig. 68).** Using a meticulous repositioning technique, the Emory Vision Correction Center has decreased their rate of epithelial ingrowth from 10% in early experience with LASIK to their current rate of less than 1%. **Epithelial ingrowth comes from a fistulous tract at the edge of the flap** rather than from implantation of epithelial cells during the procedure **(Fig. 69).** If an area of less than 1 mm of epithelial ingrowth is present at the edge of the flap and not advancing, there is no need for treatment because the cells will

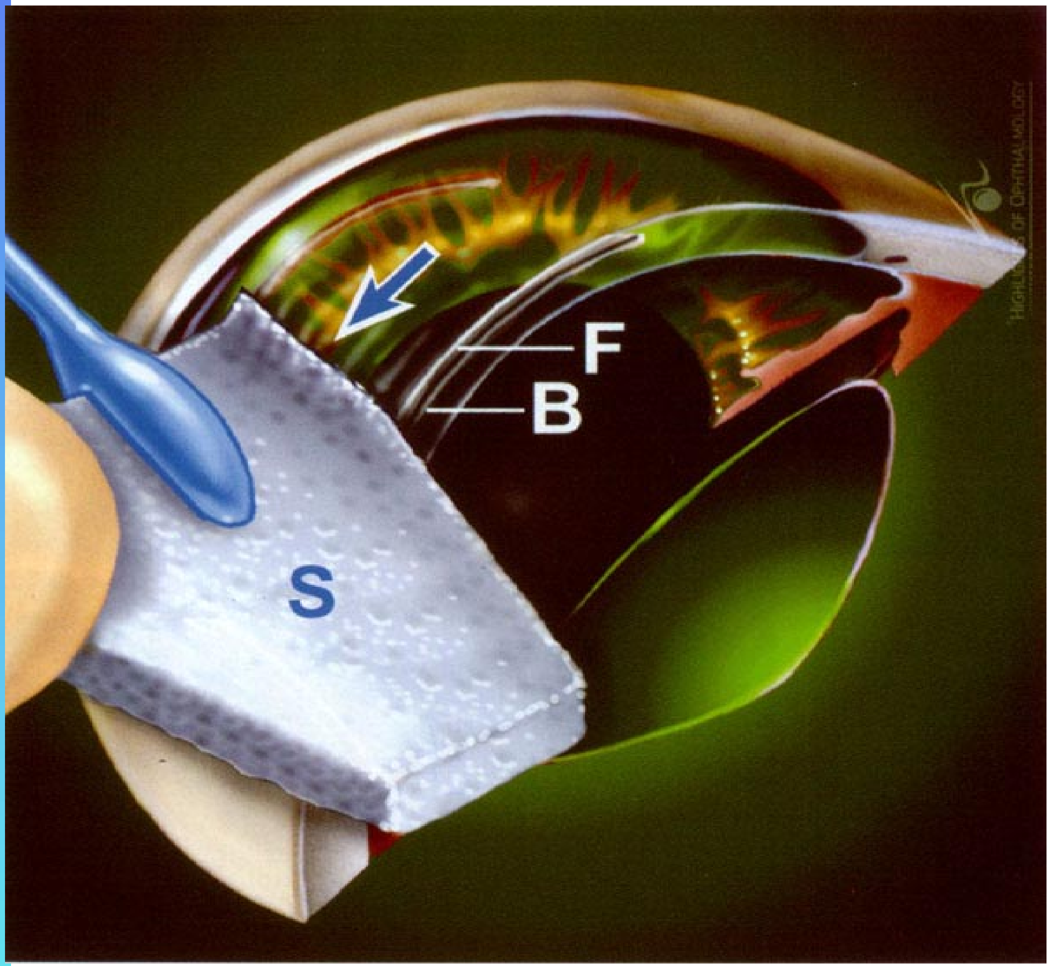


Figure 68: Prevention Technique for Lamellar Flap Slippage and Epithelial Ingrowth

The major technique for preventing epithelial cell ingrowth from the edge of the flap is to secure the edge of the flap at the end of surgery by pressing it into place with a micro sponge (S) as shown. This eliminates any space between the edges of the flap (F) and the corneal bed (B).

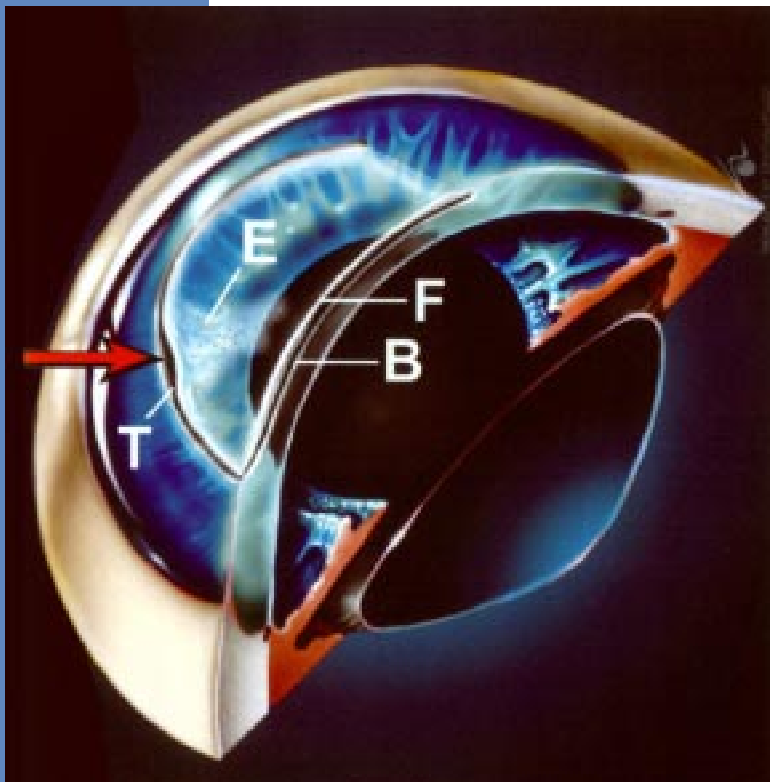


Figure 69: Epithelial Cell Ingrowth: the Problem

The majority of epithelial ingrowth (E) between the corneal lamellar flap (F) and corneal bed (B) come from a fistulous tract (T) at the edge of the flap. If more than 1mm of epithelium is present under the flap, and advancing centrally, surgical intervention is indicated for its removal.

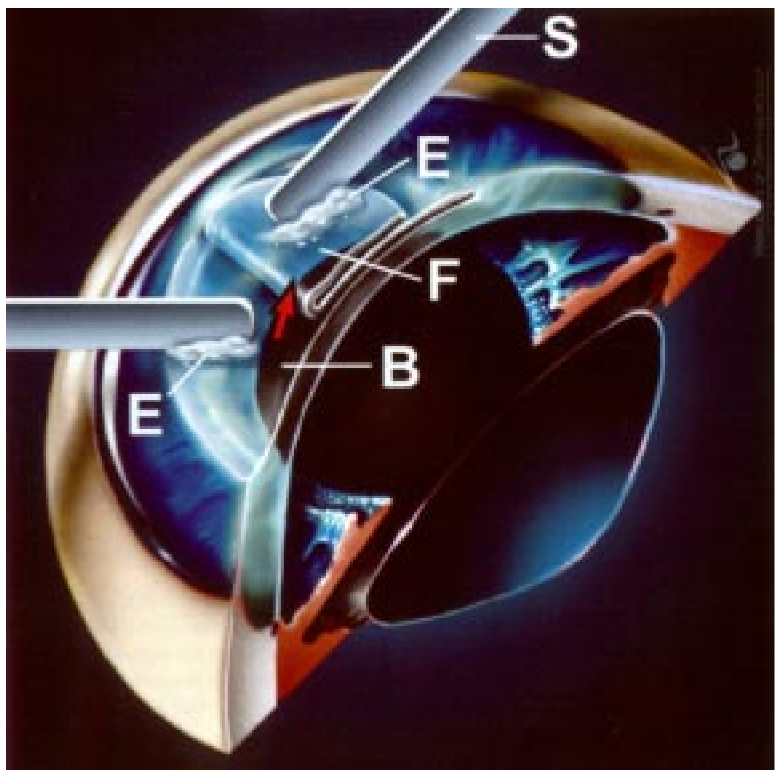


Figure 70: Repair of Lamellar Flap Epithelial Ingrowth - Step 1: Removal and Scraping

If removal of epithelial ingrowth is indicated beneath a lamellar corneal flap, the flap is lifted (arrow). Mechanical scraping of the epithelium (E) and surrounding fibrous tissue is performed with a spatula (S) on both the corneal bed (B) and the back of the flap (F). The flap is then repositioned as it would be following a normal LASIK procedure.

atrophy and leave a small gray scar, sometimes with a focal area of flap melting at the edge. If more than 1 mm of epithelium is present and advancing centrally, however, the flap must be lifted, and the epithelium and surrounding fibrous tissue must be mechanically scraped from the bed and from the back of the flap **(Fig. 70).** The flap is then repositioned, just as it would be after a usual LASIK procedure. **Waring** places a single or double

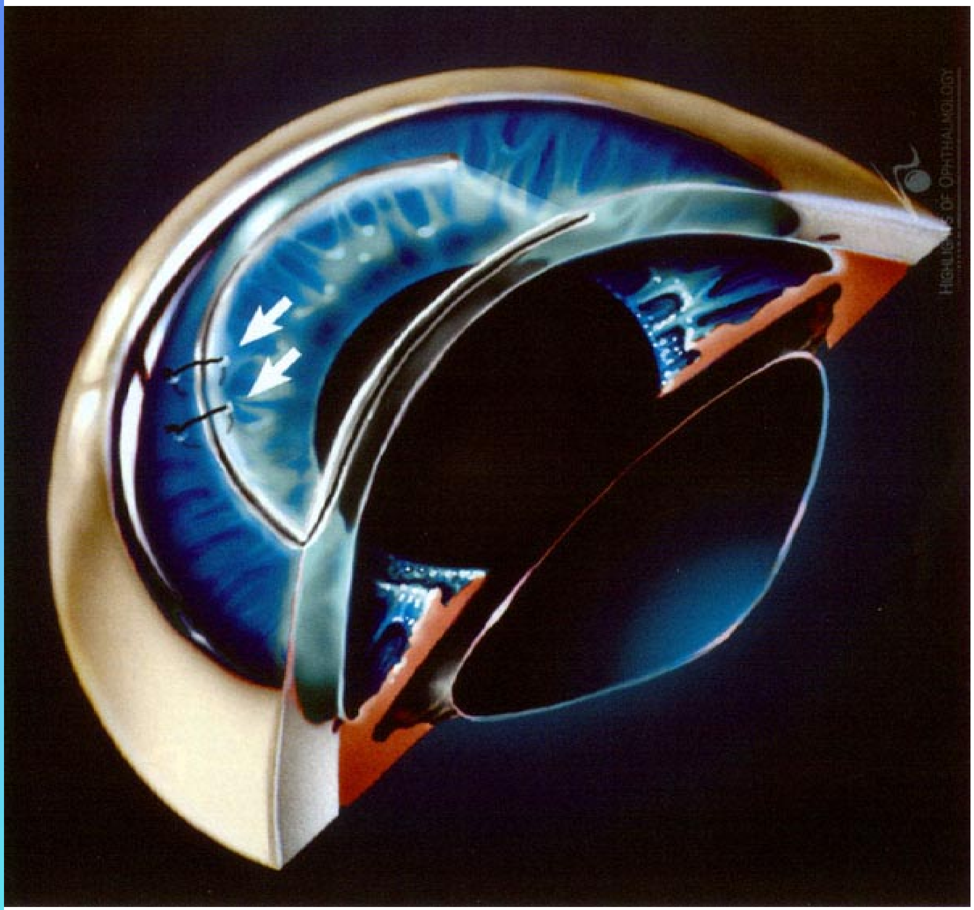


Figure 71: Repair of Lamellar Flap Epithelial Ingrowth - Step 2: Suturing

After the repaired flap has been repositioned, a single or double interrupted suture (arrows) is placed at the spot where the epithelium encroached under the flap. This will help close the fistula and prevent the recurrence of the epithelial ingrowth. epithelium (E) and surrounding fibrous tissue is performed with a spatula (S) on both the corneal bed (B) and the back of the flap (F). The flap is then repositioned as it would be following a normal LASIK procedure.

interrupted suture at the spot where the epithelium was, so as to help close the fistula and prevent recurrence of the epithelial ingrowth **(Fig. 71)**. Only rarely does epithelium appear beneath the center of the flap without a connection to the edge. **Epithelial ingrowth should be treated early** because it is easy to manage at an early stage. If the center of the flap and the bed are not affected, the laser treatment itself is not affected. **It is an error to wait until the epithelial ingrowth reaches the pupillary zone before treating it (Fig. 72).**

Central Islands

Central islands result from uneven stromal hydration or obstruction to laser energy from the ejected corneal vapor. The problem occurs infrequently with scanning slit and flying spot excimer lasers (Figs. 16-20) and software modifications have also made it less common with broad beam lasers (Fig. 15). Central islands cause glare and ghosting. They often resolve spontaneously over a period of 3 to 12 months.

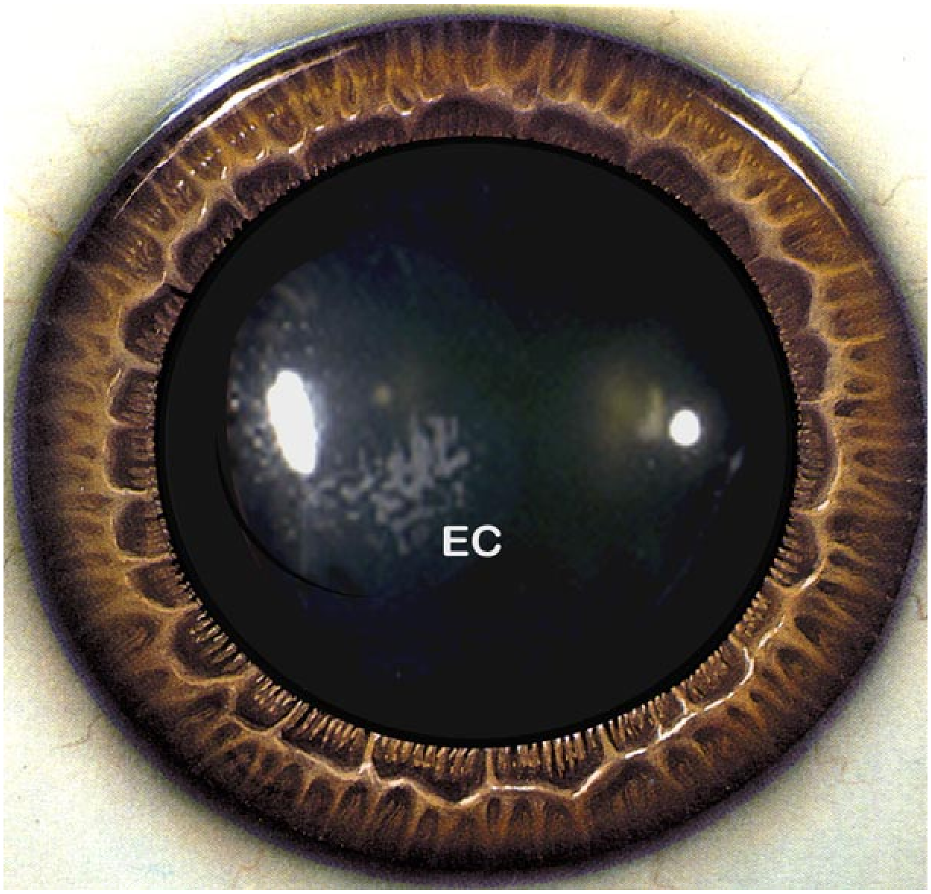


Figure 72: Epithelial Cells Observed under the Paracentral and Midperipheral Areas of the Flap

Epithelial ingrowth should be treated early because it is much easier to remove at an early stage, as shown in Figs. 69 – 71. It is an error to wait until the epithelial ingrowth reaches the pupillary zone or even the paracentral area before treating, as shown in this figure. The accumulation of epithelial cells may have various shapes. It usually appears in the center or the margin of the flap as cotton-like, white clumpy zones. It causes irregular astigmatism and visual impairment when they are located centrally.

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Surgical Management of Low and Moderate Myopia (-1.00 to -5.00 D)

CHAPTER 5

(PRK) PhotoRefractive Keratectomy

(ICRS) IntraCorneal Ring Segments

(RK) Radial Keratotomy

(GIAK) Gel Injection Adjustable Keratoplasty

Enter

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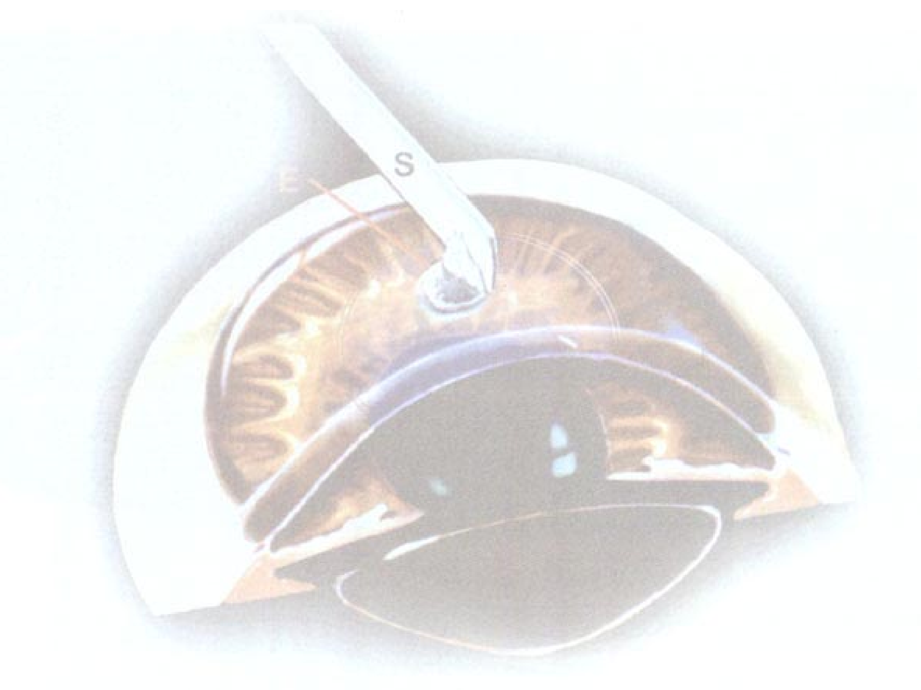

(PRK)

PHOTOREFRACTIVE KERATECTOMY

In his classic book titled “The Excimer: Fundamentals and Clinical Use,” published by Slack in 1997, **Harold Stein, M.D.,** (Toronto, Canada) devoted much space to cover the clinical aspects of PRK. At that time, in Canada and the U.S., PRK was the predominant excimer laser procedure.

Three years later (year 2000) **Stein** as well as most prestigious refractive surgeons worldwide consider that the dominant procedure is LASIK and not PRK.

Indications for PRK (Fig. 73)

Stein prefers PRK for low grades of myopia, two (2) diopters or less. **Lindstrom** considers PRK to be the **procedure of choice** in the following conditions:

1) Superficial scar with myopia.

2) Basement membrane dystrophy with myopia.

3) Myopia when unable to use a microkeratome because of a high brow or tight lid with narrow palpebral fissures.

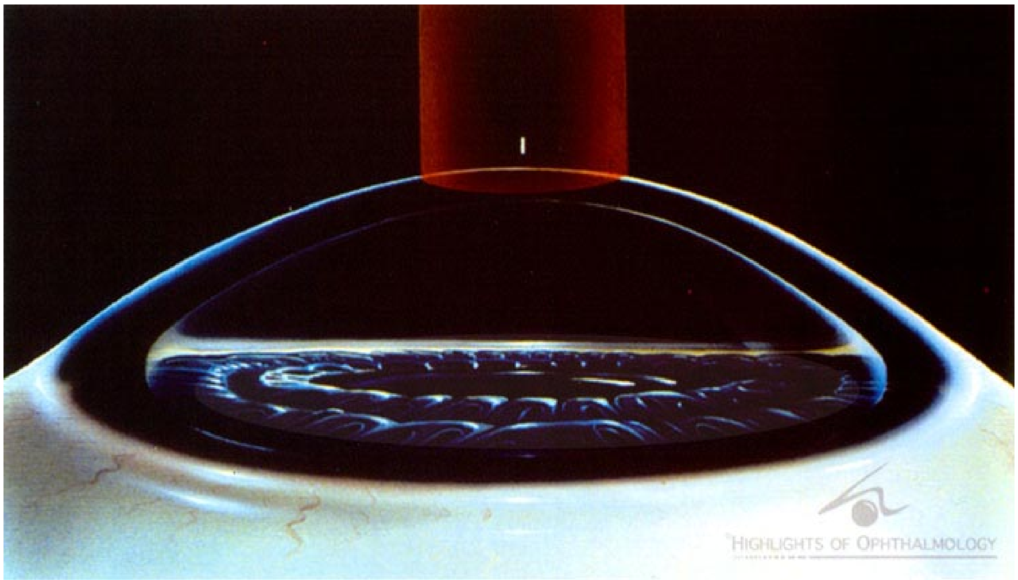

Figure 73: PRK Surgical Technique - External Intraoperative View

This magnified external view shows treatment of the central cornea with the excimer laser for PRK. The laser beam (1) ablates the superficial corneal tissue by a predetermined amount. This ablation will create a refractive change to correct myopia by slightly flattening the central corneal curvature. The pre-op shape is shown here to compare with the following figures.

Prof. Rosario Brancato, M.D., one of the world's eminent scientists, with special emphasis on lasers in ophthalmology, considers that **PRK** has proven to be effective and quite predictable in the correction of low to **moderate myopia.** The safety of the procedure has been extensively assessed as well, with only a minimal percentage of eyes ending with loss of best corrected visual acuity after treatment. But **Brancato** now also prefers LASIK in most cases of myopia within the range of -2.00 to -10.00 diopters, as most refractive surgeons do when they can manage the microkeratome well.

Even though PRK is safe and effective, it has a fairly large incidence of postoperative corneal haze, which often leads to a delayed visual recovery.

Other Indications for PRK over LASIK (Fig. 74)

In addition to the indications for PRK outlined above, the following conditions make PRK a better choice than LASIK:

1) Cornea thinner than 2.50. Such corneas do not allow an effective and saf e LASIK procedure (Fig. 28).

2) Patients who have previously had corneal incisions from RK or astigmatic keratotomy and who need further refractive surgery.

3) Patients who previously had RK and became overcorrected (hyperopes).

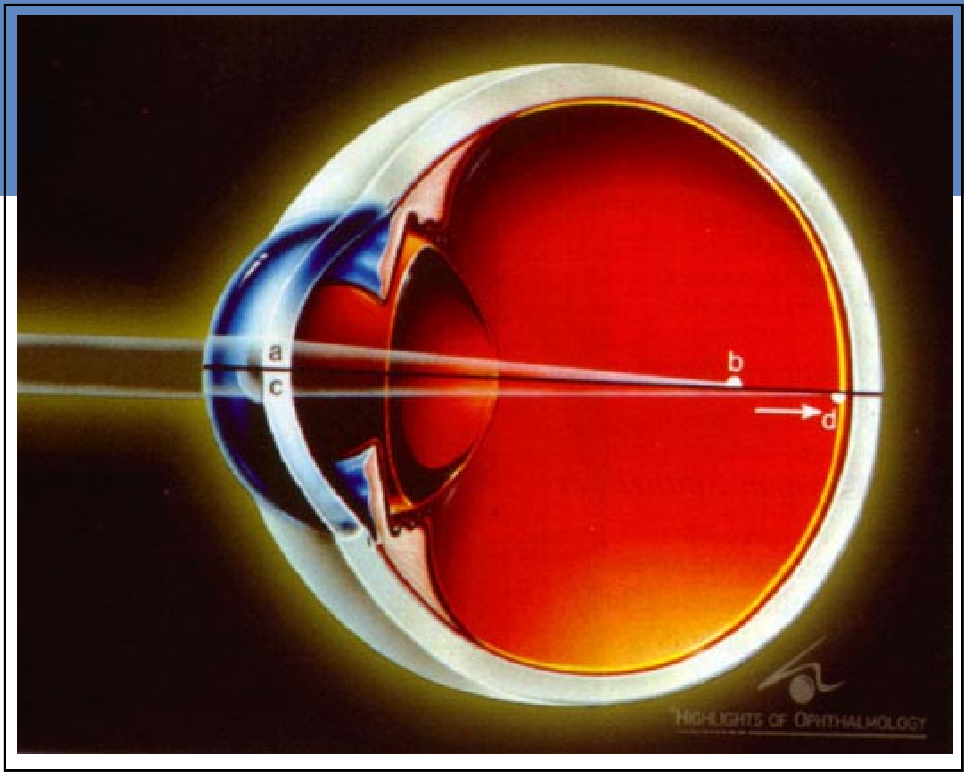

Figure 74: Refractive Concepts of PRK

The globe shown is divided into two halves (superior and inferior) for direct comparison of pre and post-op corneal curvature change from PRK, as it relates to the resulting change in refraction. The upper half shows a steep, pre-op corneal curvature (a) causing a myopic refractive effect. Note that the focal point (b), (from a point source of light), is anterior to the retina. The lower half shows the flatter, treated central cornea (c) following PRK. The resulting minus refractive change now causes light to focus on the retina (d).

4) Crowded orbits with tight or narrow lid space that would make it very difficult to pass the microkeratome.

5) Patients with recurrent corneal erosions.

PRK vs LASIK - Advantages and Disadvantages

Surgeons who do not perform refractive surgery in high volume may perform PRK, and get good results with safety for their patients when treating myopia from -1.00 to -5.00 D.

Although LASIK may be also routinely used to treat low and moderate degrees of myopia, PRK is much less surgically demanding than LASIK. LASIK is superior to PRK in causing minimal postoperative discomfort, in the rapid recovery of clear vision and stabilization of refractive change, and in the infrequent occurrence of haze.

Performing PRK

Preoperative Evaluation

Marguerite McDonald, M.D., of New Orleans, Louisiana, performed the first PRK, and has been one of the key surgeons responsible for extensive pioneering work in the appropriate approach to PRK. She highly recommends a careful preoperative examination after the patient has been out of soft lenses for a minimum of 2 weeks or out of gas-permeable or polymethylmethacrylate (PMMA) lenses for a minimum of 3 weeks.

Detailed preoperative evaluation for refractive surgery as presented in Chapter 3 is essential.

Surgical Technique

The actual surgery begins with marking the center of the entrance pupil (Fig. 44.)

Removing the Corneal Epithelium

The next step is to remove the **epithelium mechanically (Fig. 75).** This is followed by ablation of the corneal stromal with the excimer laser **(Fig. 76).**

Corneal Stromal Ablation

The amount and depth of the excimer corneal stromal ablation to be performed is previously calculated by the surgeon and has a direct relation to the amount of ametropia to be corrected. This desired correction and the diameter of the optical zone are entered into the laser's computer. The corneal bed of the ablation must be sufficiently dry obtain the desired correction. A humid bed may interfere with the full effect of the laser.

Postoperative Management of PRK

Principles of Management

While postoperative regimens vary widely, the most popular ones are **oriented toward overcoming pain,** which is one of the disadvantages of PRK. A disposable soft bandage contact lens is applied in the immediate postoperative period, to make the patient comfortable. A nonsteroidal topical anti-inflammatory agent is instilled in the eye to reduce pain. In addition, cold packs and mild analgesia are advised. Antibiotic drops (twice daily to four times daily) are needed until the epithelium regenerates.

These measures not only lead to the best postoperative results but also contribute significantly to patient satisfaction. Since the average patient after PRK is +1 on the first day, a +1 disposable contact lens may be used to correct the mild hyperopia. Instead of being 20/200, patients will be 20/60 or 20/70 and functional on the first day. These lenses cost only about $2 each.

Pre and Postoperative Use of Medications in PRK

What to use preoperatively and postoperatively depends, of course, on the individual physician's preferred choice of medications. The standards are:

1) For Pain: a nonsteroidal anti-inflammatory drug (NSAID) is the key to control or minimize postoperative pain. The preferences of most surgeons are either **Acular** (Ketorolac thomethamine 0.5% - Allergan), **Voltaren** (diclofenal sodium 0.1% - Ciba Vision), **Acular PF** (Allergan) or **Flarex** (fluoromethalone acetate - Alcon). The latter is a low potency steroid that does not affect intraocular pressure nor the process of re-epithelialization following PRK. Instilling these drops over the contact lens every 4 to 6 hours significantly reduces pain. These drops, however, can cause infiltrates in the cornea if they are used too long, so use them only for the first 2 or 3 days. If you can obtain **preservative-free Acular (Acular PF)** you can speed the process of re-epithelialization in addition to providing comfort.

2) Preventing Infections: a topical antibiotic is always used. This is as important as pain control. We must prevent the development of infectious keratitis, the most feared complication of refractive surgery. The risk of infection is directly related to the size and duration of the epithelial defect.

Ideally, the ophthalmologist should see the patients daily for 3 days until the epithelium is intact, because there is some risk of infection with a therapeutic soft lens and a large epithelial defect. Seeing the patient daily also often increases the patient's comfort level and reduces the level of anxiety and postoperative pain. Discontinue the contact lens and the nonsteroidal drops after healing of the epithelium (usually 3-4 days).

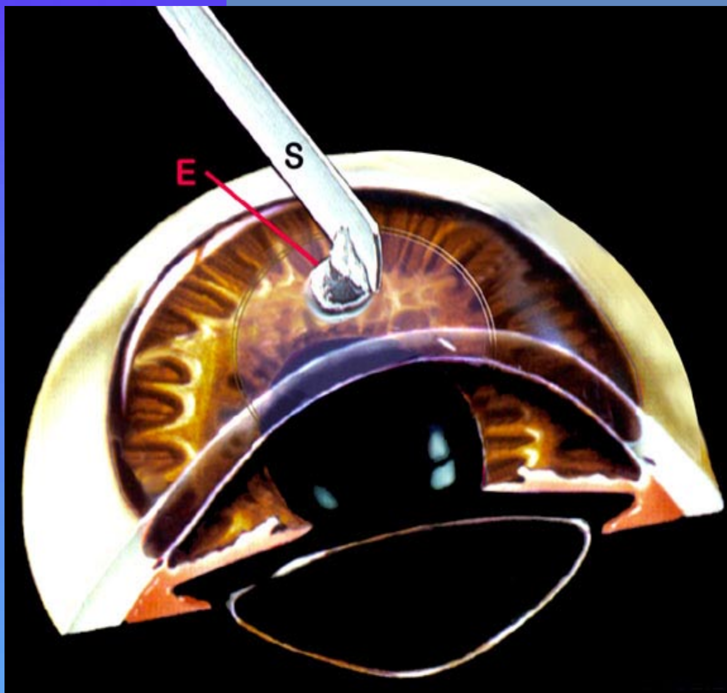

Figure 75: PRK - Mechanical Removal of Corneal Epithelium

After marking the center of the entrance pupil (Fig. 44), the corneal epithelium is debrided or removed usually mechanically as shown here. In cases of myopia, a treatment zone approximately 6 mm in diameter over the center of the pupil is identified. The corneal epitheliium is removed with a fine spatula (S) using circular movements from the periphery toward the center (E). This maneuver is accompanied by frequent irrigation with BSS, which helps in the mechanical removal of the epithelium. In this way we prevent dehydration of the central area of ablation.

Figure 76: PRK - Intraoperative View of Corneal Stromal Ablation with Excimer

After epithelial removal, it is important to maintain very good centration before applying the laser, either by using eye-tracking lasers or by fixation of the globe with forceps. This figure shows the excimer laser (L) being applied to the central optical zone after epithelial removal - identified by light pink.

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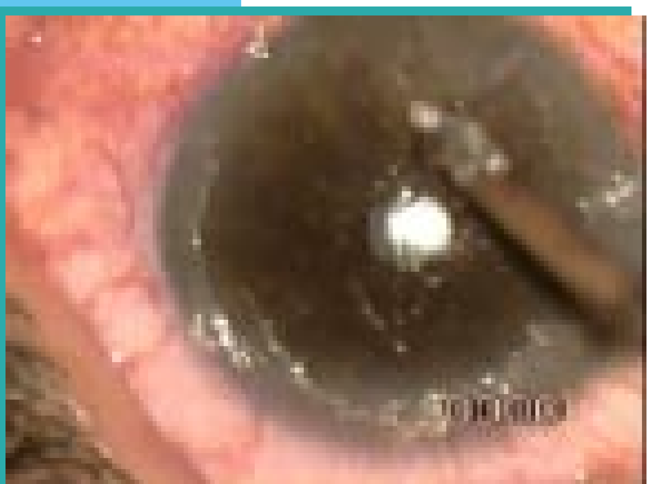
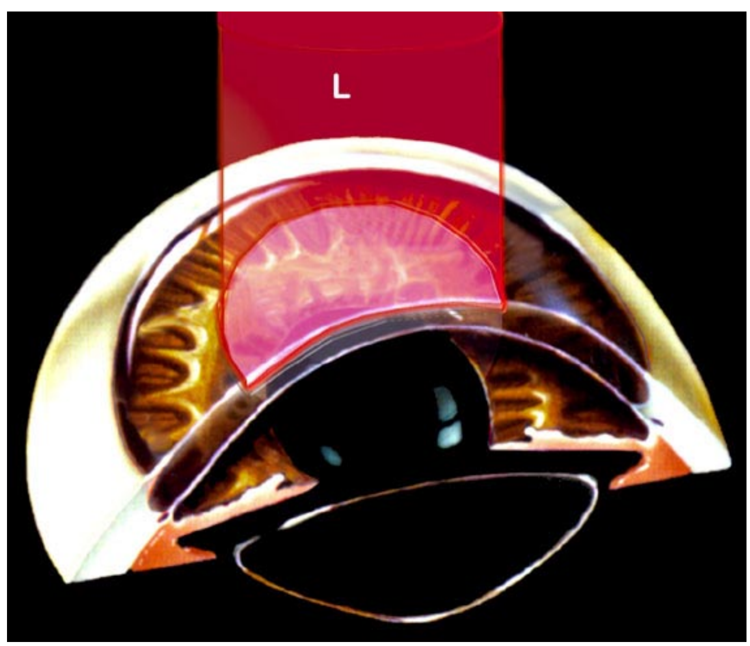




The antibiotics most used topically in PRK and other refractive surgical procedures are **Ciloxan** (ciprofloxacin HCL, 0.3% - Alcon) and **Ocuflox** (ofloxacin - Allergan). Either one may be used one drop every 10 minutes for three times during the **immediate** preoperative period and

postoperatively four times a day for 5 days, to protect the eye at least one day after removal of the bandage contact lens. **Antibiotics are continued topically until the corneal epithelium totally heals.**

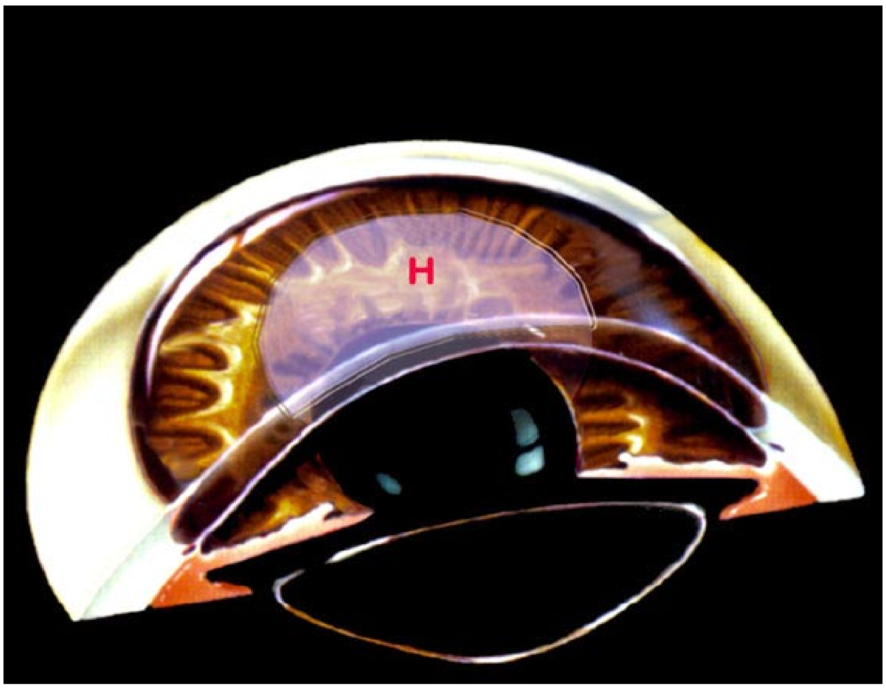
3) Steroids: their use postoperatively continues to be controversial. There is no proof that they prevent or shorten the duration of the **haze** that appears in a good number of patients following PRK **(Fig. 77).** Instead, the most effective measure is to keep the corneal tear film in good condition for at least six months to a year with **artificial tears without preservative.** This seems to be more important than steroid drops.

Postoperative Changes in Corneal Shape

Following PRK for myopia from -1.00 to -5.00 D the central corneal curvature of the laser treated area is flattened, thereby decreasing or correcting the preoperatively existing refractive error **(Figs. 78 and 79).**

Figure 77: PRK - Stromal Haze Formation

Some patients develop a diffuse subepithelial haze between 3-4 weeks following PRK. The amount of haze is not usually related to the degree of ametropia treated. It may even appear in eyes with low degrees of refractive errors. In this illustration a grade 3 haze (H) is presented, which may significantly affect the patient's visual acuity. In most cases, the haze greatly diminishes or even disappears after one year. This is a major disadvantage of PRK.



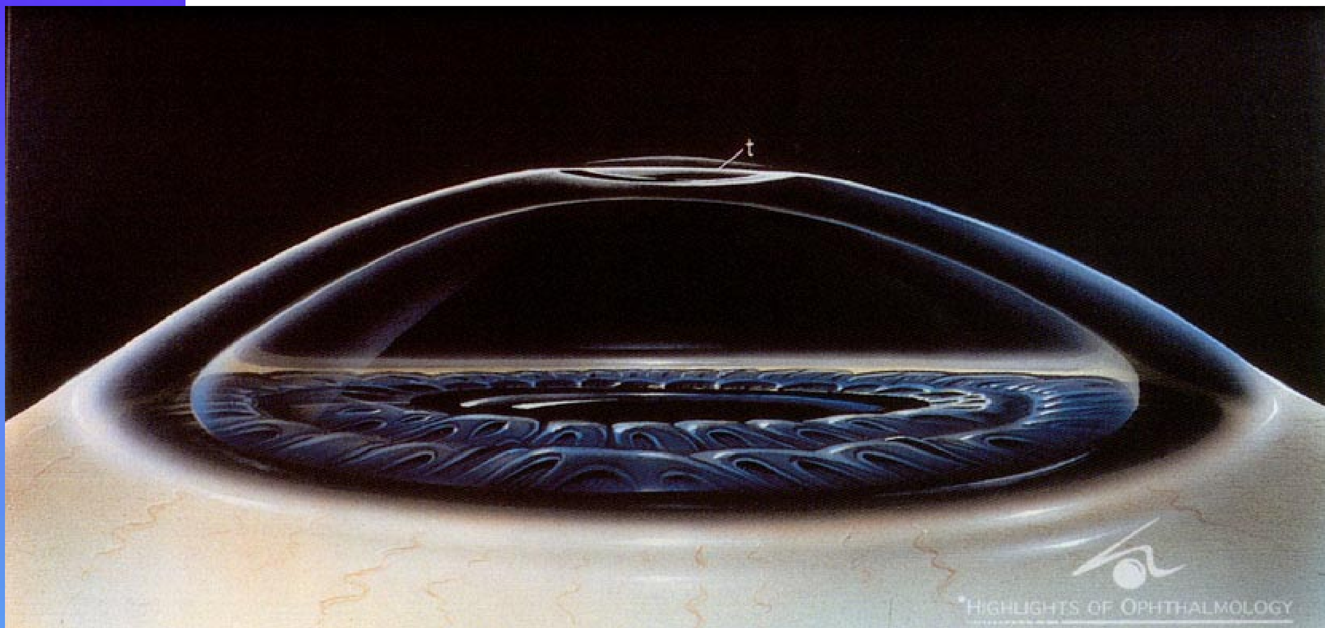


Figure 78: PRK Surgical Technique - External Postoperative Surgeon's View

In this postoperative view, the central corneal curvature of the laser treated area (t) is seen to be effectively flattened, thereby decreasing or correcting the myopia previously existing (see also Fig. 74). The steeper, pre-op corneal curvature is shown in a ghost view for comparison. (Note: the amount and shape of corneal tissue shown removed is exaggerated to highlight the concept of this procedure).

Figure 79: PRK Surgical Technique - Cross Section Postoperative View

For clarity, a half-section of the cornea has been removed to view the post-op cornea in cross section. The flatter post-op curvature of the anterior surface of the cornea can be seen (t). The steeper, pre-op corneal curvature is shown in ghost view for comparison. (Note: the amount and shape of corneal tissue shown removed is exaggerated to highlight the concept of this procedure).

Figure 80: PRK - Re-epithelialization of Treated Area

During the process of reshaping the cornea, the excimer laser destroys the basement corneal epithelium in the area of treatment. This is in addition to the mechanical removal of the corneal epithelium shown in Fig. 75 as the first step of the operation. Postoperatively, the corneal epithelium from the untreated surrounding cornea will naturally re-epithelialize (arrows) the treated area. This process lasts between 3-4 days and it is essential to obtain good postop results, including the prevention of infection.

Importance of Prompt Re-epithelialization of Treated Area

Prompt re-epithelialization is essential to rapid and safe recovery **(Fig. 80).** It usually takes 3-4 days for all of the epithelial surface to heal. During that time, the patient wears the soft bandage contact lens and is treated with topical NSAID's and topical antibiotics. Delayed re-epithelialization may lead to discomfort, pain, and risk of infection.

Training Required to Master PRK

A well-trained general ophthalmic surgeon can become proficient at PRK. The performance of the surgery itself can be learned well rather quickly. A surgeon who has mastered phacoemulsification will not have difficulty learning to do an excimer PRK. **The procedure does not require a microkeratome.** But ophthalmologists **need specialized training** before they can expertly handle the range of problems that may present during follow-up. Considerable training is required to handle the postoperative complications, which can include overcorrection, undercorrection, marked haze (Fig. 77), a decentered ablation, polyopia, and halos.

ICRS

INTRASTROMAL CORNEAL RING SEGMENTS

ICRS technology **is possibly the most important development in refractive surgery for low levels of myopia** (-1.00 to -3.00 D and astigmatism of 1.00 D or less) since the development of excimer laser techniques. This group comprises a majority of myopes.

Why the ICRS Is Such An Important Development

1. The **confirmed clinical results are outstanding,** so that the United States FDA has recently approved the procedure (Figs. 81-86).

2. The surgical procedure is **safe.** There is almost no risk of perforation.

3, The operation is **easily performed at relatively low cost** and provides **very rapid visual rehabilitation.** The ICRS provides at last a refractive surgical procedure that is not very technically demanding so that **the majority of anterior segment surgeons will be able to perform it safely and effectively in their patients.**

4. Because of its relative simplicity, and with a cost accessible to many more patients than the excimer laser procedures, the **ICRS will in time become the**

procedure of choice in patients who have from -1.00 to -2.75 D, maximum -3.00 D and very low astigmatism (-0.75 D, maximum -1.00 D). **This operation as structured at present does not correct astigmatism.**

5. The **ICRS** provides stable and predictable correction through several years post-operatively.

6. Visual results are excellent. The ICRS does not touch the central area of the cornea, so patients preserve their best spectacle-corrected visual acuity.

7. **The ICRS can be reversed or adjust-ed,** unlike excimer laser procedures. Enhance-ments can be performed easily by exchanging the ring segments (Fig. 82). The segments can also be removed,thereby **reversing** the refractive effect if so desired (Figs. 83-86).

Brief History of Development

Jose Barraquer pioneered the study of intracor-neal devices with keratophakia in 1949. In 1966 he reported relatively discouraging results with synthetic lenticular implants.

The innovative modern ICRS tech-nology is due to the combined work of A.E. Reynolds, O.D. patented in 1984, J.Z. Krezanoski, Ph.D. and John Petricciani. This led to the formation of the **KeraVision Corporation** (California) which has been responsible for the technical developments and significant funding of the long trial studies.

The pioneers who undertook the task of clinical trials for at least 10 years to finally prove its success and safety are **Walton Nose, M.D.**, and Professor **Rubens Belfort., M.D.**, at the Federal University School of Medicine in Sao Paulo, Brazil, and **David J. Schanzlin, M.D.,** in the United States. The three of them worked together although independently in admirable coordination to develop the techniques in humans.

Following extensive and careful animal trials, **Walton Nose, M.D.,** and **Rubens Belfort, M.D.** operated on the first blind cases and then on 10 myopic patients in 1991. Afterwards, they proceeded to use different types of rings to treat various degrees of myopia. Protocols under specific constraints both in Sao Paulo with **Belfort** and **Nose** and in the U.S. under **Schanzlin's** supervision were strictly followed finally leading to FDA approval in the U.S. **Belfort** is enthusiastic about the results already obtained as well as the potential for the intracorneal ring as a technique to correct hyperopia and presbyopia as well as low degrees of myopia. **Arturo Chayet, M.D.,** in Mexico has experience using rings in cases of presbyopia and hyperopia. His results seem to be promising but need further, long term evaluation.

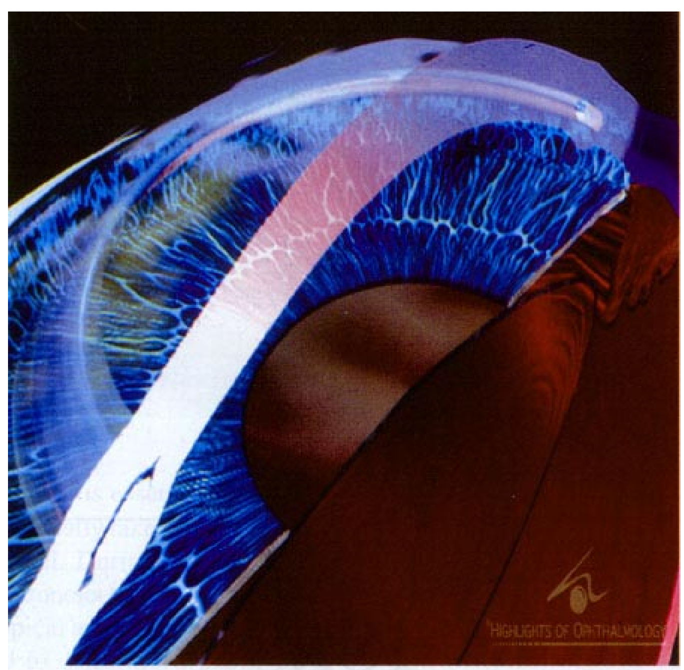


Figure 81: Intrastromal Corneal Ring Segments (ICRS)

Artistic concept of the ICRS. Introduction of ring segments into the mid-peripheral corneal stroma is an easy and safe way to alter the central corneal curvature without touching the central cornea itself.

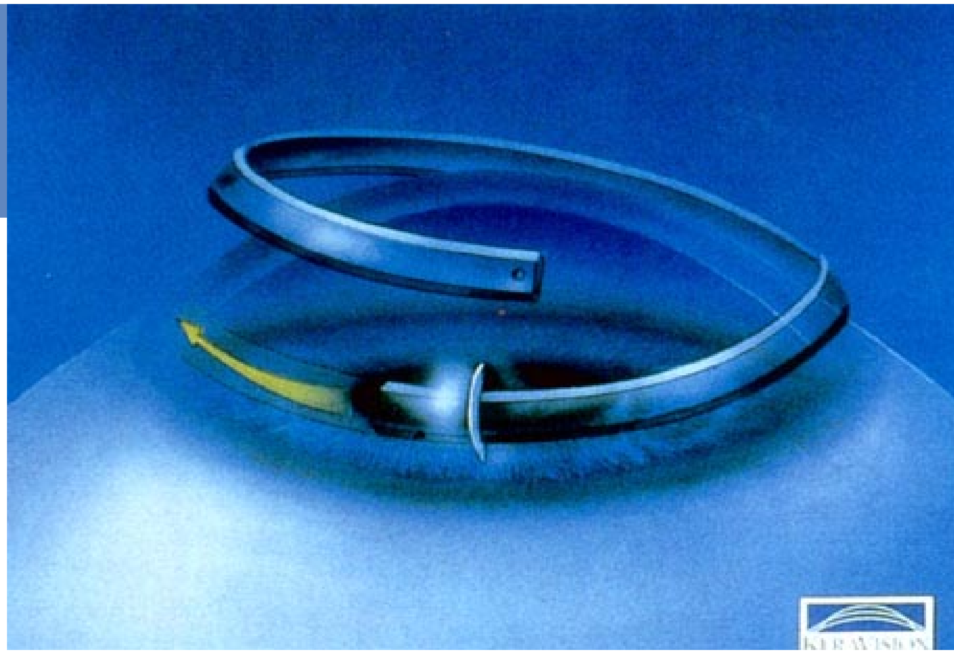


Figure 82: Intracorneal Ring Being Introduced into the Corneal Stromal Channel

(Photo courtesy of KeraVision, with permission from Machat: "The Art of LASIK", published by Slack).

How Does ICRS Work in Low Myopia?

The rings consist of two polymethylmethacrylate ring segments made by KeraVision Corporation in California (Figs. 82, 83, 84, 85, 86). The ICRS technique adds bulk to the **mid-peripheral stroma**. The intracorneal ring segments actually force the lamellar fibers to vault over and under the ring (Figs. 82, 83). This shortens and flattens the cornea centrally and peripherally (Figs. 84, 85, 86), with reduction of the myopia. The ring implant flattens the cornea differently than incisional or laser ablative procedures. The rings flatten the peripheral cornea more than the central cornea (Figs. 84, 85).

In contrast, incisional and ablative procedures convert the normally prolate cornea into a more centrally flattened shape postoperatively. The way ICRS flattens the central cornea without touching it also minimizes the aberrations seen with other procedures.

How Does ICRS Affect Corneal Physiology?

According to **Terry Burris, M.D.,** studies reveal that a narrow device such as a ring implant, even if water impermeable, can be successfully supported within the stroma, particularly if placed somewhat deeply. Lateral diffusion of nutrients around the device allows access to the superficial corneal layers, which normally receive their nutrition from the aqueous and limbal blood supply. The ICRS does not significantly disturb the distribution of glucose in the cornea.

Previous clinical studies with other intrastromal devices showed that biocompatible materials could be well tolerated without stimulating corneal inflammation.

SURGICAL TECHNIQUE FOR ICRS

The ring segments are marketed under the name "Intacs" by KeraVision Inc. of Fremont, California, the manufacturer (Figs. 83, 84, 85, 86).

Preoperative Evaluation and Preparation

The preoperative evaluation, preparation of the patient for surgery and postoperative management are basically the same as for other refractive surgery techniques as outlined in Chapter 3.

It is an outpatient procedure that takes a short time to perform. Tetracaine may be used as the topical anesthetic, one drop each within a 10 minute period ranging from the preparation of the eye for surgery and actually starting the procedure.

The preparation and drape are important because all the lashes must be covered and isolated so that the ring segment will not be in contact with any of the lashes which otherwise bring bacteria into the intrastromal channel (Fig. 82).

The light wire lid speculum is the most widely used. In the U.S. most surgeons use Betadine (povidone iodine - Purdue Frederick) paint on the eyelids, and may place 2% povidone iodine solution into the cul-de-sac for 1 to 2 minutes and wash it out prior to the procedure to make sure there is no implantation of bacteria. In other parts of the world, preferential use of preventive antiseptic preparation vary but this may be used as a guideline to

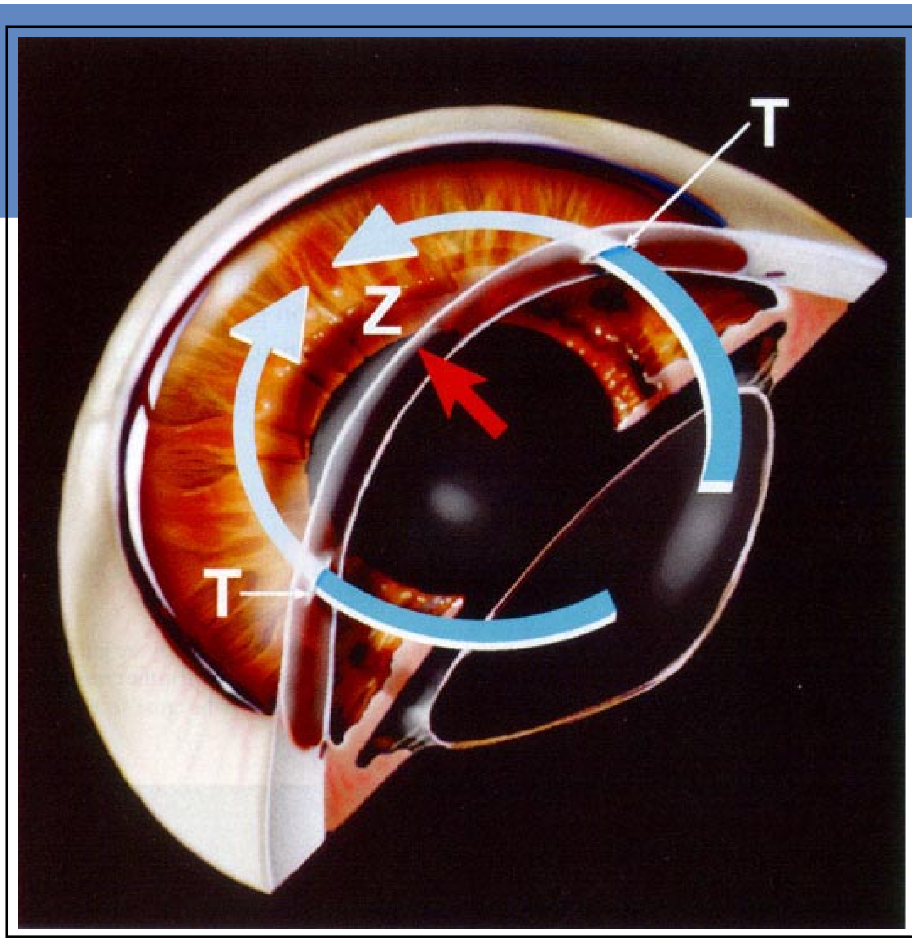


Figure 83: Technique for Implantation of the Intrastromal Corneal Ring - Pre-op

This cross section of the anterior chamber shows the location of the tracts (T) which are made in the corneal stroma. A tract is made in the stroma at a predetermined fixed depth in a circular fashion (blue arrows) around the optical zone (Z). This is accomplished with a special instrument. Note the curvature of the central cornea (red arrow) for comparison to the next figure.

emphasize that more strict measures to prevent infection must be taken than in LASIK.

The Implantation Procedure

Four Fundamental Steps

1) The Incision

The implantation procedure involves making an incision, a channel and then implanting the ring (Figs. 82-84). The corneal geometric center is marked (KeraVision marker) and the peripheral corneal thickness is measured by ultrasonic pachymetry over the planned incision site, most of the times at the 12:00 meridian.

The **incision location** should be measured at 8 mm from the **geometric center** of the cornea instead of from the center of the pupil. The implant needs to be equally spaced from the limbus. The incision marker makes a 1.8 mm mark. A diamond knife is set to 68% of the peripheral corneal thickness and is used to create a 1.8 mm incision allowing introduction of the lamellar dissecting instruments (KeraVision, Inc., Fremont, California).

2) Creating the Channel

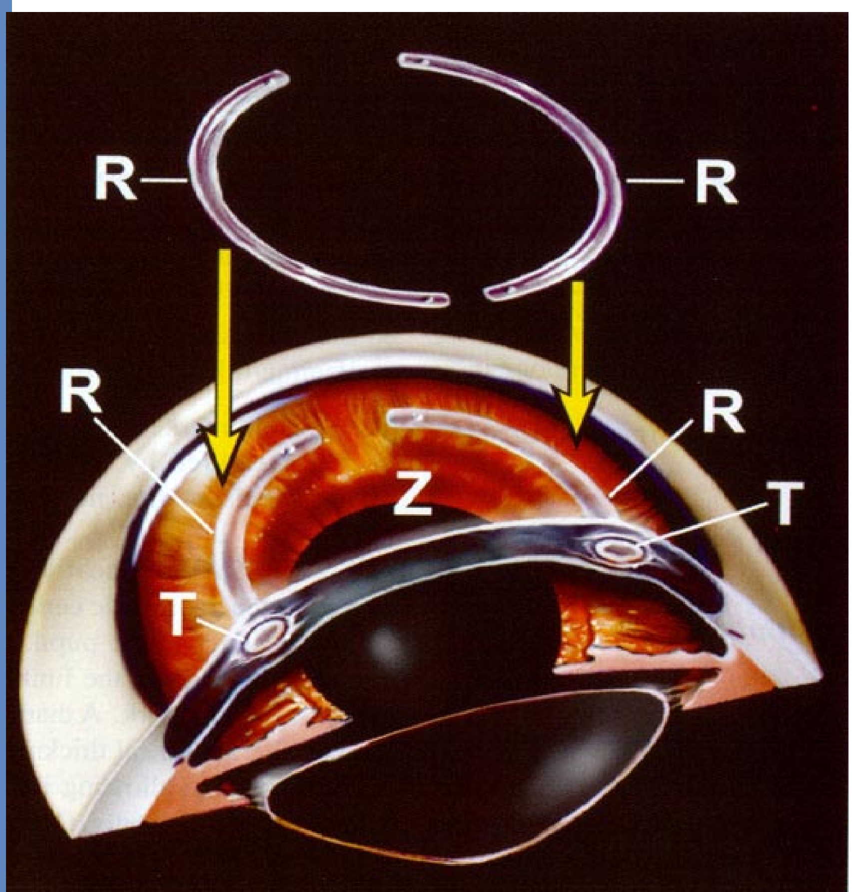
A corneal lamellar spreader is used to initiate the lamellar dissection in both a clockwise and a counter-clockwise direction (Figs. 83, 84, 85). A **Suarez** corneal lamellar stromal spreader is one of the most useful instruments for dissecting a "pocket" during this stage of the procedure.

As described by **Terry Burris, M.D.,** a vacuum centering guide (suction guide) is applied to the globe, and the clockwise or counterclockwise stromal dissector is introduced through the incision and rotated 180 to 190 degrees to create a mid-peripheral half-circular channel. The dissector is rotated out of the channel, and its mirror image-shaped dissector is used to fashion the other half channel (Fig. 84). The vacuum centering guide is removed.

In essence, following the incision, the implantation procedure entails creating the channels in the stroma in a clockwise and counterclockwise direction. The suction ring also helps in maintaining a good grip on the eye.

Figure 84: Technique for Implantation of the Intrastromal Corneal Ring

The intrastromal ring consists of two semi-circular implants (R). They are guided into the tracts (T) on each side of the optical zone (Z). Their final position is shown in the cross section view below. Note how the rings alter the shape of the cornea as seen in the cross section.



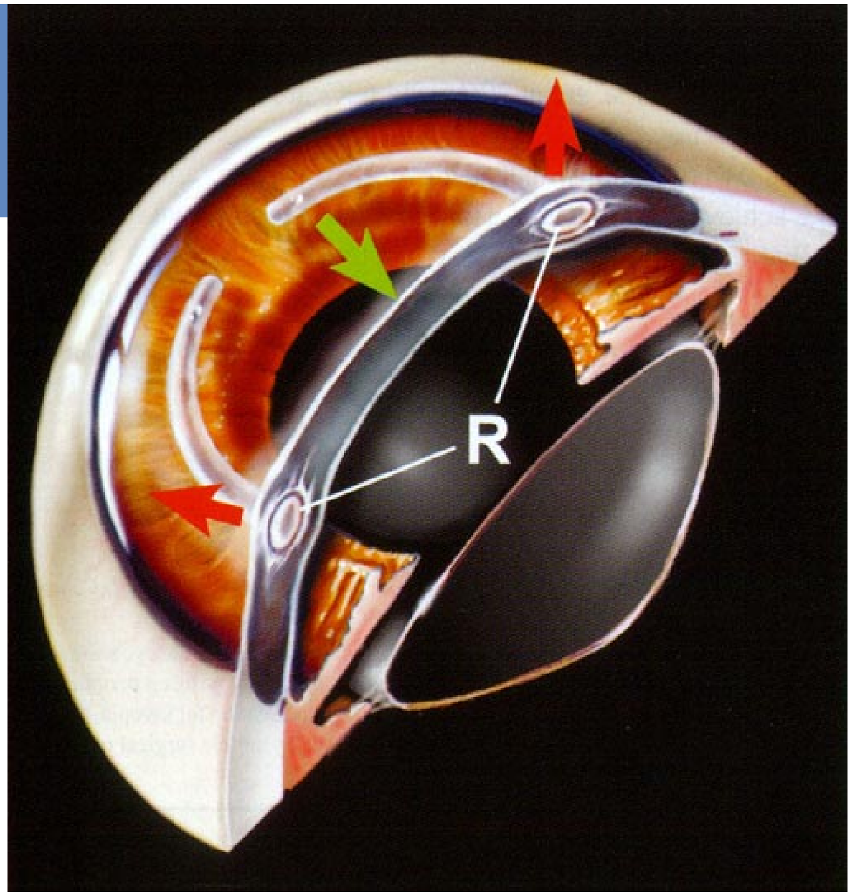


Figure 85: The Intrastromal Corneal Ring - How It Works - Post-op View

Once the semi-circular implants (R) are in place within the corneal stroma, their effect is to cause the central cornea to flatten slightly (green arrow) by changing the shape peripherally (red arrows). Compare the central corneal curvature shown here with the pre-op figure (Fig. 83) and note the reduced central curvature. Optically, the focal point of light entering the eye is moved posteriorly, onto the retina, correcting the pre-op myopia.

3) Implanting the Ring

After suction is released, one of the two ICRS is inserted and rotated into either the clockwise or counter-clockwise channel and pushed into place with a Sinskey hook. Its mate is similarly rotated into its respective portion of the channel. As described by **Daniel Durrie, M.D.,** there is a clockwise and a counter-clockwise ICRS ring (Fig. 82). Each ring is designated as such in the packaging so that you know in which direction to go. Those are placed in the channel with a twisting or dialing motion.

4) Final Step - Suturing

A single 10-0 or 11-0 nylon suture is placed to ensure closure of the incision edges. If the wound is left open even slightly during the first 1 to 2 weeks postop, tears can enter the channel and could cause variability in wound healing or some variation in vision throughout the day. Of course, suturing has the drawback that you may induce astigmatism if tied tightly. Keep this in mind. Sutures should be removed approximately 1 month after surgery.

Visual Results

reports that according to data from the FDA, 97% of the patients achieve 20/40 or better visual acuity. At 1 year, 74% of the patients achieve 20/20 vision and 53% see 20/16 or better. About 30% see 20/12.5 or better at 1 year.

Much like LASIK, 35% of patients are 20/20 or better on postoperative day 1, 13% are 20/16 or better and stay there through the remainder of the time, and 57% achieve 20/25 or better 1 day postoperatively. By 1 month, 41% are at 20/16 and 62% are at 20/20, **Dr. Schanzlin** said.

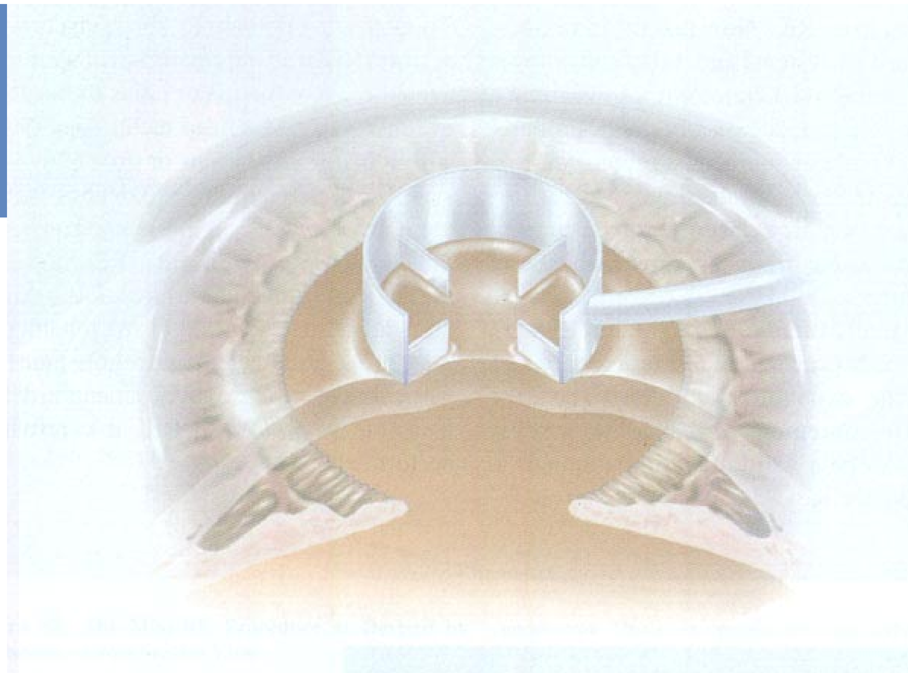
By 6 months, half achieve 20/16 vision, and 70% achieve 20/20 vision. This continues to improve so that at 12 months, 53% had 20/16 and 74% had 20/40.

Visual recovery is just as quick, if not more rapid, than a LASIK procedure. Predictability is good, with 68% of patients falling within 0.5 D of plano.

Best corrected visual acuity loss is really not a significant issue with the ICRS because the center of the cornea is not touched. Few cases had some irregular astigmatism induced by having a ring that was dislocated inferiorly. Therefore, centration of placement is key.

Figure 86: Intrastromal Corneal Ring - Final Configuration

This frontal view of the eye shows the intrastromal corneal ring elements (R) in their final position peripheral to the optical zone (Z). As compared to laser correction for myopia, this procedure has the advantage of being reversible by simple surgical removal of the ring elements.



RK
Radial Keratotomy

The Present Role of Radial Keratotomy (RK)

George Waring considers that radial keratotomy (RK) for myopia is still an acceptable procedure in the early 2000's. This operation has been around in its modern sense for over 50 years. It has even more utility with the recent advances in technique: staged surgery allows for enhancements to fine-tune the operation for the individual patient; safer knives create more uniform incisions; and the mini-RK as devised by **Lindstrom** relies on shorter incisions in an attempt to preserve the strength of the globe and decrease the long term hyperopic shift. **With these three advances, modern radial keratotomy is still a desirable option for both surgeon and patient (Fig. 87).**

Waring believes that refractive keratotomy is still alive and well. It is particularly important in areas where an excimer laser is not available, which is most cities in the world. Most ophthalmologists and groups of ophthalmologists cannot afford a $500,000 laser and cannot sustain the cost that running such a laser requires. But they can afford to do RK. Now that the procedure has been formalized in systems and taught in courses around the world, refractive keratotomy can become a part of the ophthalmic practice of any good, properly trained and prudent anterior segment surgeon.

Aron Rosa in Paris, France agrees with this position. Although she is **a laser expert**, she still performs RK with some frequency, particularly as enhancing procedures.

Professor Juan Murube, M.D., (Madrid, Spain), one of Europe's most prestigious refractive surgeons who also has wide experience with the needs of populations in different regions of the world, believes that RK continues to be a valid operation although in slow and continued decline.

He has observed that in countries "less economically developed", ophthalmic surgeons in rural areas still perform RK as an important part of their surgical practice, even though in the major cities of those same countries excimer laser advanced technology is available either within major institutions or private eye centers.

RK may continue to decline with the advent of the ICRS discussed in this chapter, which has the same indications (low myopia) than RK but is safe, predictable, not demanding of high surgical skill, confirmed excellent clinical results and rapid visual rehabilitation.

We still need to know how much its cost will be particularly for the groups of patients in different countries that still do well with RK, if carefully planned and performed.

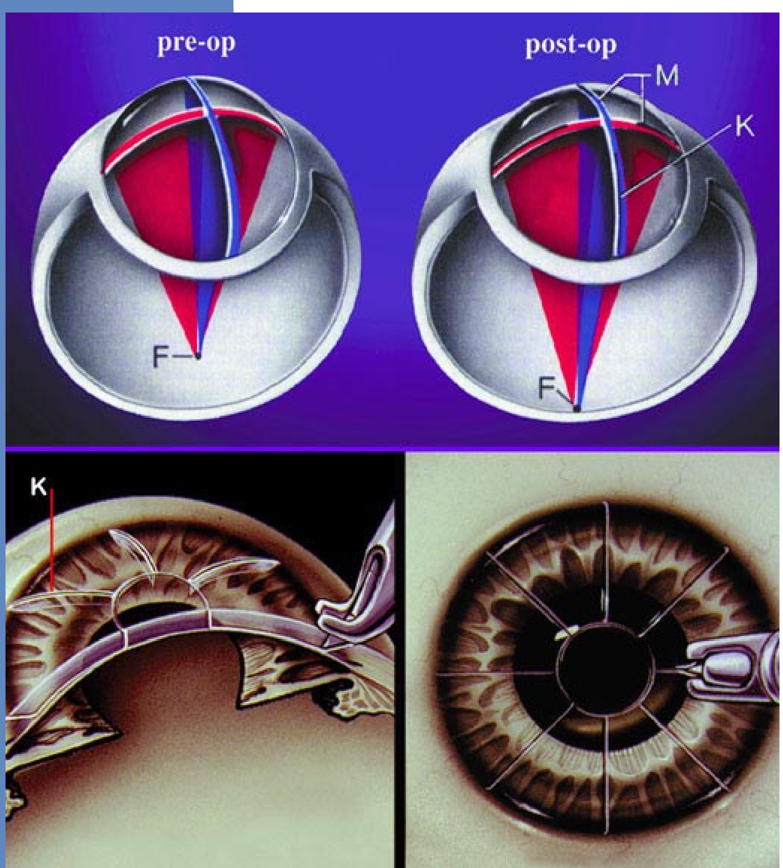


Figure 87: Radial Keratotomy - How Low Myopia is Corrected Through Relaxation of Corneal Fibers.

The figure at top left shows a conceptual view of the refractive error in myopia pre-op. Light rays passing through both the horizontal (red) and vertical (blue) meridians have focal points (F) within the vitreous cavity anterior to the retina. After placement of the radial keratotomy incisions (K-top right) the light rays passing through both meridians (red and blue areas) are now focused (F) on the retina due to the flattened central corneal curvature. Notice the corneal curvature is flatter post-op as compared with the pre-op view (i.e.-compare blue and red arcs of the vertical and horizontal meridians (M) of both corneas). The views below show a cross-section of RK incisions (K-left) and a surgeon's view (K-right).

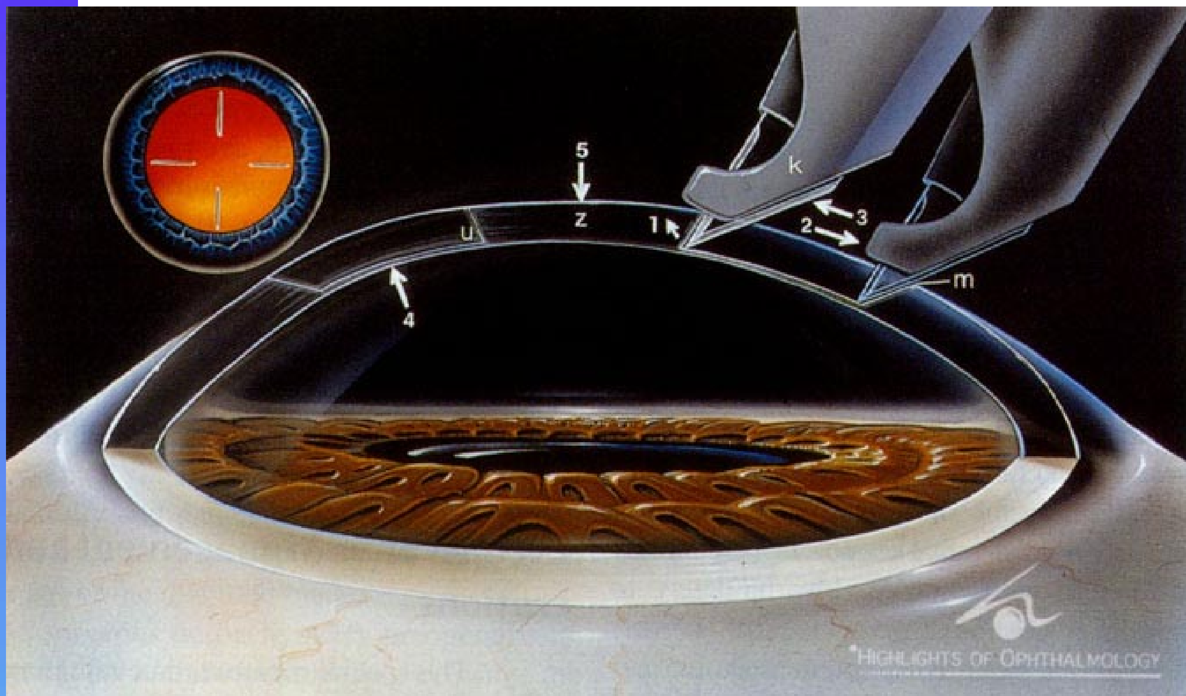


Figure 88: The Mini-RK Procedure as Devised by Lindstrom - Cross Section View

A section of cornea is shown removed to reveal the cornea in cross section. The 2.0 mm to 2.5 mm length Mini-RK incisions extend within the "zone of maximum benefit" between the central clear zone (z) and the 8 mm diameter mark (m). The incisions are begun at the margin of the central clear zone mark where they are undercut slightly (arrow - 1). The first pass is made peripherally (arrow - 2), shown here under arrow 3 but in the opposite direction, and the second pass is made centrally (arrow - 3) with the RK knife (k). The left side of the cornea shows a completed Mini-RK incision. Note the undercut central extension of this incision (u). The effect of the incisions is to cause the cornea to "bulge" where it was incised (arrow - 4), resulting in a counteractive flattening of the central cornea (arrow - over Z). This flattening of the central cornea results in a minus corrective effect of the refraction. Inset shows the configuration of a four incision procedure.

Because of these major considerations, RK is properly included in this Atlas. Hereby we present the highlights of RK, particularly its indications, how to do it, what to avoid in the technique to prevent complications and how to take care of them when they occur.

RK Techniques

There are two techniques for radial keratotomy and their main objective is to treat low to moderate myopias. They are: 1) The **Mini-RK (Mini-Radial Keratotomy) (Fig. 88)** which is essentially indicated in myopias of lesser degrees between -1.00 and -3.00 diopters, with alternatives of performing 4, 6 and even 8 cuts depending on the patient. **2) Conventional radial keratotomy.** The latter can also be used either with 4 or 8 cuts, depending on the amount of correction aimed at. The main difference between these two techniques is that in Mini-RK the surgeon utilizes small incisions of 2.0 and 3.0 mm (Fig. 88) instead of the larger incisions utilized for conventional radial keratotomy which vary between 4.5 and 5.0 mm length (Fig. 87).

The development of Mini-RK by **Lindstrom** stimulated great interest because of some problems observed with conventional radial keratotomy, essentially a refractive change with a very slow tendency to hypermetropia in a substantial percentage of patients during ten years after performing the surgery.

Indications for RK and Mini-RK

For patients above -2.50 and -3.00 diopters, the tendency now is to replace radial keratotomy for refractive surgical techniques with excimer laser , preferably LASIK and then PRK as second choice if up to -5.00 D.

This is only if the excimer laser is available and if the patient is in favorable financial conditions and can afford the expenses involved with excimer laser surgery. Radial keratotomy in patients between -3.00 and -5.00 is still being performed when indicated in the hands of a skilled surgeon but only if there is no other choice.

Lindstrom still uses RK but essentially Mini-RK even though his extensive surgical practice is done in an advanced eye center in Minneapolis and his procedure of choice in **most** cases is now LASIK. He may use Mini-RK or RK in low myopia of -1.00 to -3.00 D and never uses more than 4 (four) cuts. He finds that **RK and Mini-RK are more easily adjusted for enhancements and fine-tuning than photorefractive keratectomy (PRK).**

The **Mini-RK** is also very useful as an **enhancement** procedure (2 to 4 small incisions) when there is small residual myopia following a previous RK, Mini-RK, excimer laser operation and in cataract surgery. The surgical technique is not particularly demanding.

Preoperative Management and Considerations

The special measures in evaluating and assessing the refractive surgery patient, the pachymeter determination of corneal thickness (Fig. 28), corneal topography and other considerations have been amply discussed in Chapter 3. Topical anesthesia, adequate lid speculum, operating room cleaning and sterile precautions, fixation and marking the visual axis (Fig. 44) are discussed in Chapter 4. The antibiotics and anti-inflammatory drugs to be used topically pre and postoperatively are presented in this Chapter 5, pages 106-108, for all major refractive operations.

Why So Important to Properly Mark Pupillary Center

If you do not mark the pupillary center properly, then you will center the optical clear zone of the patient's eye around an incorrect visual axis mark and you may accidentally place radial incisions through the real visual axis, causing decreased vision and glare (Fig. 44).

Presetting the Corneal Thickness with the Pachymeter

Pachymetry (ultrasonic instrument shown in Fig. 28) is essential for a very solid reading of corneal thickness centrally and paracentrally because this will serve in guiding the surgeon's judgment as to how deep to set the length of the diamond blade.

Some surgeons do pachymetry preoperatively, others prefer to do it intraoperatively. In using the pachymeter, one must take at least two identical readings **in each of the four paracentral areas** in order for the reading to be "final" (Fig. 93). If one is holding the ultrasonic pachymeter at 12 o'clock and the measurements are .51, .52, .53, .52, then you would record the official thickness at that point as 0.52 because, from those readings, this was the first reading to appear twice. Often you will get two that are identical immediately, but on occasion you must take five or six readings to get two that are the same.

MAKING THE RIGHT DECISIONS

The Great Value of Nomograms

Nomograms are important guides as to what to do in a specific patient. They are based on a surgeon's extensive experience, his/her results and the factors of importance that he attributes as really valid to obtain the best reliable results.

Essential Factors in Determining Results

Murube considers there are three (3) proven factors that play a role in determining results. **Two (2)** of them are essential: **age** and **amount of myopic correction aimed at.** The third one is important but not essential: the keratometric curvature of the cornea. **Murube** has learned that many other factors previously recommended during the initial RK studies are of minimal significance and controversial.

Those factors that can be done without are: sex, corneal asphericity, corneal diameter, intraocular pressure variations within normal range and scleral and corneal rigidity.

Key Parameters

From the three factors that **Murube** considers important, four (4) parameters are essential, of which two (2) are fixed:

Fixed Parameters

1) **4 or 8 incisions** (based on the nomogram).
2) **Depth of cut** 90 - 95% of corneal thickness.

Variable Parameters

1) **Clear central optical zone** from 3.0 to 4.75 mm.
2) Peripheral deepening of cuts (really applicable to corrections higher than -4.5 diopters of myopia). We do not recommend RK for these higher degrees of myopia unless there is no other better choice available.
myopia unless there is no other better choice available.

Murube's Nomogram

I hereby present Professor **Juan Murube's** nomograms for RK (4 and 8 incisions) and the factors he considers essential to consider. These are based on his experience of 6,000 cases of RK through 10 years before excimer technology came into the forefront.

The following nomogram for RK has significant predictability and may serve as a basis for any well trained ophthalmic surgeon to perform an RK and do it well, with satisfactory results.

As with any nomogram, each surgeon should slowly integrate into it some variations depending on his/her own results. These may differ slightly according to the instruments used (shape and material of blade - Fig. 94), the position of the knife-blade either vertical or perpendicular to the cornea (Figs. 97-98) and the surgeon's own habits such as more or somewhat less pressure on the knife and/or the globe with fixation.

MURUBE'S NOMOGRAM FOR RK

Diopters to be Corrected	Diameter of Clear Central Optical Zone	Number of Incisions	Depth of Incision	Peripheral Deepening
-1.0	4.25 mm	4	90-95% of central pachymetry	None
-1.5	4.00 mm	4	90-95% of central pachymetry	None
-2.0	3.75 mm	4	90-95% of central pachymetry	None
-2.5	3.50 mm	4	90-95% of central pachymetry	None
-3.0	3.75 mm	8	90-95% of central pachymetry	None
-3.5	3.50 mm	8	90-95% of central pachymetry	None
-4.0	3.25 mm	8	90-95% of central pachymetry	None
-4.5	3.00 mm	8	90-95% of central pachymetry	None
-5.0	3.00 mm	8	90-95% of central pachymetry	Starting at 4.5 mm from central optical zone
-5.5	3.00 mm	8	90-95% of central pachymetry	Starting at 4.0 mm from central op-

Important Clues to Understand Murube's Nomogram

1) Number of Incisions: listed as either four (4) or eight (8) depending on the amount of myopic correction we are aiming at.

2) Depth of Incisions: always based on the central corneal depth as measured with the ultrasonic pachymeter. Since the cornea becomes thicker from the center toward the periphery, if we set the blade length based on the pachymeter readings, the central cornea is incised to 95% of the corneal thickness at 1.5 mm from the center and to 90% depth at 2.5 mm from the center.

3) Calculating the Correct Optical Clear Zone: the diameter of the central, clear optical zone basically depends on the amount of diopters of myopia to be corrected. To this, we must consider two additional factors that require a slight adjustment to the basic nomogram. These factors are:

a) Age: the nomogram here presented refers to patients from 20 to 29 years of age. The older the patient becomes, the same incisions increase their corrective effects. Consequently, we should compensate by enlarging the clear central optical zone by 0.25 mm for each additional decade of the patient's age. For instance, if the nomogram indicates that the clear central optical zone is 3.50 mm, but the patient is from 30 to 39 years of age, the clear zone is enlarged to 3.75 mm.

b) Keratometry: **Murube's** nomogram has been done for corneas with keratometer readings ranging between 42 to 46 diopters. If the patient's cornea is steeper, it becomes more easily flattened. Therefore, in corneas with keratometry higher than 46 D, **enlarge** the diameter of the clear central zone by 0.25 mm. To the contrary, if keratometry shows a curve flatter than 42 D, reduce the diameter of the clear zone by 0.25 mm.

c) Peripheral Deepening of Incisions: if we are attempting to correct higher degrees of myopia such as -5.00 to 6.00, which we do not recommend, it is fundamental to further deepen each one of the 8 incisions performed initially in order to obtain a larger correction. These further deepenings are started at a second optical zone, **always inside the intial cuts**, but located as follows:

-5.00 D - Start from 4.5 mm optical zone.
-5.50 D - Start from 4.0 mm optical zone.
-6.00 D - Start from 3.5 mm optical zone.

These paracentral and peripheral deepenings are accomplished by readjusting the blade length 20 microns from the previously gauged length.

SURGICAL TECHNIQUE

Marking the Central Optical Clear Zone

The Murube Marker

One of the most useful and reliable instruments to mark the clear optical zone is the **Murube Marker (Figs. 89, 90, 91, 92).** The surgeon centers the cross-bars of the marker around the previous mark used to identify the pupillary center itself (Fig. 44).

Epithelial Imprint of Optical Clear Zone

When the **Murube Marker** is centered with the cross-bars aligned with the pupillary center, a very firm circular impression is made in the epithelium. **Murube** usually presses the globe back a millimeter or two and makes an epithelial imprint that will last for the duration of the case (Figs. 89-92). Beginners often make such a shallow epithelial mark that they lose sight of the optical clear zone by the end of the operation.

During this entire period the assistant has been putting topical anesthetic drops on the cornea approximately every 10 seconds.

Specific Advantages of the Murube Marker for RK

This instrument has "perforated" or segmented cross bars (Figs. 89 and 90). It provides two key advantages over other markers of which there is a large variety. 1) It allows seeing the already marked center of the clear zone. This facilitates exact positioning of the marker that in turn leads to correct centration of the clear optical zone (Figs. 89, 90).

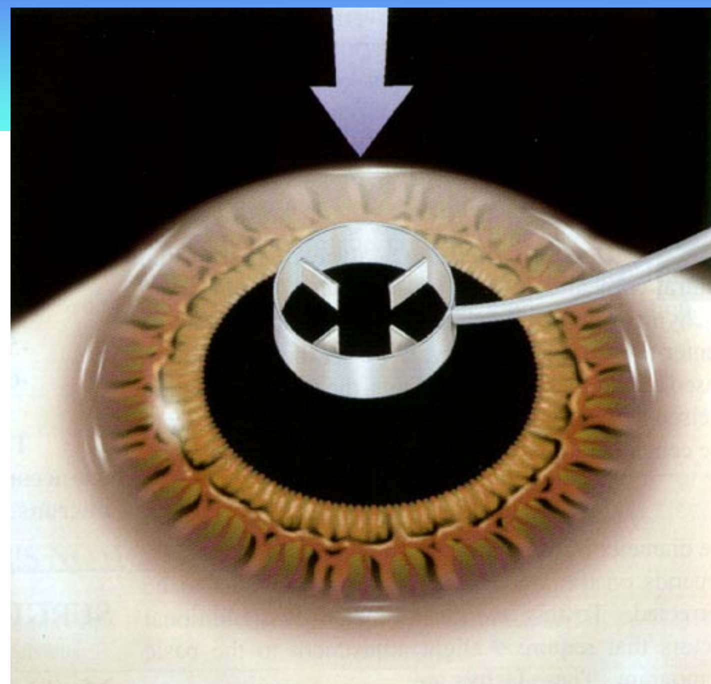


Figure 89: The Murube RK Marker - Surgeon's View

The surgeon centers the segmented cross-bars around the mark previously made to identify the pupillary center. The marker is designed to allow seeing the already marked center of the cornea. (Photo courtesy of Prof. Juan Murube, M.D.)

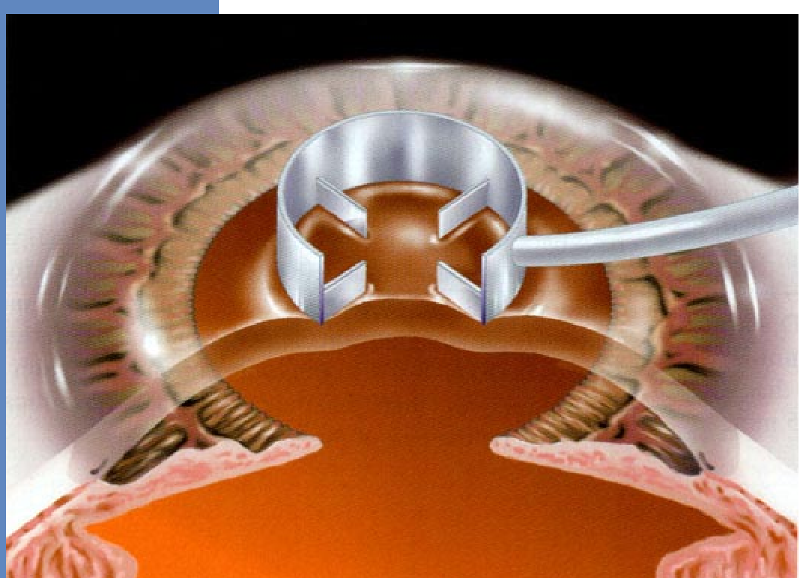


Figure 90: The Murube RK Marker - Cross Section View

The instrument is shown here over a cross section of the cornea. The cross-bars are aligned with the pupillary center. (Photo courtesy of Prof. Juan Murube, M.D.)

2) the second and most important advantage is that it marks over the clear optical zone the four (4) basic radii at 90º from each other (Fig. 91). The surgeon has a clear visual reference of the exact sites where he/she is to **initiate** the radial incisions. The surgeon begins the incision at the border of the marks made with the marker and has a clear guide as to how and in which exact direction the knife is to be displaced peripherally for making and completing the incision.

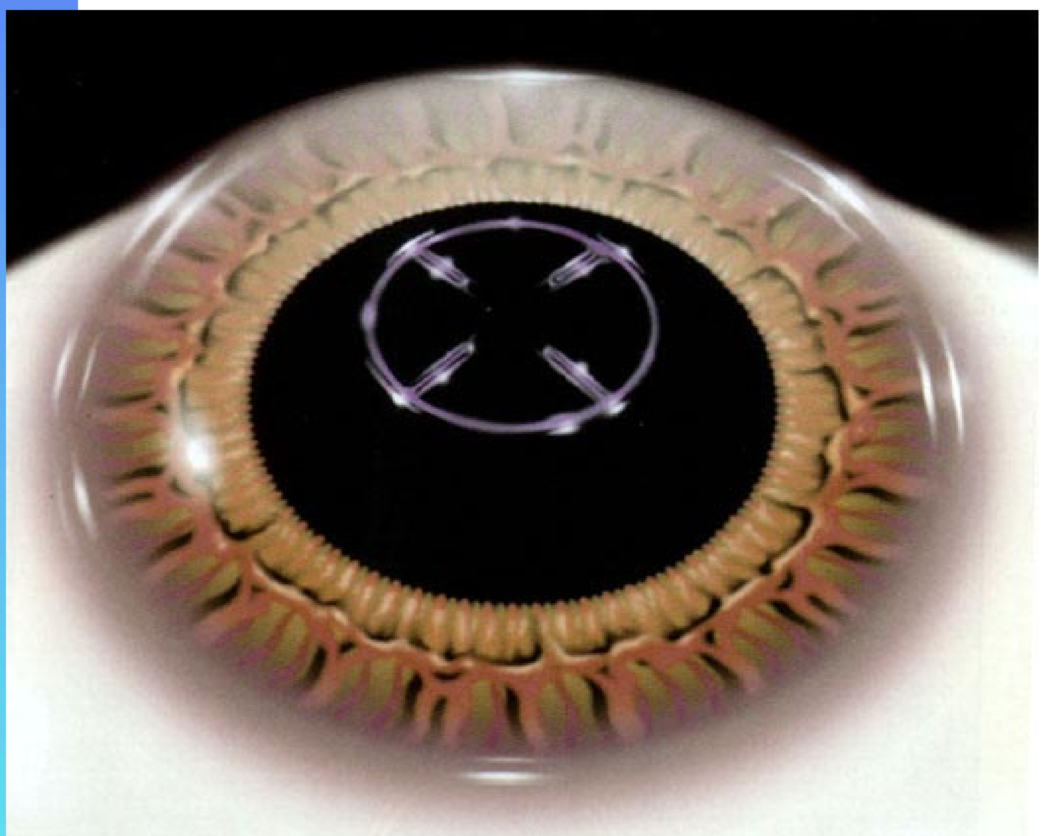


Figure 91: Epithelial Imprint with Murube RK Marker

After aligning the marker with the pupillary center, a very firm circular impression has been made in the epithelium. The four basic radii at 90º from each other are very clearly marked. This provides the surgeon with a clear guide on which to displace the knife in the exact direction peripherally. (Photo courtesy of Prof. Juan Murube, M.D.)

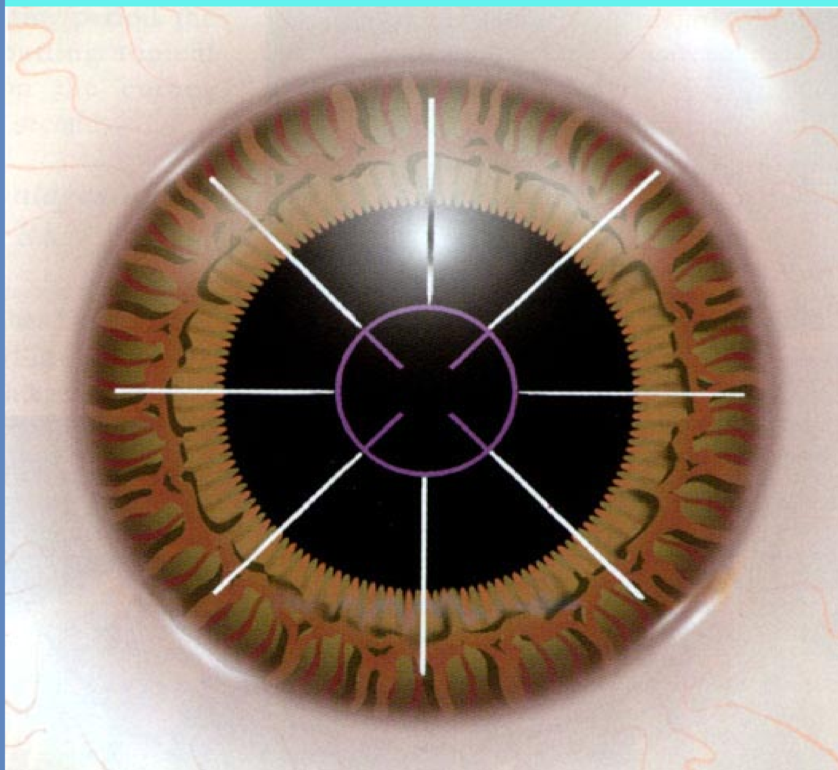


Figure 92: Eight Incisions RK Following the Guide of the Murube Marker

The additional 4 incisions are placed exactly between the original 4 (four) shown in Fig. 91. Since the latter are marked exactly at 90º from each other, it is easy to identify the correct placing of the additional four incisions. (Photo courtesy of Prof. Juan Murube, M.D.)

This is the only marker that provides this special feature of significant value to the surgeon. Most others only make a peripheral circular mark (Fig. 93) which is of little use because as the surgeon proceeds to slide the knife, his/her hands and the knife itself interfere with exact viewing of the respective peripheral mark, so he does not know if he is in the right path (Figs. 97-98). In order to detect whether he is making the cut in the **exact** radius, he needs to get oriented by looking at the opposite radius.

Although the Murube RIC Marker has only four (4) radii, it serves just as well to make eight (8) exactly placed incisions because the other four (4) incisions are placed between the original four (Fig. 92). Since the latter are marked exactly at 90º from each other (Fig. 91), no error is made in identifying the correct placing of the additional four incisions (Fig. 92).

Other Marking Techniques

Other useful marker for RK is the Mendez marker. Some surgeons in the past utilized a corneal trephine to mark the optical clear zone (Fig. 93) but this required placing the trephine exactly perpendicular to the cornea to the extent that the surgeon would see through it without the inner walls of the trephine being visible. This is a must to be sure the trephine is exactly centered. In addition, the trephine mark left only a circular imprint (Fig. 93) with no orientation as to where to place the radii exactly 90º from each other.

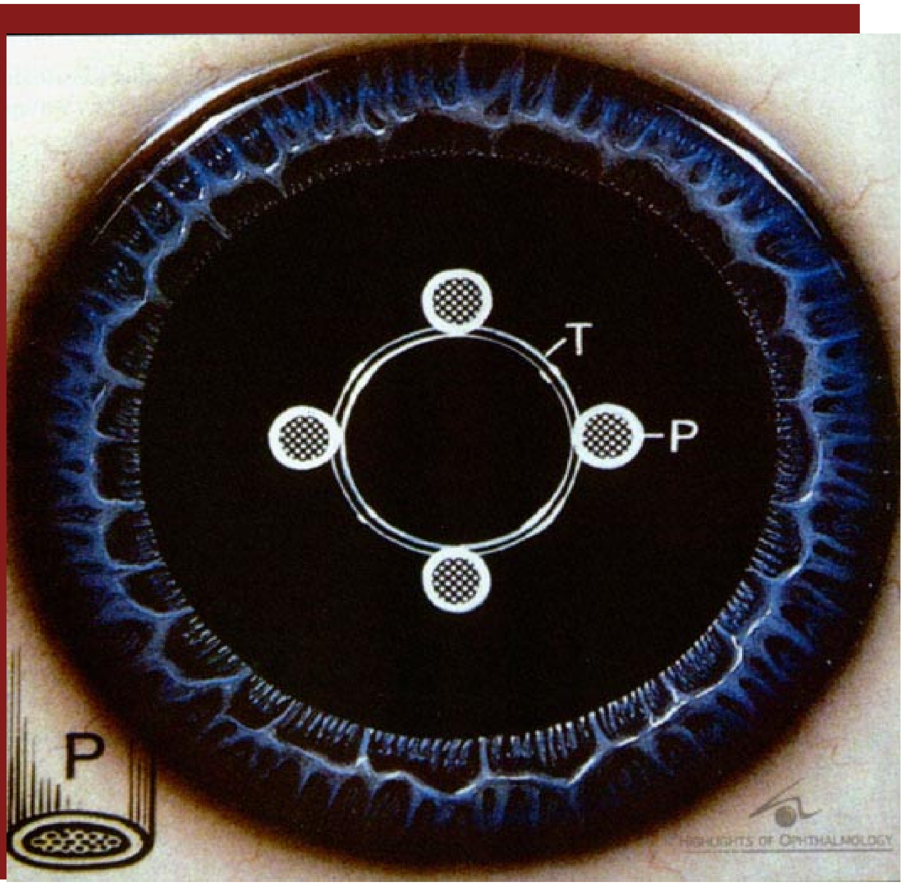
Determining the Corneal Thickness with the Pachymeter

Guide for Length of Blade

The corneal thickness is determined with the ultrasonic pachymeter. Some surgeons do it preoperatively, others prefer to do it **intraoperatively** which is done at this stage of the procedure immediately following the marking of the central clear optical zone. The central measurement is accompanied by four paracentral measurements (Fig. 93).

Figure 93: Determining Corneal Thickness with the Ultrasonic Pachymeter - Guide to Determine Blade Length

The pachymeter readings (P) to determine the corneal thickness are taken at 3, 6, 9 and 12 o'clock at the edge of the optical clear zone. The dotted shaded area shows the location of the actual pachymeter probe with the probe sleeve being the white ring surrounding this area. A detail of the pachymeter probe tip is seen in the inset. While the probe tip sleeve (white ring) crosses over the thickness of the optical zone (T), the actual probe (dot shaded area) is tangent to the outer perimeter of the mark. The knife blade is set to 100% of the thinnest of the four paracentral corneal thickness readings. The optical clear zone border in this illustration has been marked with a trephine and does not provide the markings of the 4 basic radii at 90º to each other that are obtained with the Murube Marker (Fig. 91)

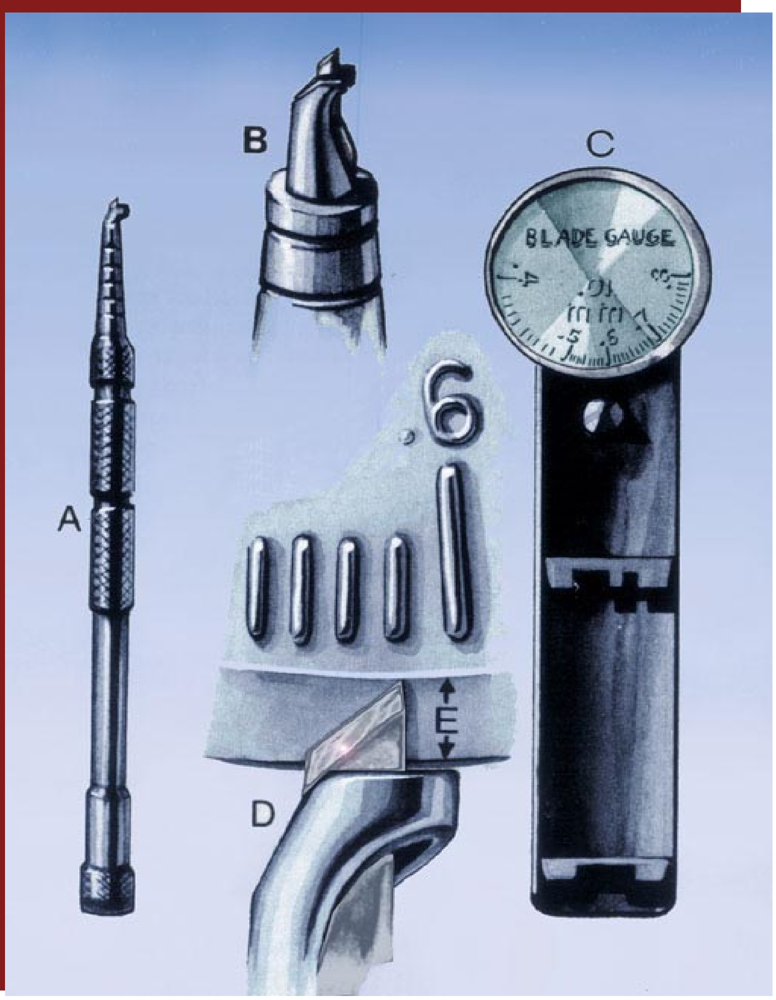


Setting and Using the Diamond Blade

When one has measured all four (4) paracentral areas (Fig. 93), one sets the diamond blade at 100% of **the thinnest of the four** (Fig. 94). Consequently, if your final readings were 0.52 at 12 o'clock, 0.53 at 3 o'clock, 0.54 at 6 o'clock and 0.50 at 9 o'clock, one would set the blade at 0.50.

The "coin" gauge is designed to help the surgeon check the knife setting in a safe way, holding the knife firmly in place, thereby preventing chips in the diamond. The knife is set with the micrometer handle but double-checked in the coin gauge (Fig. 94).

Although the diamond blade is set by the micrometer handle, which is usually fairly accurate, it is often incorrect by several microns.



Diamond Knife Calibration
(Click Over the Videoclip)

Fig. 94: Radial Keratotomy Diamond Knife and Coin Gauge - Setting Blade Length

The diamond knife is shown to the left at (A). A detail of the blade is seen at (B). To set the diamond blade length, as determined by the thinnest of the four paracentral corneal thickness readings, the knife is placed firmly in the coin gauge holder (C) and the reading is tested against a strip of metal that is very carefully calibrated (D and E). A magnified detail of the knife blade resting against the coin gauge is seen at (D). Example blade length 0.59mm (E) is shown set against the coin gauge.

More sophisticated, microscope-like instruments for calibrating the exact depth of the knife blade are also available.

Therefore, instead of just setting the micrometer handle on the knife, the knife is put into the coin gauge and the reading is tested against a strip of metal that is very carefully calibrated (Fig. 94). More sophisticated, microscope-like instruments for calibrating the exact depth of the knife blade are available.

The blade is inspected under high magnification and high zoom for chips, while it is in the holder, and it is placed at exactly the right depth. The diamond blade tip must be in perfect condition.

Preventing Loss of Corneal Thickness and Perforations

During this time the cornea should be covered with Weck-cel sponges soaked in the topical anesthetic of the surgeon's choice and the assistant should be dropping anesthetic drops every ten seconds while the surgeon issetting the knife blade. If the cornea is not continuously moistened, it will lose one percent of its thickness for every minute that it is exposed to the hot light of the microscope. Consequently, if the cornea thins, and if the blade is set to the ultrasonic pachymetry readings taken when the cornea was thicker, there will be a high perforation rate. This can be prevented by frequent irrigation of the cornea and proceeding at a good pace without wasting time after ultrasonic measurements are made.

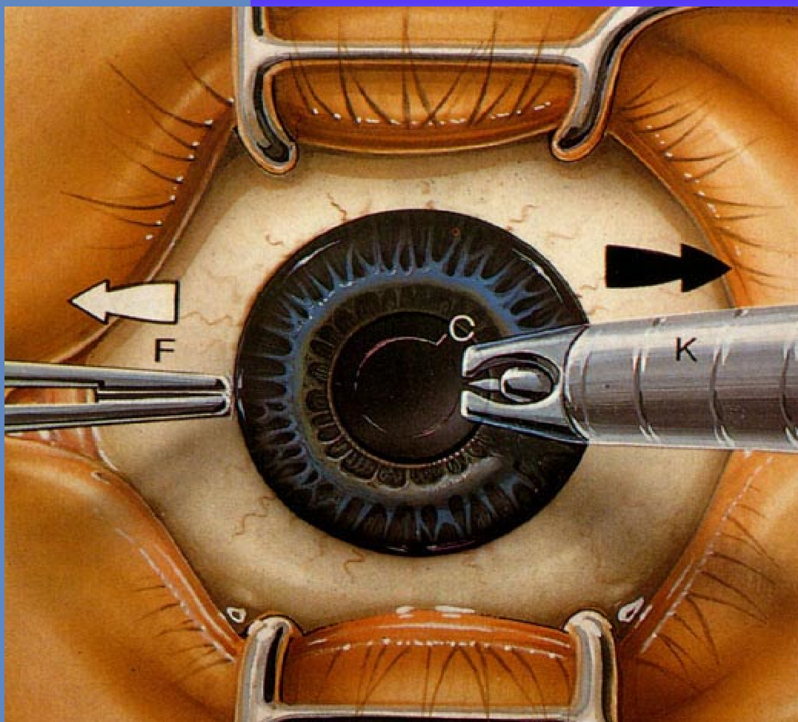
Making the Radial Corneal Cuts

Use Lowest Magnification

It is recommended that the cuts be performed under the lowest magnification of the microscope because you need to see the entire cornea to make sure that the cuts are radial. High zoom will cause you to make non-radial and poorly spaced cuts.

Role of Surgeon's Accommodation

If the surgeon is under 40 years of age he/she should focus very close to the eye and use accommodation because during the cuts he will push back hard on the globe which is displaced backward in the orbital fat. A younger surgeon can relax accommodation if the eye moves away. An older surgeon without accommodative reserve has to re-focus quickly up and down with his/her foot controlling the microscope during each cut, which is slightly inconvenient but can certainly be mastered.



Radial Incisions Technique

The incisions are carried out beginning at the margin of the central clear optic zone and directed toward the limbus (Figs. 95 and 96). To make a perfect radial incision, guidance from **Murube's** marker are very helpful (Figs. 89-91). The method known as the Russian technique begins at the limbus and is directed toward the optic zone. The latter, however, has been abandoned by most surgeons because it resulted in frequent and serious errors. The incisions entered the visual axis and resulted in permanent decrease in visual acuity.

Figure 95: Radial Incisions Technique - Stage 1

The radial incisions are begun at the optical clear zone margin (C) with a diamond blade knife (K). The blade length is pre-set according to the corneal thickness previously determined by pachymetry. The incisions are directed toward the limbus (black arrow). The temporal incision is completed first. The fixation forceps (F) grasp the globe at the limbus directly opposite the incision to be made. When making the radial incisions, the fixation forceps (F) move the globe in the opposite direction (white arrow) from the movement of the diamond knife (black arrow).

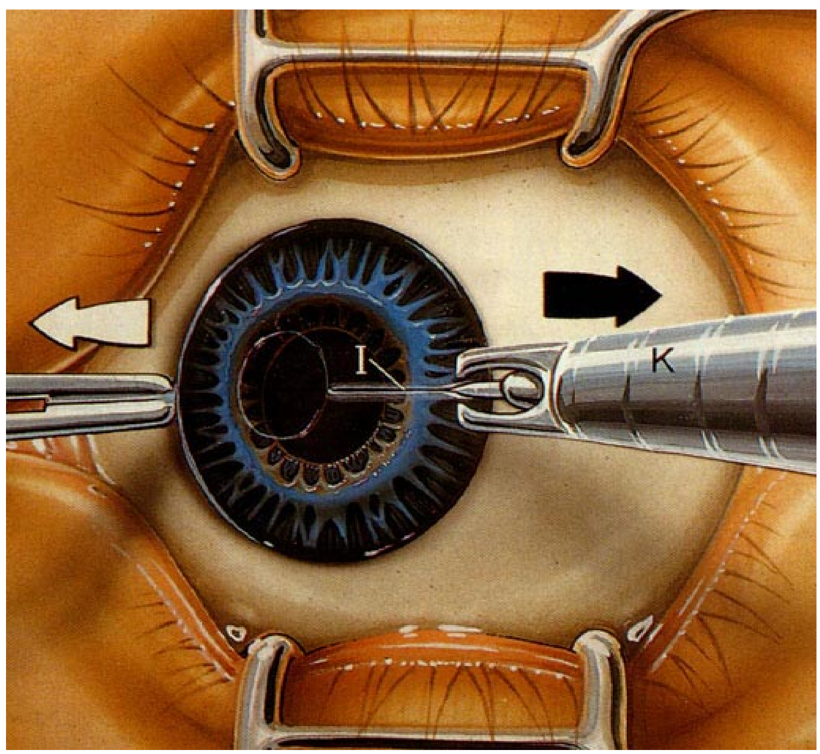


Figure 96: Radial Incisions Technique - Stage 2

Here the globe is shown rotated (white arrow) as the knife (K) approaches the limbus, completing the radial incision (I). Stop short of the limbus to avoid cutting the paralimbal vessels with consequent bleeding.

Position of Knife Blade During Radial Incisions

Hold your fingers on the side of the blade so that you can look directly down the shaft. Take every precaution to enter the cornea absolutely perpendicular at the optical zone mark (Figs. 97 and 98). If slanted cuts or undercuts are made, this will drastically reduce the corrective effect of the operation and may cause regular or irregular astigmatism.

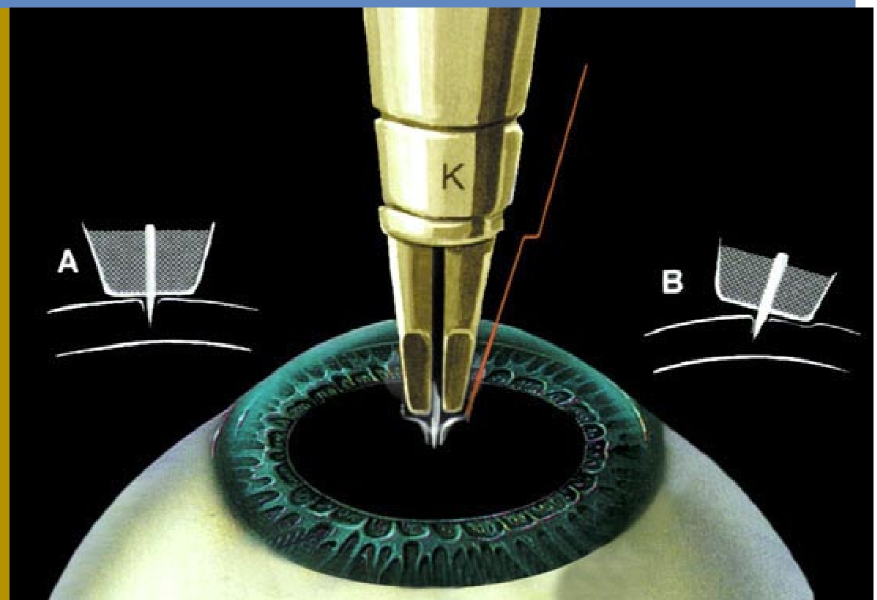


Figure 97: Correct and Incorrect Positions of Knife Blade During Radial Incisions - Surgeon´s View

Seen above is a properly positioned knife (K) which is perpendicular to the cornea. Inset (A) shows this correct blade position in cross section. Tilting the knife from the perpendicular (dotted line) results in an undercut of insufficient depth as seen in detail inset (B). This will reduce the effect of the operation and may cause astigmatism.

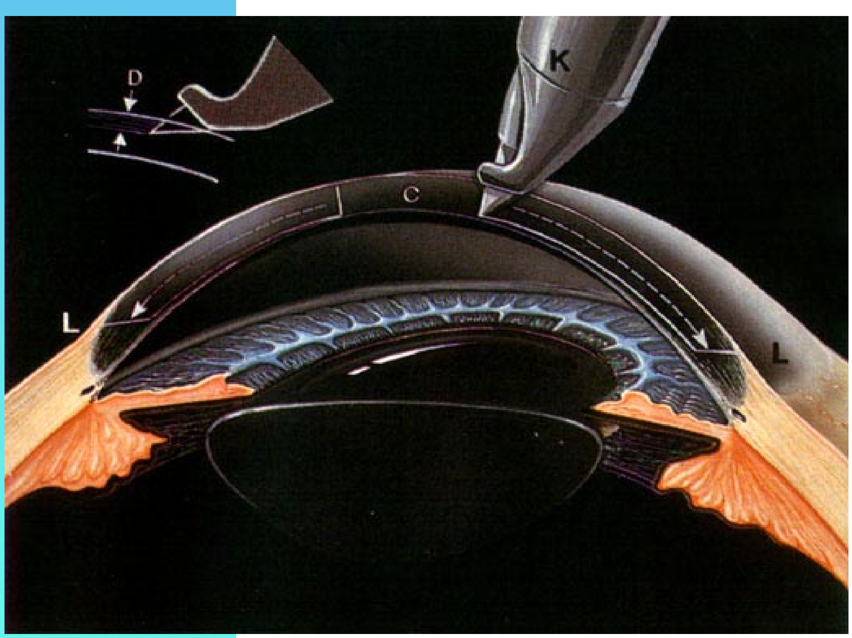


Figure 98: Correct and Incorrect Positions of the Knife Blade During Radial Incisions - Cross Section View

This figure shows the knife (K) entering the cornea perpendicular at the optical clear zone (C) perimeter. The incisions are made from this point down to the limbus (L). The inset demonstrates an incorrectly positioned knife blade which is not riding perpendicular to the cornea. This situation produces an undercut incision of insufficient depth (D) which results in a reduced corrective effect and possible astigmatism.

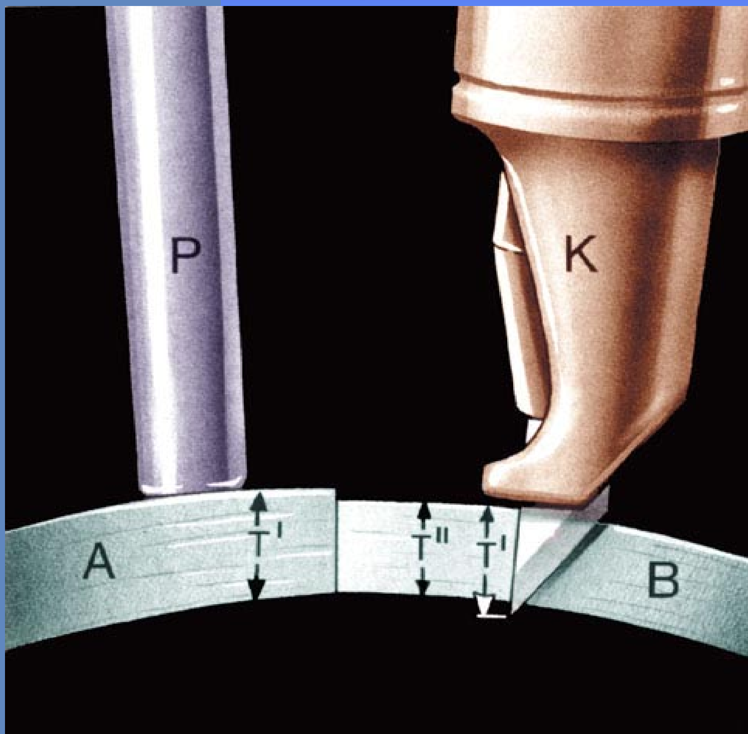


Figure 99: A Common Cause of Corneal Perforation

Figure (A) shows corneal thickness reading being taken with the ultrasonic pachymeter probe (P). Corneal thickness in this case is (T1). If the cornea is not continuously moistened, it will lose one percent of its thickness for every minute that it is exposed to the warm light of the surgical microscope. Figure (B) shows such a case where the cornea was not kept moist and about 10% of the corneal thickness has been lost from the time that the pachymeter reading was taken. It now has a reduced thickness (T11). The knife (K) blade length (T1) was set according to 100% of the pachymeter reading (T1) before the corneal thickness became reduced to (T11). The result is a perforation of the cornea.

Operate With Dry Instruments and Field

Marguerite McDonald, M.D., has recommended to surgeons who perform RK that just before starting surgery, dry off the cornea quickly and instruct the assistant to stop putting drops on the cornea while the cuts are being made.

After entering with the diamond blade, one should be certain the instruments are completely dry, because if a drop of fluid appears, one can be certain that it is coming from the anterior chamber. If the instruments are soaked in water or anesthetic drops beforehand, it is impossible to know where the liquid is coming from; it could be sliding down the knife handle. If the cornea and instruments are dry, then you will know immediately that any fluid appearing will be aqueous humor. By taking these precautions, you can withdraw the blade when there is only a microperforation as opposed to a major perforation (Fig. 100).

Cutting Toward Limbus

Slowly proceed with the corneal cut, moving your hand away from the optical clear zone until you stop when reaching **close to the limbus** in order to avoid cutting the paralimbal vessels. Most of the action surgically occurs in the 4.0 mm paracentral area between the optic zone and the limbus.

Always fixate the globe with the forceps 180º degrees from the cut that is being made. If you are cutting at 3 o'clock , your other hand should be fixating at 9 o'clock. Move the fixation hand for each and every cut.

Obtaining Proper Incision Depth

The length of the blade has been previously set based on the pachymeter readings (Fig. 94) at 90-95% of full corneal thickness. The radial keratotomy knife should be plunged to its full depth at the margins of the optical clear zone before proceeding with the incision. This is important. The knife must reach its full level of depth before one begins carrying out the incision. The actual incision is made very slowly. **Perforations are most likely to occur during the first millimeter or two of the incision** since this paracentral area is the thinnest part of the cornea. **Perforation close to the limbal area is very unlikely because this is the thickest area of the cornea.** Moving the knife very slowly will allow you to detect a microperforation when it occurs. It appears as a small oozing and not a gushing of aqueous from the incision as one would see if the knife were passing through the tissue at a rapid speed (Figs. 99 and 100).

Order of Radial Incisions

Following the first incision which is done on the temporal side, the next (second) incision is carried out directly across the first incision; that is, in the nasal quadrant (Fig. 91). Move the eye with one hand in the opposite direction of the flow of the diamond knife. This allows the knife to flow through the tissue in a very straight line, which prevents an irregularity to the incision.

After completing the temporal and nasal incision, you may complete the four initial cuts following the orientation made by the Murube Marker (Fig. 91) or the 8 incisions as shown in Fig. 92.

Figure 100: Detecting Inadvertent Microperforation of the Cornea

The instruments should be completely dry during the execution of the radial incisions. This is done so that if a drop of fluid (A) appears, it is certain to be from the anterior chamber and not from liquid running down the knife handle. With a dry surgical field any dry instruments, a microperforation can be noted immediately and the blade withdrawn before a major perforation is produced.

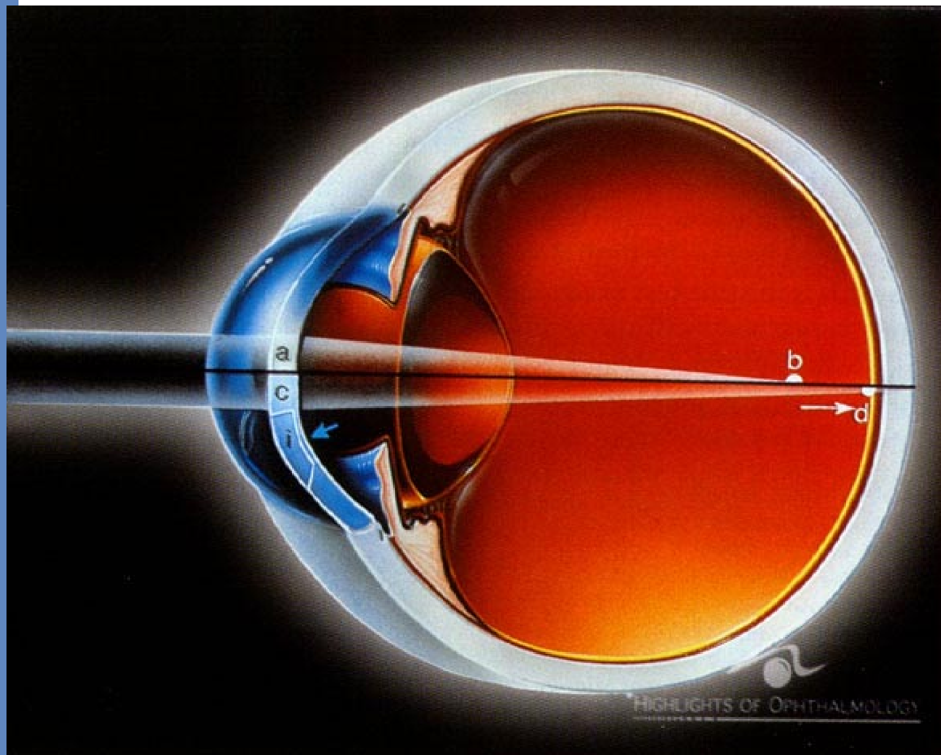


Figure 101: Refractive Concepts of the Mini-RK Procedure The globe shown is divided into two halves for direct comparison of pre and post-op corneal curvature change which produces the change in refraction following a Mini-RK procedure. The upper half shows the pre-op corneal curvature (a) resulting in a myopic refractive effect, as a point source of light is focused (b) in front of the retina. The lower half shows the flattened central cornea (c) resulting from the Mini-RK incisions (i). The resulting minus refractive effect is to allow light now to focus on the retina (d).

THE MINI-RK (MINI RADIAL KERATOTOMY)

Dr. Richard Lindstrom has found good results with an incision just 2 mm to 2.5 mm long-or half as long as the standard incision. He identified the "Zone of Maximum Benefit", as being the zone from 3 to 8 mm from the pupillary center. He makes a deep but short, or staccato, cut in that small area using a dual track, double-pass blade (Fig. 88).

The depth of the incision makes it possible to correct a **small amount** of myopia. **Lindstrom** now has longitudinal data after following these patients for 6 years; there has been no significant hyperopic shift. The eye is **not** weakened in case the patient suffers a trauma later on. For the optics related to the Mini-RK, see Fig. 100.

Surgical Technique

Amount and Technique for Incisions

In general, **Lindstrom favors making the least number of incisions possible.** He uses two incisions of only 2 mm to 2.5 mm in length if possible, which do not destabilize the cornea. From investigations performed by **Lindstrom** in his laboratory, he found that it is the length of the incisions as utilized in conventional radial keratotomy what destabilizes the cornea. This could be the reason for a slow change toward hypermetropia 8 to 10 years after a conventional radial keratotomy. **Lindstrom** increases to four incisions only if necessary. **He hardly ever plans a primary case with Mini-RK unless he expects to achieve a good result with a four-incision Mini-RK.** If necessary, he can enhance up to six or eight safely.

Surgical Options

LINDSTROM'S NOMOGRAM FOR MINI-RK

For illustration of corneal markings in a four incision RK or Mini-RK, see figure 91.

How to Use this Nomogram

- Identify the patient's age and the diopters of refractive myopia that you wish to correct.
- Find the patient's age in the first column on the left.
- Move to right until you reach the surgery results closest to the refractive myopia of the patient. In order to avoid overcorrection, it is suggested that you select a surgical goal somewhat less than the actual refractive myopia. The column heading then tells you which surgery is needed to achieve this result, listed in the column headings as follows: Age, number of incisions (4 in this nomogram), diameter of central optical clear zone. Since the present nomogram is for a four incision Mini-RK, there are these variables: age, diameter of central clear optical zone and refrac tive myopia you wish to correct.

Example

- A 45-year old patient with a refractive myopia of 3.75.
- Moving to the right on the Age 45 line, you see that 3.75 falls between 3.90 and 3.25. Looking at thecolumn headings, you see that a 4 incision x 3.25 mm central optical zone will correct to 3.90 diopters of myopia. A 4 x 3.5 mm optical zone will correct 3.25 diopters of myopia.
- The recommendation in this case is to do a 4 x 3.25 mm central optical zone.

Emmetropia Being our Common Goal

AGE	Number of Incisions per Diameter Central Optical Zone 4 X 3.0	4 X 3.25	4 X 3.5
20	2.80	2.40	2.00
21	2.87	2.46	2.05
22	2.94	2.52	2.10
23	3.01	2.58	2.15
24	3.08	2.64	2.20
25	3.15	2.70	2.25
26	3.22	2.76	2.30
27	3.29	2.82	2.35
28	3.36	2.88	2.40
29	3.43	2.94	2.45
30	3.50	3.00	2.50
31	3.57	3.06	2.55
32	3.64	3.12	2.60
33	3.71	3.18	2.65
34	3.78	3.24	2.70
35	3.85	3.30	2.75
36	3.92	3.36	2.80
37	3.99	3.42	2.85
38	4.06	3.48	2.90
39	4.13	3.54	2.95
40	4.20	3.60	3.00
41	4.27	3.66	3.05
42	4.34	3.72	3.10
43	4.41	3.78	3.15
44	4.48	3.84	3.20
45	4.55	3.90	3.25
46	4.62	3.96	3.30
47	4.69	4.02	3.35
48	4.76	4.08	3.40
49	4.83	4.14	3.45

Complications of RK and Mini-RK

Intraoperative

Microperforations undoubtedly occur at a higher rate in the initial series of a novice radial keratotomy surgeon. Even highly experienced surgeons, every time they perform this operation have a micro needleholder, fine tissue forceps, two tying forceps and a 10-0 nylon suture on an auxiliary surgical table. Having this ready gives them a good sense of security. There is nothing worse than getting these instruments together in a hurry when you have a perforation that requires suturing. Fig. 100 shows how you may detect inadvertent microperforation of the cornea. You may use an olive-tipped syringe and irrigate on an angle and **not perpendicular to the cornea** to clean out the incisions and ensure that there are no epithelial cells, or blood or foreign bodies that will interfere with wound healing and cause glare.

If there is a microperforation, placing the 10-0 nylon suture requires a particular technique. The suture should be placed as far away as possible from the optical zone and through the margin of the perforation closest to the limbus **(Fig. 102).** Apposition of the wound should be just edge to edge with no pressure at all. If one ties the suture too tightly because of fear of wound leakage, this will probably lead to a significant amount of induced astigmatism **(Fig. 103).**

Undercorrections and Overcorrections

These complications will be discussed in a separate chapter 10, dedicated to **enhancements** for all major refractive surgical procedures.

POSTOPERATIVE MANAGEMENT

Principles

The success of cosmetic incisional keratotomy for refractive errors such as RK, Mini-RK, and Astigmatic Keratotomy, is dependent on good wound healing and the maintenance of a healthy cornea with a stable refractive result. **Kurt Buzard, M.D.,** considers that the three principles of post-operative management are:

1) Early identification and treatment of wound healing problems which may lead to overcorrections or astigmatism. 2) Frequent postoperative follow-up. 3) Make the appropriate choice of secondary surgical procedures only when the refractive result is stable.

Major Post Operative Concerns

Buzard divides **the post operative course** into four periods, the first 24 hours, the first two weeks, the first six weeks and long-term.

First 24 Hours

In the **first 24 hours patient discomfort** is the primary concern. The surgeon should anticipate this problem and should be prepared to see the patient if only to provide reassurance. Adequate medications to control pain are essential.

Therapeutic Contact Lens

Buzard advises the use of a therapeutic contact lens to be applied immediately after surgery with hourly artificial tears. This may reduce postoperative pain and discomfort. If a therapeutic contact lens is not used, patching is indicated for the first 24 hours.

First Two Weeks

During the first two weeks the major concerns are: 1) completion of epithelial healing; 2) reduction of ocular inflammation; 3) appropriate stromal wound healing; 4) intraocular pressure. In the patient over age 40, the use of steroids to control ocular inflammation in the first week should be balanced against the possibility of slowing wound healing and inducing an overcorrection. Steroid eye drops, if used at all, should be employed for

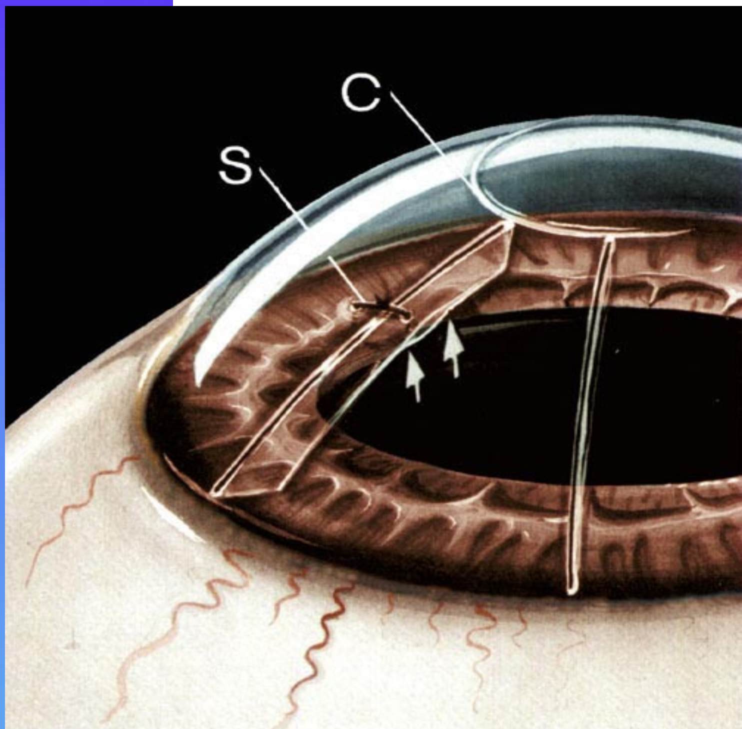


Figure 102: Proper Technique of Repair of Microperforation

Here, a one mm perforation into the anterior chamber (located between the arrows) is repaired by placing the suture (S) through the edge of the perforation closest to the limbus. Adequate apposition of the wound lips is a must, but over-tightening should be avoided to prevent inducing astigmatism. The 10-0 nylon suture (S) should be placed as far away from the optical clear zone (C) as possible so as to affect the refractive result only minimally.

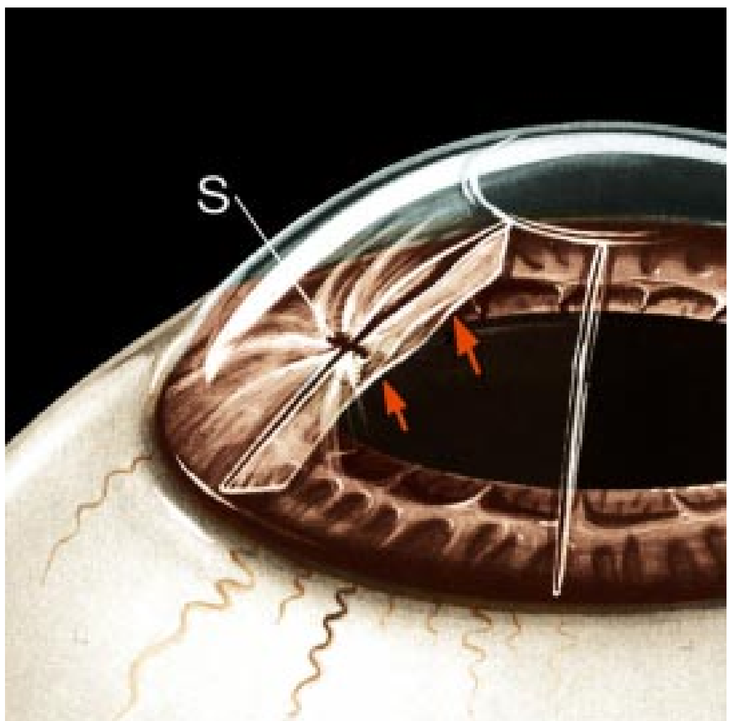


Figure 103: Improper Technique of Repair of Microperforation

A microperforation of the cornea is shown between the two arrows. The suture (S) has been pulled too tight resulting in large induced astigmatism in this over zealously repaired case.

only 2-3 days during this two weeks period. Increased intraocular pressure, above pre-operative values, can increase the refractive effect of the operation. For principles to follow in all refractive surgical procedures regarding the use of non-steroidal anti-inflammatory drugs, steroids, low-potency steroids and antibiotics see pages 106 - 108.

First Six Weeks

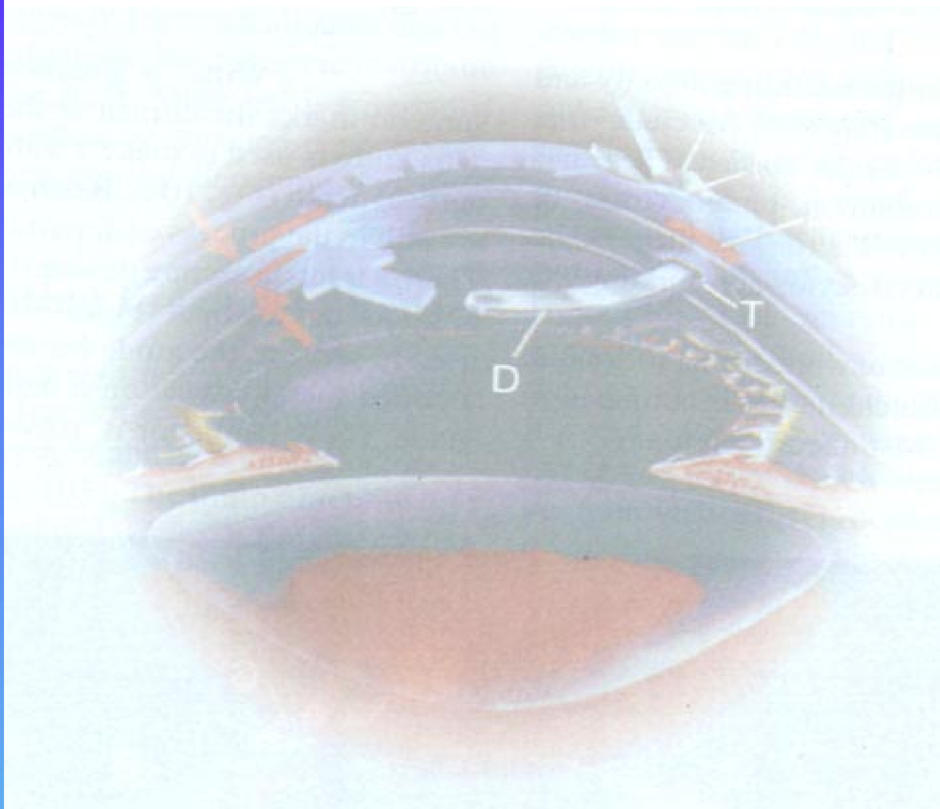
The refraction and the cornea stabilize during the **first six weeks** allowing the surgeon to critically evaluate the results of the surgery. Concern during this period must focus on: 1) stability of the refractive result; 2) visual satisfaction of the patient; 3) whether and what further intervention might be required.

During this period careful evaluation of clinical signs of wound instability, such as staining and photokeratometric signs of breaking of mires and microdehiscence, will indicate incomplete wound healing often associated with overcorrections. Similarly, shallow corneal incisions might be associated with regression of the refractive corneal effect.

Once a clear diagnosis has been established, appropriate surgical and/or pharmacologic intervention can be instituted.

Postoperative Refraction

Changes will occur during the first six weeks. At thst time, it becomes more stable. The ideal is to end up with -l.00 diopters at six weeks postoperatively. If the patient is emmetropic at the six week period, he/she will be very happy at the time but eventually the eye may change to +1.00 diopters.



GIAK

Gel Injection Adjustable Keratoplasty

Gel injection adjustable keratoplasty is a new technique developed by **Dr. Gabriel Simon** while he was working in Jean Marie Parel's laboratory at the Bascom Palmer Eye Institute in Miami in the late 1980's. The methodology involves **injecting a semi-solid gel in the paracentral corneal stroma in order to flatten the central cornea and thereby reduce myopia.**

Indications

It is anticipated that GIAK be used to correct between -1.00 to -4.00 D of myopia.

Present Status of Procedure

Although it is still in its infancy, GIAK seems to have a promising future. The investigators behind this procedure, both in the laboratory and clinically, are very respected authorities in the field of corneal and refractive surgery. Mainly, **Gabriel Simon, M.D.,** now in Madrid; **Douglas Koch, M.D.,** main medical monitor in the United States with the responsibility of obtaining FDA approval, and Professor **Juan Murube, M.D.,** in Madrid, Spain.

Scientific Findings Supporting GIAK

Extensive studies including toxicity and biocompatibility have led researchers to conclude that the gel is very well-tolerated by the cornea. There has been no evidence of inflammation, phagocytosis, or scarring along the gel tract. There was little or no decrease in the density of keratocytes surrounding the gel.

The probable evolution of work on this technique will be other international clinical studies in conjunction with Dr. Michael Knorz of Mannheim, Germany.

Surgical Technique

With a guarded diamond knife, the surgeon marks the cornea at the desired optical zone. This knife is used to make a stab incision to the desired corneal depth (Fig. 104). **Koch** and his co-investigators are still in the process of determining the optimal depth. Then, a tract dissecting device is placed in the groove in order to start the tract (Fig. 104). A small metal guide is used to serve as the guide for the delaminator, which is a coiled metal device on a handle placed beneath the guide. The delaminator is rotated in a gentle fashion

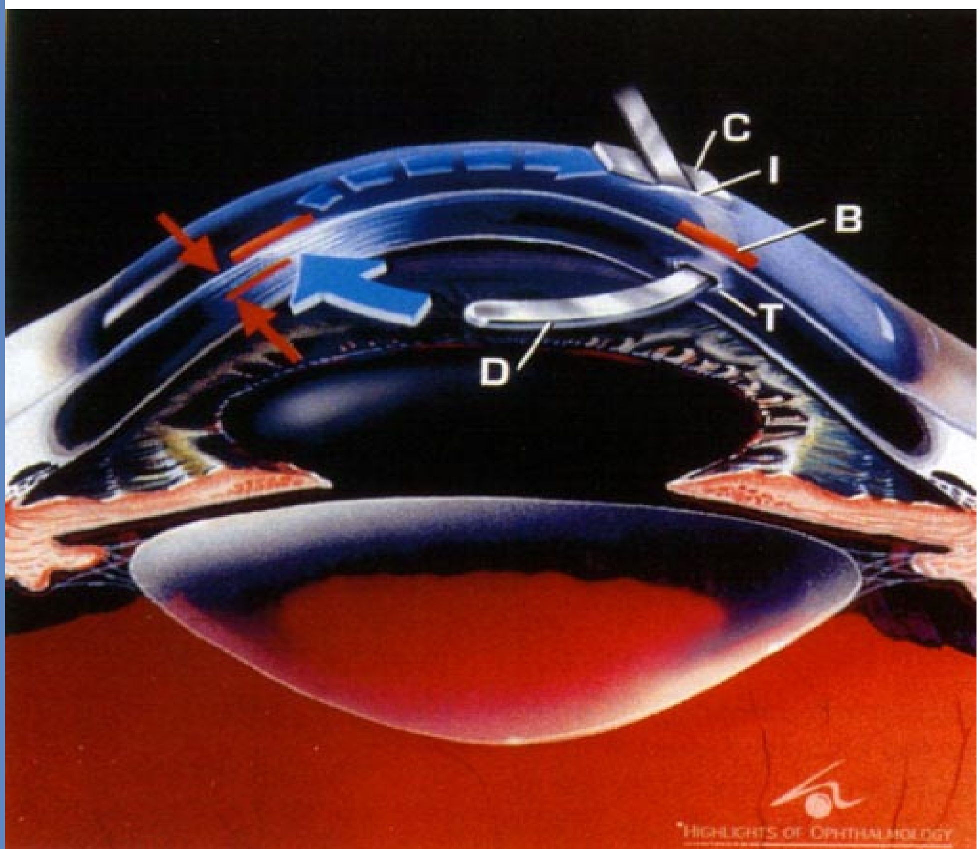


Figure 104: Gel Injection Adjustable Keratoplasty - Stage 1

First, a stab incision (I) is made in the cornea to the desired depth at the optical zone. The stromal plane selector (C) is placed in the groove to start the tract. The delaminator (D) which is a coiled metal device on a handle, is rotated 360 degrees within the corneal stroma beneath a small metal guide (B) to produce a circular tract in the cornea (blue arrows) around the optical zone. The guide ensures that the delaminator enters the stroma at the proper depth (red arrows). The delaminator is then rotated out of the tract (T). The structure of the delaminator is shown simplified in the main illustration to display the concept. The actual delaminator is shown in the inset.

as the 360 degree tract is dissected. The delaminator is then rotated out. Gel is injected in small aliquots into the tract and then massaged around the cornea to distribute it evenly throughout the tract. More gel is inserted if indicated, and the procedure is repeated if necessary, depending on how much corneal flattening is desired (Fig. 105).

Benefits - Adjusting Refractive Errors

By distributing various amounts of gel to different parts of the dissected tract, the ophthalmologist can **presumably** correct myopia above 5 or 6 diopters as well as astigmatism (Fig. 105). The **main aim now** is to correct low myopia up to -3.00 to -4.00 D. **This refractive procedure may make it possible to correct myopia in a way that is not only reversible but also adjustable.**

Its **unique benefit** is that the position of the gel in the cornea can be adjusted through simple postoperative modifications. A patient who ends up 0.75D and is unhappy with the results can be treated with an injection of a little more gel (Fig. 106).

What is most stimulating about the procedure is that it may make it possible to adjust patients' refractive errors throughout their lives (Fig. 106). Gel can either be added or removed. For example, for patients between ages 20 and 40 who tend to experience a myopic shift, more gel can be injected. Patients between 40 and 60 tend to have a hyperopic shift. **Koch** believes some gel can then be removed. This procedure, then, may provide a reversible way of changing a patient's refractive error in order to compensate for age-related changes in the eye.

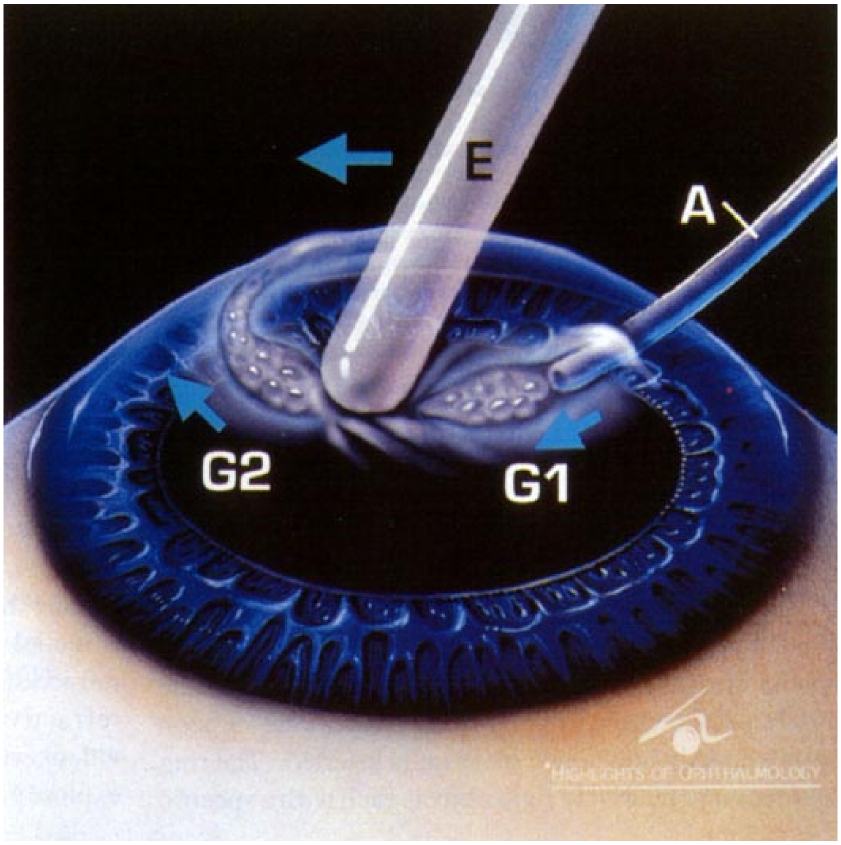


Figure 105: Gel Injection Adjustable Keratoplasty - Stage 2

Gel (G1) is then injected in small amounts into the tract using a special cannula (A) inserted into the tract. Specially designed instruments (E) are used to distribute (arrows) the gel (G2) evenly throughout the tract. Note the central corneal flattening produced by the presence of the gel.

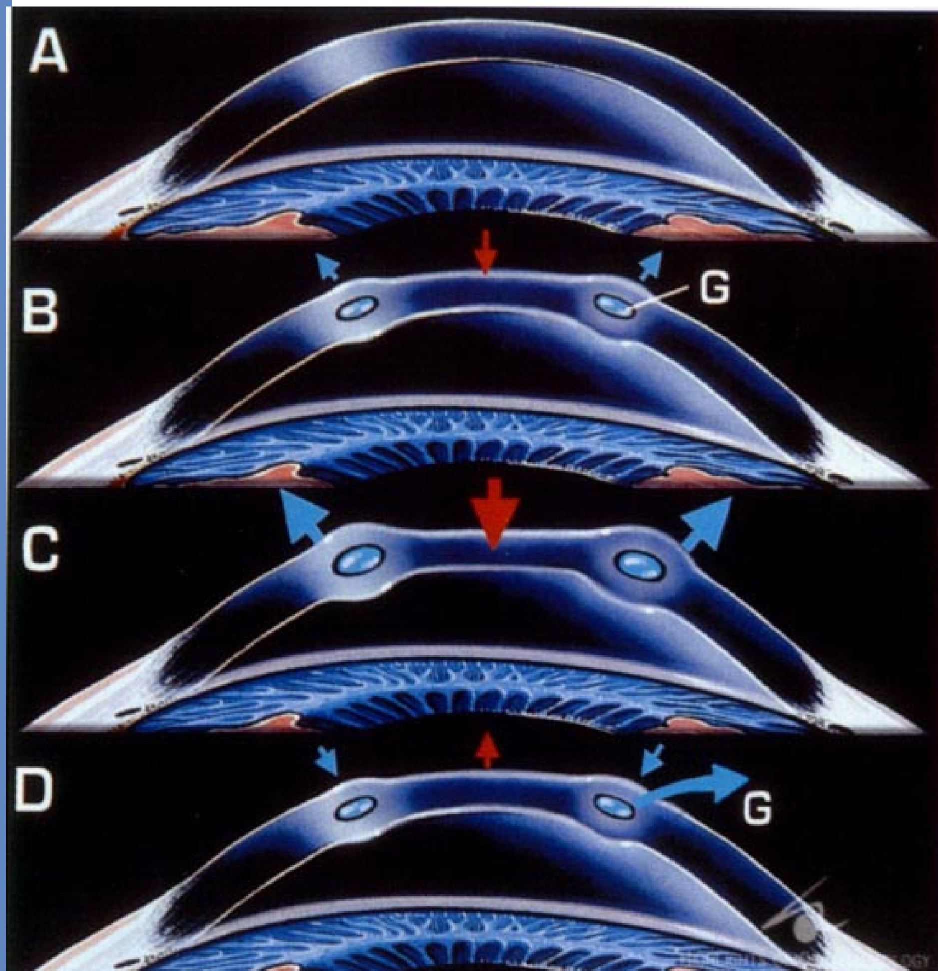


Figure 106: Concept of Adjustable Keratoplasty

(A) Shows the pre-op corneal curvature for comparison. (B) Shows gel (G) placed within the circumferential tract and the resultant flattening of the central cornea (small arrows). (C) Theoretically, if more correction is desired, more gel can be injected, even at a later date. Note additional flattening of central cornea (large arrows). (D) The procedure may also offer the ability to reverse the refractive correction later in life by removing some or all of the gel (G -arrow) from the tract. Note that the central cornea steepens (arrow) slightly with removal of some gel. The corneal curvature changes in this illustration are highly exaggerated from reality to convey the concept.

Remaining Challenge

Koch emphasizes that one of the greatest challenges with this type of procedure is to monitor the results accurately. With the related technique of the intrastromal corneal ring segments (ICRS), the surgeon knows exactly how much material is inserted. The ring segments are relatively rigid objects each with a specific size. (See Figs. 81-86 in this chapter). With this semi-solid gel, on the other hand, the surgeon does not know exactly how much is to be inserted. It is therefore essential to monitor either the corneal curvature or the refraction at the time of surgery in order to determine the refractive effect that is achieved. Intraoperative videokeratoscopy and refractometry are now being explored as ways of monitoring these effects.

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Surgical Management of High Myopia (-10.50 D and Higher)

Chapter 6

Phakic IOL´s

ANTERIOR CHAMBER

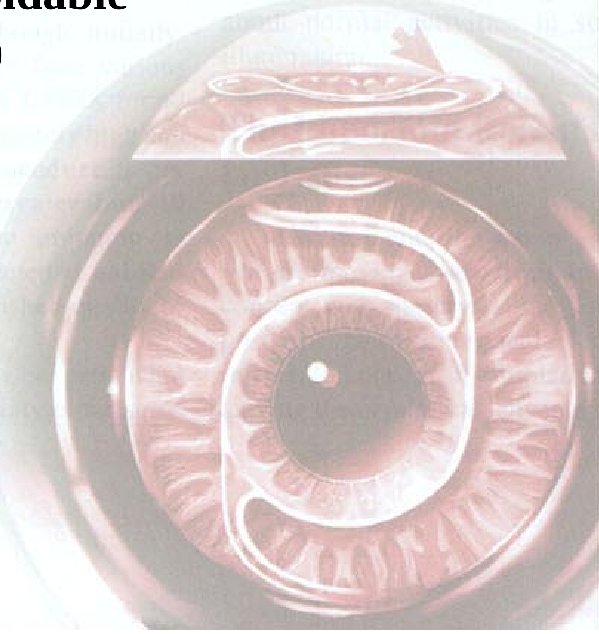
The Artisan Lens

The Nu-Vita Lens

PRE-CRYSTALLINE LENS

The Barraquer PMMA Lens

The Implantable Foldable Contact lens (ICL)



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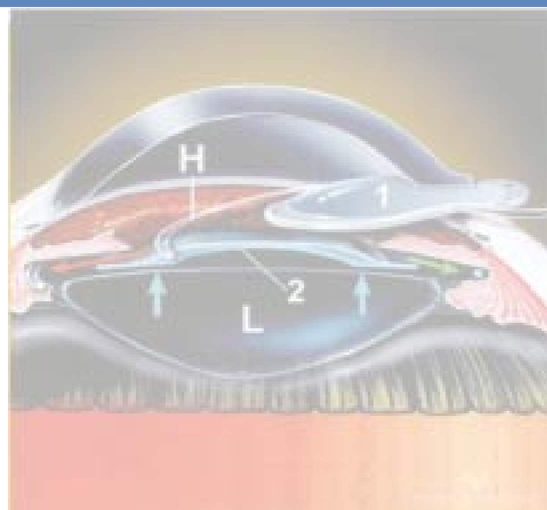

PHAKIC IOL's
THE PROCEDURE OF CHOICE

Limitations of LASIK in Very High Myopia

The general consensus is that although, initially, different prestigious refractive surgeons from various countries performed and recommended LASIK for all degrees of myopia (low, moderate, moderately high and very high) it is now clear that **this procedure is not recommended in very high myopias (greater than -10 diopters).** This is because of important limitations in night vision, loss of best spectacle-corrected visual acuity, some visual aberrations and diminished quality of vision.

The surgeon's goal is to provide his/her patient not only a satisfactory postoperative visual acuity as measured in the Snellen chart, but also to sustain a very good quality of vision.

Some ophthalmologists have seen patients operated with LASIK for myopia larger than -10.50 D who end up with a postoperative vision of 20/25 without spectacles or contact lens correction but, at day's end, they must rush back home because they cannot drive at night or go about normal activities in surroundings with low illumination.

The Important Role of Phakic Intraocular Lenses

We are entering a new age with this procedure. We are moving away from an **exclusively** extractive concept with the crystalline lens being replaced by a posterior chamber intraocular lens for aphakia, toward a refractive concept of implanting an intraocular lens leaving the crystalline lens intact.

Contributions of Phakic IOL's

In these specific patients (-10-50 D or higher) phakic IOL's provide the following: 1) excellent refractive accuracy; 2) preservation of corneal sphericity and the patient's accommodation; 3) reversibility or adjustability; 4) predictable healing and; 5) rapid visual recovery and a stable postoperative refraction.

High myopes are usually very satisfied. Their post-op uncorrected visual acuity is generally better than their pre-op best-corrected visual acuity.

Advantages Over Corneal Refractive Surgery

Phakic IOL's have a major advantage over corneal refractive surgery: they can be removed; the procedure is reversible. It is easy to remove a Baikoff style anterior chamber lens (Nu-Vita lens) by sliding it out of the incision (Fig. 120). The Worst's Artisan lens can be removed by spreading the claws to release the iris (Fig. 114). The posterior chamber plate lenses can be easily removed (Fig. 133). **Waring's** experience with the soft, foldable lens made by Staar is that this very thin lens can be slid back out through the original incision without cutting the IOL into smaller pieces (Fig. 138).

Limitations of Phakic IOL's

1) There are concerns about safety. We lack long-term data and strict follow-up with the Nu Vita and the foldable posterior chamber plate lens. The procedure and the lenses are still being improved. The longest experience has been that of **Dr. Jan Worst's** anterior chamber **Artisan Lens** although both design of the lens and the implantation technique have gone through modifications that we feel are positive. **Joaquin Barraquer's** hard, PMMA pre-crystalline lens has had the second longest and very thorough follow-up.

Because of the safety concerns and limited follow-up with some lenses, it is important that the ophthalmic surgeon use only those phakic lenses which have been tested and for which there is long or medium-term data. Those include the four (4) phakic lenses that we presented in this chapter, as follows: (1) Anterior Chamber Lenses: the Artisan and the Nu Vita lenses. (2) Posterior Chamber Phakic "Plate" Pre-crystalline Lenses: the Barraquer PMMA Lens. The Guimaraes-Zaldivar is made of a hydrogel collamer.

Experience with other lenses, of various designs and made of different chemical materials have begun to show significant late complications. **Brauweiler** et al from Bonn, Germany, have reported a 73% incidence of anterior subcapsular cataract after implantation of posterior chamber **silicone** lenses in phakic eyes followed for a minimum of two years. These Fyodorov style lenses were made of silicone, by Adatomed. So far these anterior subcapsular opacities have not affected visual acuity but they do discourage the implantation of this specific type of phakic lenses.

Consequently, surgeons using posterior chamber phakic plate lenses should be extra cautious and inform their patients of this risk. Other posterior chamber phakic lenses presented in this chapter have also shown this complication but they have been minimal. **Long term data and using the already tested lenses is essential.**

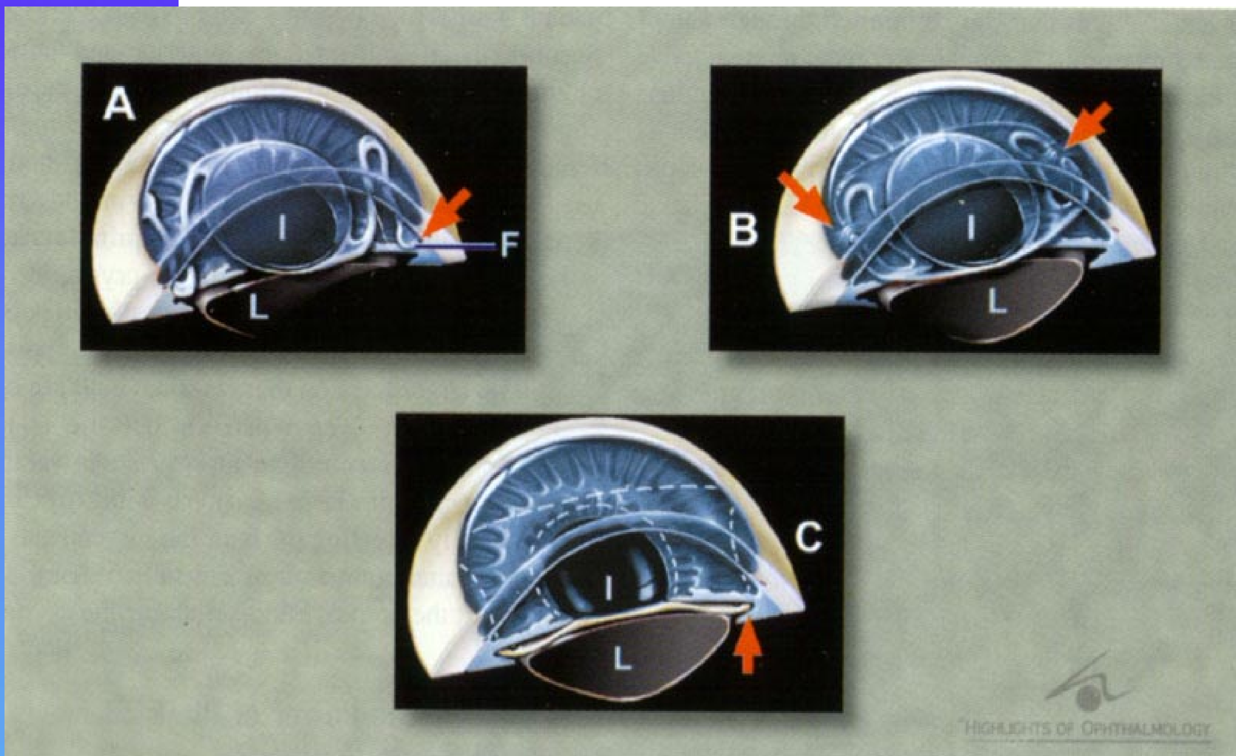

Figure 107: Three Basic Styles of Phakic Intraocular Lenses

The anterior chamber Multiflex NuVita phakic intraocular lens has fixation of the lens haptics (F) within the angle (arrow) of the eye. Note the relationship of the artificial lens (I) anterior to the natural lens (L) and to the iris. (B) The Artisan (iris claw) lens is also placed in the anterior chamber but is clipped to the peripheral iris stroma (arrows) by means of a slot in the haptic. Note the relationship of the Artisan lens (I) anterior to the natural lens (L) and the iris. (C) A third type of phakic IOL is the posterior chamber plate lens group, which are fixated in the ciliary sulcus (arrow). These lenses (I), are anterior to the natural lens (L), but located posterior to the iris (shown in dotted line).

2) The implantation of these lenses demand much surgical skill and great attention to detail. It is much more demanding than phaco and posterior chamber IOL insertion for cataract surgery. Certain parts of the surgery are similar, but there are many new difficult challenges to meet and overcome.

For success, it is essential to prevent damage to the corneal endothelium, anterior chamber angle, the iris or the crystalline lens.

Three Basic Styles

They are: 1) The former **Baikoff Multiflex style Nu Vita** anterior chamber lens with fixation in the angle, made of PMMA (Fig. 107-A). (2) The **Artisan lens** designed by **Jan Worst** with a fixation mechanism to the peripheral iris stroma (Fig. 107-B); and (3) the posterior chamber plat e lenses that fixate in the ciliary sulcus (Fig. 107-C).

Waring prefers to use the latter in the form of a foldable lens that can be inserted through a non-sutured 3 mm or 3 1/2 mm clear corneal internal valve self-sealing incision. (**Editor's Note:** this type of lens is also known as the "implantable intraocular contact lens".) This is the type of incision many phaco surgeons use for cataract surgery. The posterior chamber phakic lenses consist of two important sub-types:

a) The **Joaquin Barraquer** hard, PMMA IOL pre-crystalline plate lens and,

b) The foldable "Implantable Contact Lens" also implanted in the pre-crystalline space between the posterior surface of the iris and the anterior capsule of the crystalline lens. This lens is made of hydrogel/collagen polymer and was jointly pioneered by **Ricardo Guimaraes, M.D.,** (Brazil) and **Roberto Zaldivar, M.D.,** (Argentina).

This group of lenses (pre-crystalline) are fixated in the ciliary sulcus.

Special Precautions During Surgery

Because of the minimal space available, it is challenging to insert a phakic IOL without causing complications like corneal endothelial damage and secondary cataract. **Waring** provides general advice for surgeons about technique:

First, when implanting anterior chamber lenses, the surgeon should determine before the surgery that the patient's **anterior chamber** is more than 3 mm deep. **Second,** in all implantations, anterior and posterior chamber, the **incision** should be very carefully constructed, and a **viscoelastic** that can be completely removed from the eye at the end of the surgery should be used. (The anterior chamber lenses: Nu-Vita and Artisan, need a corneal valve incision. The **Joaquin Barraquer** posterior chamber plate lens or pre-crystalline lens requires a 7 mm limbal incision). **Anesthesia** depends upon the surgeon's choice. Topical anesthesia is possible, but with a larger incision there is some collapse of the anterior chamber even when viscoelastic is used. **Peribulbar or retrobulbar anesthesia is certainly useful,** especially if a large incision is going to be made. When actually **inserting the lens**, the surgeon must pay meticulous attention to surgical detail so that the lens does not hit the corneal endothelium or the crystalline lens.

Calculating the Power of Phakic Lenses

Tables are used for **most** phakic IOL's currently to look up the power of the lens needed to correct a given refractive error. No mathematical formulas, yet. This makes it much easier. This includes the Artisan and Nu Vita lenses. For the Artisan lenses, the tables were constructed by Van der Heijde, a world class authority on lens implant power calculation and selection. For the Barraquer pre-crystalline lens, the manufacturer calculates the power based on clinical data provided by the surgeon, and each lens is custom-made.

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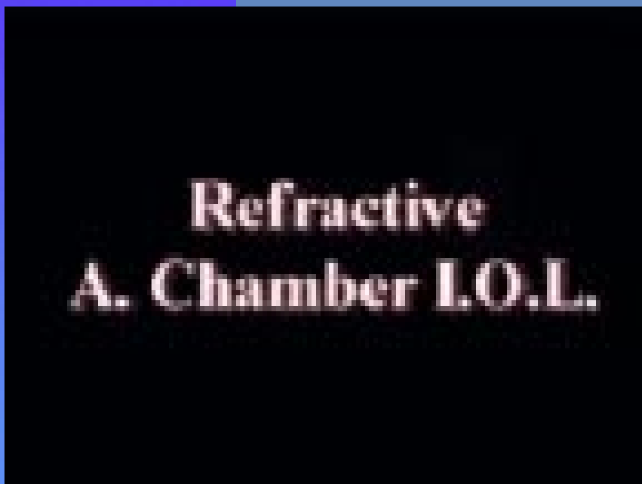


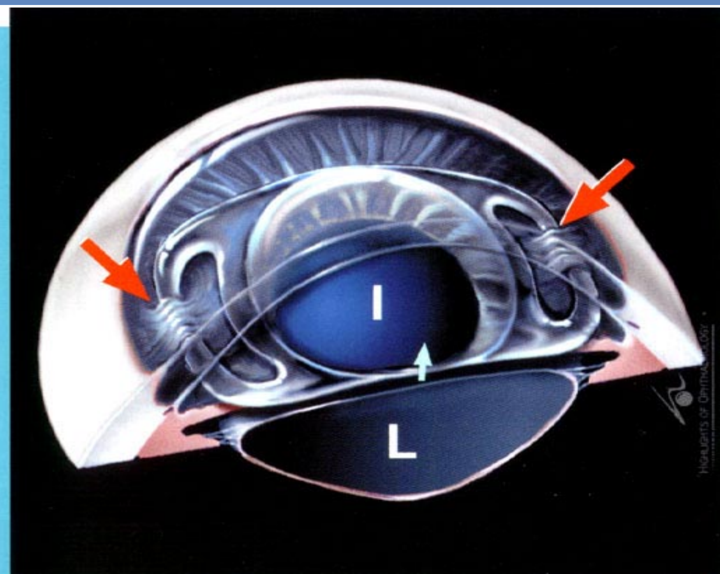


Figure 108: Concept of the Artisan Intraocular Lens

The Artisan IOL is placed in the anterior chamber and is clipped to the iris (arrows) through slots in the peripheral portion of the haptics. Note the relationship of the Artisan Lens (T) vaulted anterior to the natural lens (L) and iris.

ANTERIOR CHAMBER PHAKIC IOL'S

THE ARTISAN LENS

The Artisan (Iris Claw) Lens (Fig. 108) requires a more demanding insertion technique than anterior chamber lenses which are angle fixated such as the Nu **Vita Multiflex style lens.** The method of implanting the Artisan lens usually requires **a limbal incision of 5 mm to 6 mm.** This lens, designed by **Jan Worst** from Holland, has the **advantage that one size fits all eyes** and that it has been used with **considerable success over the past 12 years** in both aphakic and phakic eyes.

How Does Peripheral Iris Support Differ from the Old Iris Clip Lens Implant Design?

The so-called iris clip lenses such as the Binkhorst 4-loop and Worst Medallion were really pupil margin and iris supported. The haptics were never onto the iris; instead the lens was fixated by the pupil and the haptics cradled the iris in their arms. Iris clip lenses were used only in aphakic eyes. Skillfully inserted they were capable of good long term results, but they had several disadvantages. Pseudophakodonesis (wobbling as the eye moved) could lead to corneal endothelial touch and damage. This was most often seen if the lens (the pupil) was decentered, displacing one of the anterior haptics too near the peripheral cornea. Dislocation occasionally occurred, especially in patients who rubbed their eyes, and was a worrisome possibility if the pupil needed to be dilated. Dislocation could be limited to subluxation by using an iris or trans-iridectomy suture, but these added to the difficulty of the surgery.

Even subluxation could lead to major endothelial damage if the IOL fell forward and rested against the cornea. Long term pupil margin erosion by the loops led to glare and more dislocations. These problems were ameliorated if extracapsular surgery (ECCE) was done so that the stability of the posterior capsule was retained. But by the time ECCE was widely adopted, posterior chamber lenses had supplanted other styles.

In 1978 Worst began using lenses of an entirely new design, literally clipped to the peripheral iris. Because the slotted tips of the haptics pinched the iris (Figs. 108, 114, 115), Worst unfortunately named them belying the gentleness of these lenses on the eye post operatively. Happily, the name has been changed to **Artisan.**

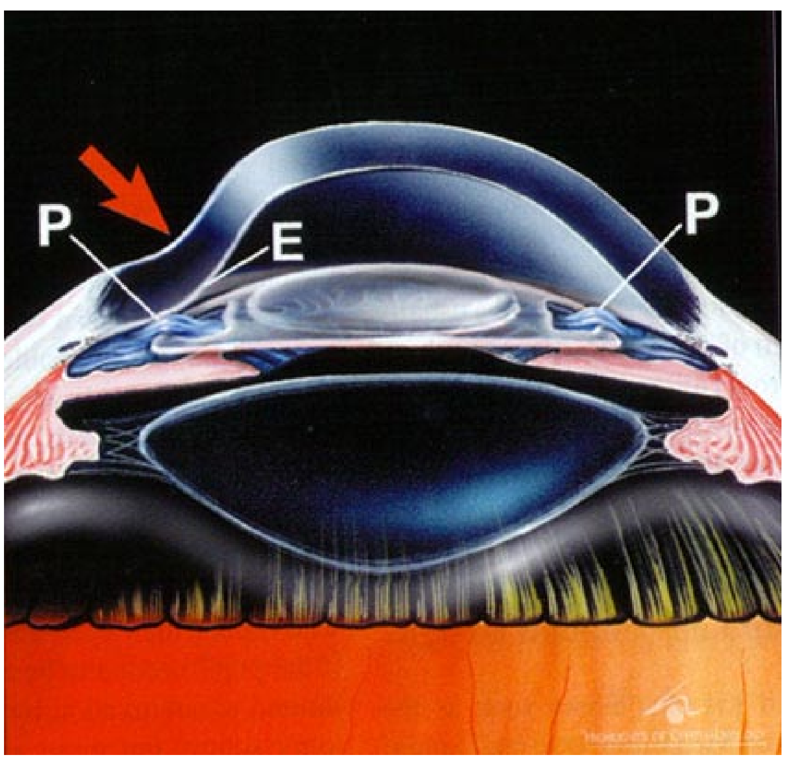
What are the Advantages?

No major investments are needed in lasers, keratomes, and disposables. Techniques are those already known well by anterior segment surgeons, and special instrument investment is small.

The iris periphery is a stable platform, moving very little even with dilation of the pupil, and providing a privileged area for the fixation of an intraocular lens. The mode of enclavation of the loop tips (Figs. 114, 115, 116, 117) produces a pillow of iris over the most peripheral part of the haptics, further guarding against touch of the plastic to endothelium **(Fig. 109).** Most (but not all) studies have shown no late leak on fluorescein iris angiography.

Figure 109: Positive Features of the Artisan IOL with Regard to the Corneal Endothelium

The Artisan IOL with its mode of enclavation of the loop tips produces a pillow of iris (P) over the most peripheral part of the haptics. This pillow of iris guards against touch of the plastic to endothelium (E) as shown in this eye with corneal depression (arrow).



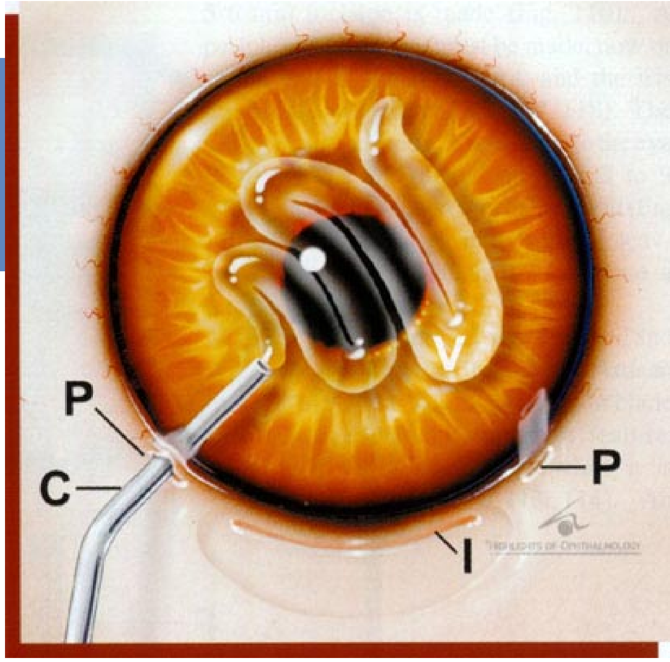


Figure 110: Artisan IOL Surgical Implantation Technique - Incisions

One or two paracentesis stab incisions (P) are made according to the technique to be used. The anterior chamber is filled with a high molecular weight viscoelastic via a cannula (C) placed through one of the paracentesis. A 5-6 mm incision (I) is then made. A peripheral iridotomy must be made now or at the end of the procedure.

Although peripheral iris damage can occur if surgery is difficult or clumsy, long term iris atrophy and/or late subluxation of the lens is rarely seen.

The pupil can be widely dilated and scleral indentation used without worry. The lens does not depend on anterior chamber angle support, thus avoiding ovaling of the pupil, UGH syndrome, and the late corneal decompensation of some anterior chamber lenses. It does not rest on the crystalline lens, avoiding possible late production of cataract, such as the anterior subcapsular cataract now being seen in some patients with phakic pre-crystalline posterior chamber lenses.

The theoretical complications of chronic iritis, iris atrophy, IOL dislocation, and corneal decompensation require more prospective study, but so far have been rare, including the results of a European multicenter study and phases 1 and 2 of the US Clinical Trials. There is no iridodonesis in the phakic eye, and therefore minimal pseudophakodonesis. **This lens has the advantage that one size fits all eyes. It has been used with considerable success over the past 12 years in both aphakic and phakic eyes.** Moreover, it can be centered directly over the pupil (Figs. 113, 114, 117, 118), unlike both the anterior chamber angle fixated lens that centers on the angle and the pre-crystalline posterior chamber plate lens that centers on the ciliary sulcus.

What are the Disadvantages?

Like most intraocular lenses, this lens depends on excellent quality control and superb finish for its good results. (Posterior chamber lenses placed in the capsular bag may be an exception.) Those lenses used by **Worst** himself are made by **Ophtec**. Poorly made copies can, of course, give bad results.

Surgical technique needs to be smooth and gentle. Patient relaxation and control are paramount. Some surgeons prefer general anesthesia when skilled modern anesthesiology is available. A high density viscoelastic should be used to ensure avoidance of endothelial touch during insertion and manipulation in the shallower phakic anterior chamber **(Fig. 110).** Until a foldable version becomes available, a 5-6 mm incision is required and must be closed skillfully.

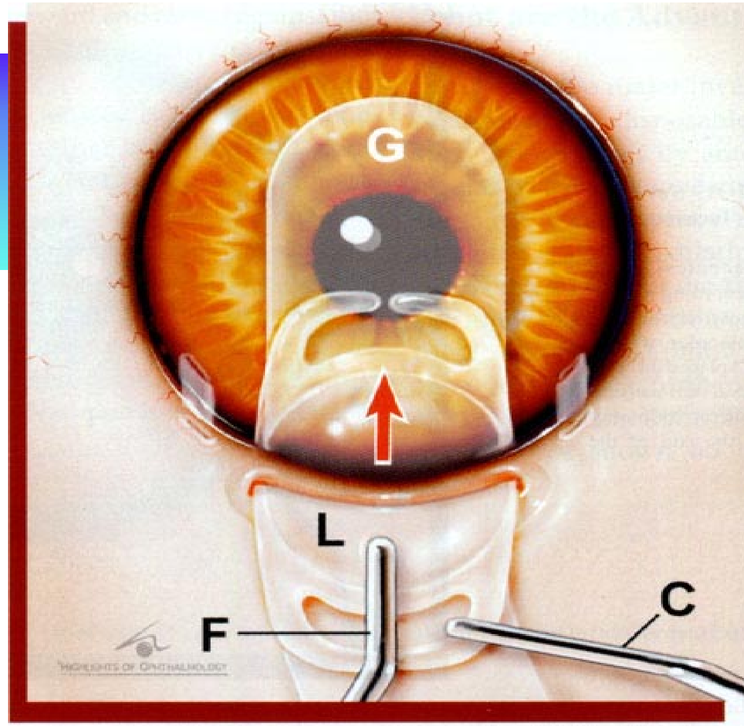


Figure 111: Artisan IOL Surgical Implantation Technique - Insertion - Stage 1

A lens glide (G) is placed through the incision and across the anterior chamber. With viscoelastic filling the anterior chamber, the Artisan lens (L) is grasped with a special forceps (F) and inserted into the wound on the lens glide. A second instrument, an irrigating cannula (C), is placed inside the haptic loop and serves to push the lens (arrow) inside the anterior chamber.

A peripheral iridotomy is needed, **as with all phakic intraocular lenses** (Figs. 117, 118). Correct clipping of the loops onto the iris is critical and so far has been best accomplished with a two handed approach (Figs. 114, 115, 116). Newer, simpler instruments should allow this part of the surgery to become easier.

Surgical Technique

How Difficult Is the Technique for Implantation?

The technique is shown in figures 111-118. Implantation of these lenses makes use of the techniques that anterior segment surgeons know well already. Because the phakic anterior chamber is not as deep as in aphakia, and because the lens is manipulated in front of the iris, extra care must be taken to assure maximum chamber depth throughout the procedure.

Two Handed Enclavation

The pupil should be kept moderately constricted. One or two stab incisions are made according to the technique to be used (Fig. 110), and the anterior chamber filled with high molecular weight viscoelastic (Fig. 110). Methylcellulose should not be used.

A 5-6 mm incision is made (Fig. 110). A peripheral iridotomy must be made, now or at the end of the procedure, and the iris reposited completely (Figs. 117, 118). The lens is gently and slowly nudged into the eye (Figs. 111, 112), rotated into the 3 to 9 o'clock axis and centered over the pupil (Fig 113). The wound is partially sutured, leaving an opening sufficient to introduce a forceps.

The lens is centered over the pupil and gently pressed onto the iris with an Artisan forceps (Fig. 113). The longer inferior blade of this forceps is an important feature, ensuring stability of the lens while it is attached to the iris (Figs. 113, 114).

Figure 112: Artisan IOL Surgical Implantation Technique - Insertion - Stage 2

The irrigating enclavation instrument (E) is then used to nudge (arrow) the Artisan lens (L) into position inside the anterior chamber.

Figure 113: Artisan IOL Surgical Implantation Technique - Centration

The lens glide is removed. A special lens forceps, the Artisan forceps, (F) grasps the Artisan lens (L) and further rotates it (arrow) into the 3 o'clock - 9 o'clock axis. The lens is centered over the pupil and gently pressed onto the iris with the Artisan forceps. The longer inferior blade (B) of the Artisan forceps is an important feature, ensuring stability of the lens while it is attached to the iris.

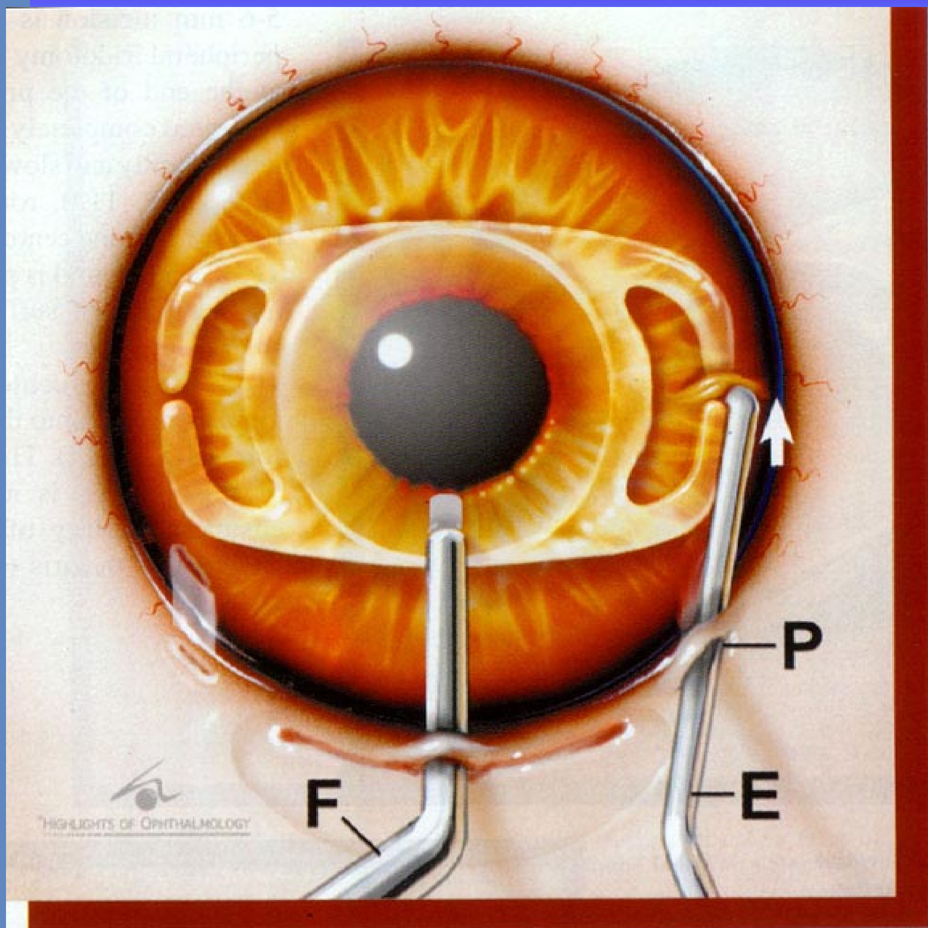


Figure 114: Artisan IOL Surgical Implantation Technique - Enclavation

The special Operaid irrigating enclavation instrument (E) is introduced through the stab incision (P) or through the main incision under the Artisan loop tip. Using the instrument, a fold of iris is lifted (arrow) through the slot in the tip of the lens haptic. The instrument is withdrawn slowly, being careful that it does not catch the iris. The Artisan forceps (F) stabilizes the lens during this maneuver.

An Operaid Enclavation Instrument is introduced through the stab incision superior to the Artisan loop tip. This instrument comes double armed, in right and left hand configurations, to use depending on which loop of the IOL the iris is being attached.

Using the enclavation instrument, a fold of iris is lifted through the slot in the tip of the lens haptic (Fig. 114 and detail in Fig. 115). The instrument is withdrawn slowly, being careful that it does not catch the iris. The maneuver is repeated for the other tip of the lens (Fig. 116). If a peripheral iridotomy has not already been made, it must be made now (Fig. 117). **The iridotomy is a vital part of the procedure and must not be omitted.** Lens position and fixation is inspected (Fig. 118).

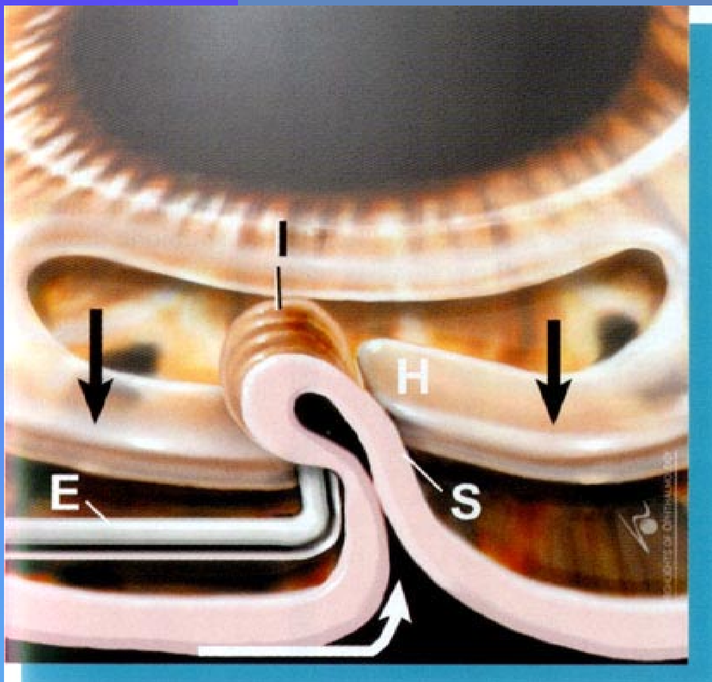
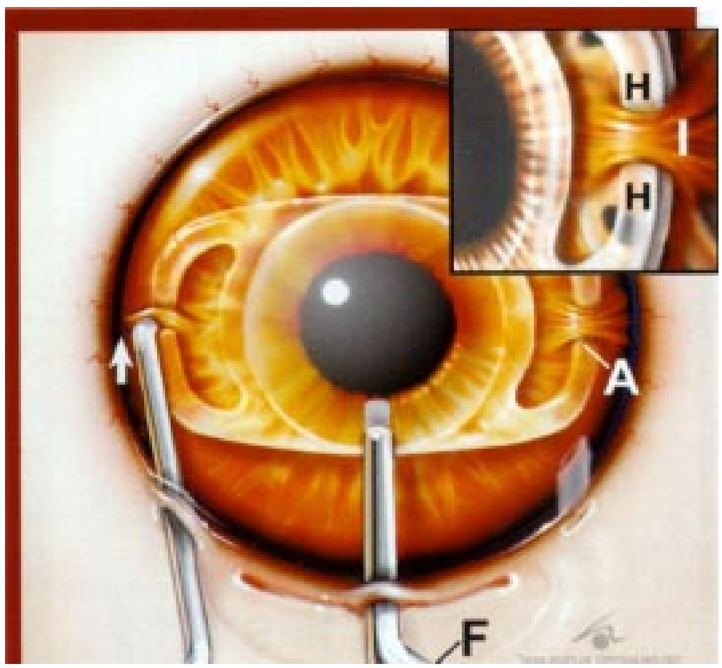


Figure 115: Artisan IOL Surgical Implantation Technique - Enclavation Detail

This magnified portion of the lens haptics shows how the enclavation instrument (E) engages a small fold of the iris (I) beneath the distal haptic (H). The iris fold is "snow-plowed" forward (white arrow) and gently captured in the slot (S) of the haptics. The IOL and its haptics are pushed posteirorly (black arrows) to assist this enclavation of the iris.

Figure 116: Artisan IOL Surgical Implantation Technique - Enclavation

The enclavation maneuver is repeated for the other tip of the Artisan lens, using the other irrigating hook. It is inserted through a paracentesis on the other side or through the main incision. The Artisan forceps (F) stabilizes the lens during this maneuver. Note the iris properly captured by the right haptic (S). The inset shows a magnified view of the iris (I) captured between the claws of the haptics (H).



When perfect, the wound is closed carefully. **All viscoelastic is patiently removed** while maintaining the depth of the anterior chamber with balanced salt. Steroid and antibiotic drops are placed. If there might be residual viscoelastic, prophylactic Iopidine or Latanoprost may be used to control any rise in pressure.

One Handed Enclavation Instruments

Instruments and techniques are being devised to allow easier, one handed attachment of the lens to the iris.

Postoperative Care

The normal postoperative course is benign, with rapid gain of vision. As with all intraocular surgery, the patient is cautioned to be seen at once if the eye becomes red or painful, or the vision becomes blurred. Intraocular pressure and cellular reaction in the anterior chamber are watched. Steroid and antibiotic drops are used until all reaction has subsided.

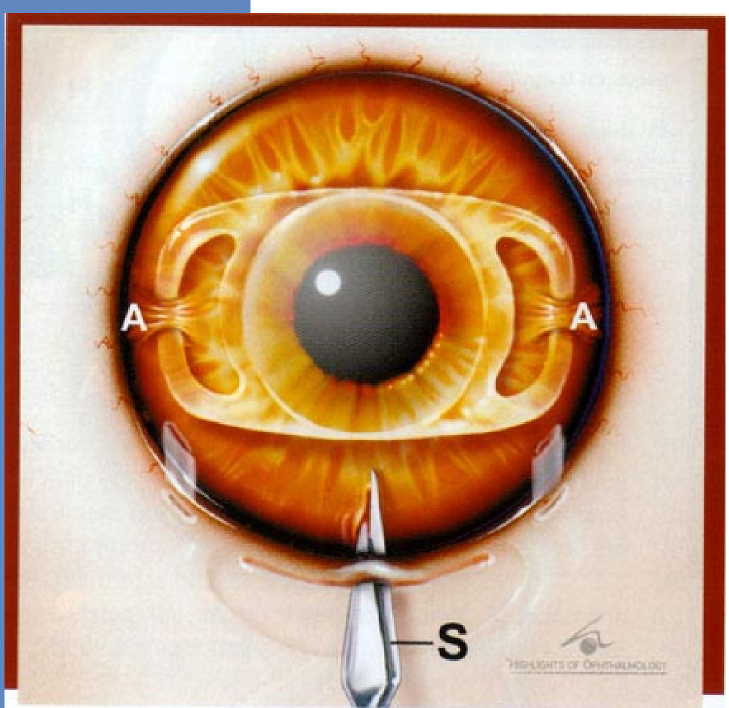


Figure 117: Artisan IOL Surgical Implantation Technique - Iridotomy

A small iridotomy is placed superiorly using a scissors (S). A check for patency is performed to ensure thorough penetration of the full iris thickness. Note that the iris is properly trapped by both the left and the right haptic slots (A).

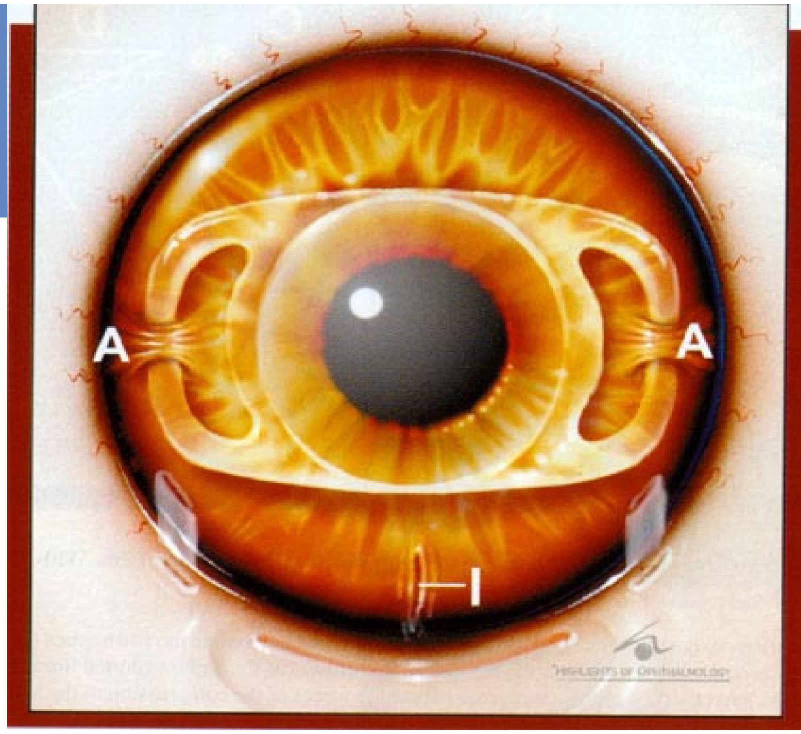


Figure 118: Artisan IOL Surgical Implantation Technique - Final Configuration

This illustration shows the properly placed and centered Artisan IOL. The wound is then carefully closed and all viscoelastic is meticulously removed while maintaining the anterior chamber depth. Note the properly trapped iris (A) within the haptic slots. Peripheral iridotomy (I).

Postoperative Complications

What if the Implant Needs to be Repositioned, Removed, or Exchanged?

Should the lens not be centered, a loop can be detached and reattached with some ease. Detachment only requires that one side of the loop be depressed while the lens is stabilized by forceps. In the rare event that a loop of the IOL is found not to be securely attached to the iris, it can be reattached through stab incisions, repeating the maneuvers illustrated in Figs. 110-116. Should an IOL need to be removed (for power exchange, for example), detachment of both tips is done as described above, under high density viscoelastic. Then enlarge the wound, slide the lens out, and replace it. Be gentle with the iris, and do not touch the corneal endothelium.

Availability

The lenses may be obtained from Ophtec, Schweitzerlaan 15, 9728 NR Groningen, Holland. They are distributed for the clinical investigation under FDA regulation in the US by Ophtec USA, Inc., 6421 Congress Ave., Suite 112, Boca Raton, FL 33487.

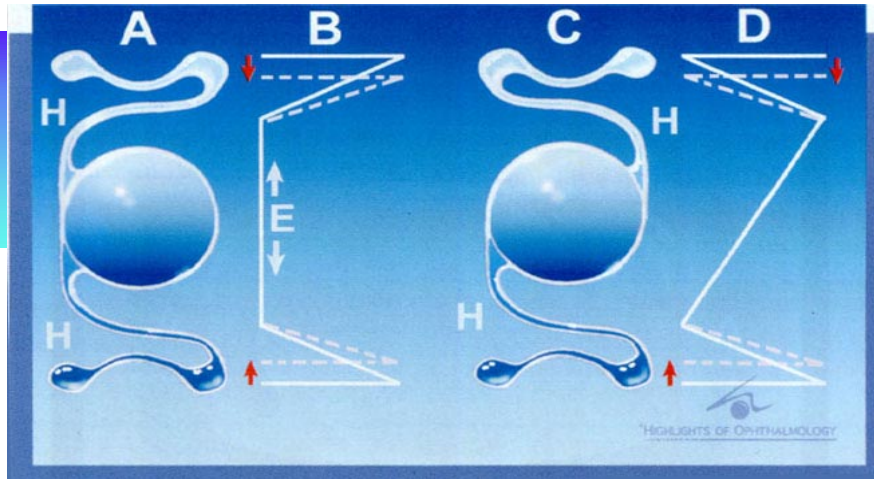


Figure 119: Comparison of Nu Vita Phakic Anterior Chamber Intraocular Lens With Previous Kelman Multiflex Design

(A) An earlier design of the Kelman Multiflex anterior chamber lens had the two haptics (H) originating from the same side of the optic. (B) Shows how the compression (arrows) of the haptics (dotted lines) was transferred to only one side of the lens (E). (C) In an attempt to distribute the forces of the compression of the haptics more evenly, to prevent decentration, the Nu Vita IOL design has the two haptics (H) originating from opposite sides of the optic. (D) Shows how compression (arrows) of the haptics (dotted lines) is now more evenly distributed in a directly opposing fashion. This cancels out lateral movement of the optic from the center on compression.

THE NU-VITA ANTERIOR CHAMBER LENS

The **Nu Vita phakic anterior chamber IOL** (MA-20) is produced by Bausch & Lomb. It is made of PMMA. A new generation lens is made of a foldable hydrogel biocompatible material that is hoped to be safer than PMMA in the anterior chamber. This may be available in the near future also through Bausch & Lomb.

The Nu-Vita lens, formerly the Baikoff AC-IOL is based on the Kelman Multiflex style. **Waring** emphasizes that the only style of **aphakic** anterior chamber lens that has survived during the last 15 years is the **Kelman Multiflex style** (Fig. 119). The published clinical literature documents that this **lens is safe for the eye.** According to **Waring,** the advantage of using a **Multiflex style phakic anterior chamber** lens is that it is the **easiest lens to insert.** Therefore, there is a lesser risk of surgical damage or complication than occurs with the other phakic IOL's.

This technology takes advantage of the fact that **most surgeons can place an anterior chamber lens** more easily than the other styles.

In Fig. 119, you will find an important comparison of the main features of the Nu Vita Phakic Anterior Chamber IOL with the previous Kelman Multiflex design.

Surgical Technique

The step-by-step technique is shown and described in Figs. 120-125. There is little difference from the usual implantation of a Kelman style anterior chamber lens except that greater care must be taken to ensure good anterior chamber depth to avoid damage to the corneal endothelium, iris, and lens.

Figure 120: Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 1

A temporal 5.5 mm self-sealing corneal incision is made. A forceps (F) grasps the optic of the intraocular lens (L) and inserts it into the anterior chamber as shown. The distal footplate must be snaked through the incision.

Maria Clara Arbelaez, M.D., considers the Nu-Vita lens her technique of choice for the correction of **high myopia,** from -8.00 D and up, because the results are predictable and safe, and the lens provides good quality of vision with improved contrast sensitivity. She emphasizes that a miotic must be used and a small iridectomy be performed, as needed when implanting all anterior chamber lenses. These are very delicate lenses and the haptics can be easily broken. Their cost is around US$700.00.

Calculation of Size

This is a most important measure to take with the use of the Nu Vita lens. Meticulous calculation of size is essential so as to avoid inserting a lens that is too small. **Dr. Arbelaez** measures the limbus from white-to white and adds 1.0 mm. The need for exact size measurement contrasts with the Artisan lens which has the advantage of one-size fits all, although it is more difficult to implant than the Nu Vita lens.

Presence of Large Astigmatism and High Myopia

In these patients**, Arbelaez** inserts the Nu-Vita lens first and later follows with LASIK in a second stage to correct the astigmatism.

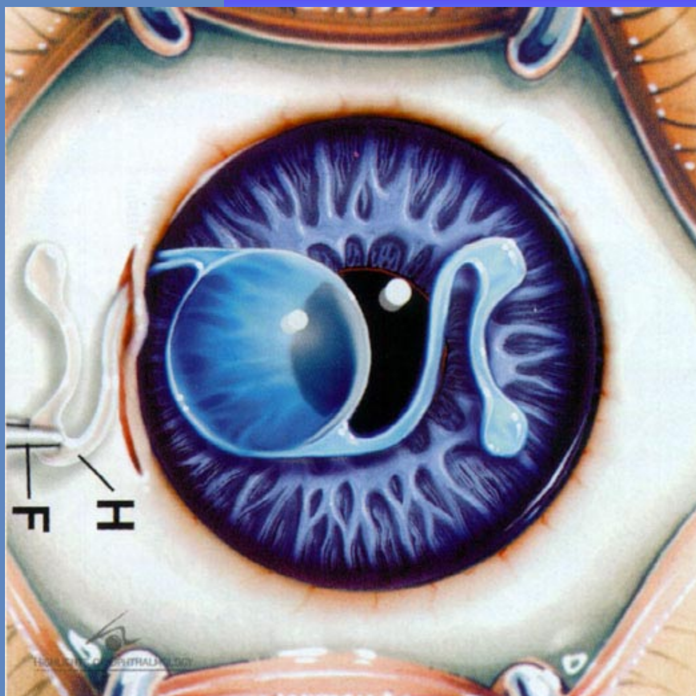
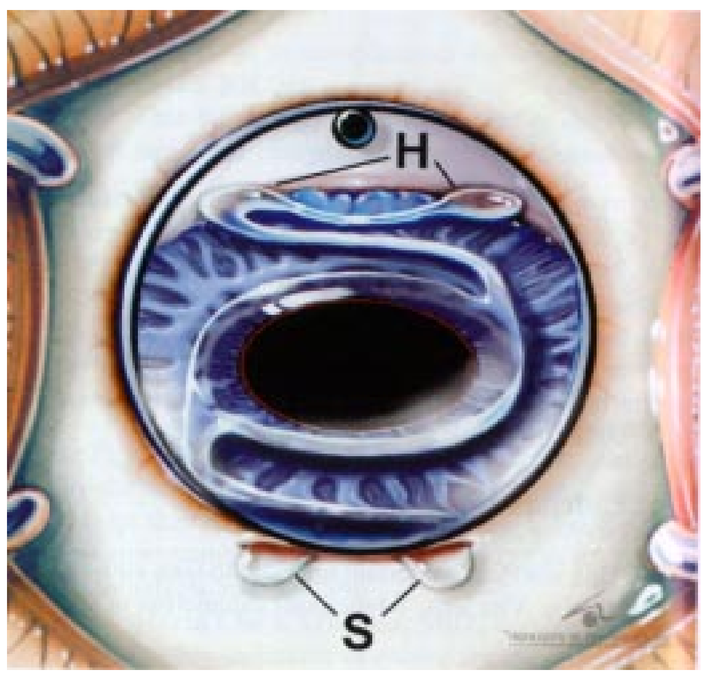


Figure 121: Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 2

The forceps retain a grasp on the optic and the IOL is placed into the anterior chamber (arrow). The forceps (F) are repositioned to grasp the elbow (H) of the proximal haptic and the IOL is continued into the anterior chamber (arrow). This technique avoids the insertion of an instrument into a phakic eye all the way into the pupillary area. The distal footplates are directed toward the angle. The proximal haptic is then placed in the incision, but the proximal footplates remain outside the eye.

Figure 122: Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 3

A check of the position of the distal footplates is made with a gonio prism. This is done to check that there is no tucking of the iris peripherally. Note that the footplates (H) are indeed in the correct location in the angle with no iris tuck. The proximal fooplates (S) are still outside the incision at this stage.



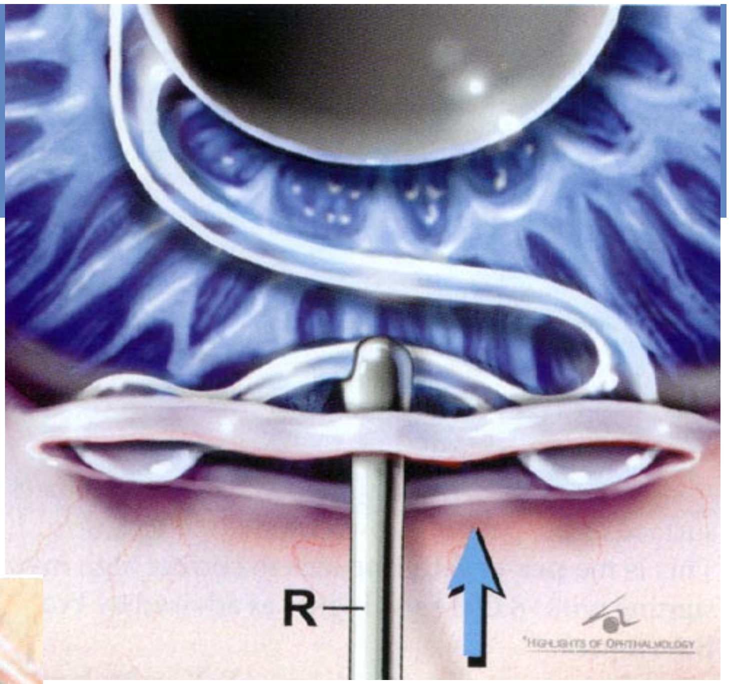


Figure 123 (above right): Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 4

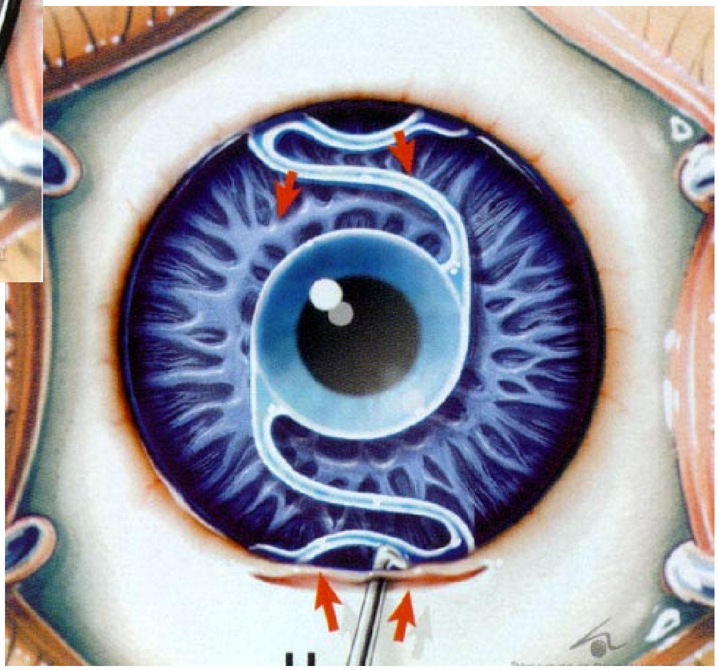
A forked or collar-button IOL manipulator (R) is positioned on the curved bridge of the haptic between the two footplates. The entire haptic is then pushed into the eye (arrow) and under the posterior edge of the incision. The footplates are placed into position. This technique avoids insertion of a forceps into the phakic eye and eliminates a second instrument for opening the incision and putting the footplates in place.

Figure 124 (left): Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 5

A gonioscopic mirror is used to check the position of the proximal footplates, and to ensure that there is no iris tuck. The distal footplates are also checked again with the gonio prism to ensure that they have not been displaced during placement of the proximal haptics.

Figure 125 (below right): Insertion Technique of the Nu-Vita Anterior Phakic Chamber Intraocular Lens - Step 6

A Sinskey hook or cystitome (H) is used to retract and reposition any footplates which are not correctly placed. Each of the four footplates can be manipulated individually (arrows) by engaging the haptics in the positions shown. An iridotomy is performed, any viscoelastic irrigated out and the incision closed with 2 or 3 sutures (not shown).



THE POSTERIOR CHAMBER PLATE LENSES

THE BARRAQUER PRE-CRYSTALLINE LENS

In the search to correct **high myopia** above -8.00 and -9.00 D with methods other than excimer laser (LASIK) Professor **Joaquin Barraquer, M.D., F.A.C.S.,** developed in 1995 an ingenious technique for the implantation of an **ultra delicate** PMMA phakic lens between the posterior surface of the iris and the anterior surface of the patient's own crystalline lens (Fig. 133). This is the **pre-crystalline** lens to correct high myopia, starting with -8.00 D and higher as advised by Professor **Barraquer.**

The reasons for avoiding LASIK in **high myopia** have already been outlined: lower quality of vision and contrast sensitivity than with phakic IOL's, in addition to the other occasional problems inherent to the LASIK technique.

Barraquer has implanted these lenses in 183 eyes since 1995 with the valuable collaboration of **Dr. Mercedes Uxo.** A **thorough and meticulous follow-up** and analysis of each case has been performed. **Fig. 126** shows how this lens fits into the pre-crystalline space and corrects high myopia.

Historical Significance

Historically, we must keep in mind that **Joaquin Barraquer,** Director of the Barraquer Ophthalmological Center in Barcelona, and Professor of Ocular Surgery at the Autonomous University of Barcelona, Spain, after becoming a world recognized leader in the implantation of anterior chamber lenses over 30 years ago, was the first one to report through multiple lectures and world literature the complications that he was observing with these lenses after several years of successful implantation.

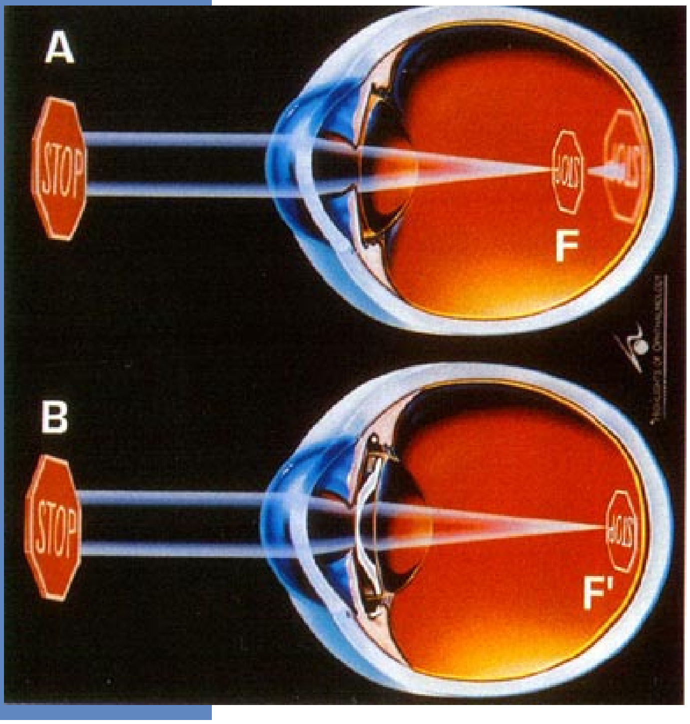
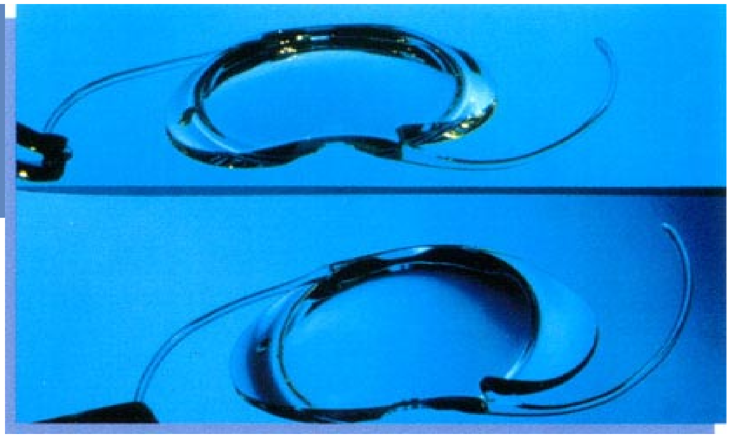


Figure 126: Optical System of Highly Myopic Patient with Pre-Crystalline Posterior Chamber IOL Versus Human Lens Only

(A) The top figure shows refraction in high myopia with the focal point of the image (F) anterior to the retina. The image is blurred. (B) The lower figure shows the post-op refraction with pre-crystalline lens in place, with the image focusing (F') on the retina.

Figure 127: The Barraquer Pre-Crystalline Posterior Chamber Lens

The second generation lens is shown at the top. The third generation lens, which is Barraquer's current choice, is shown below. There is a slight difference between the two lenses. The third generation lens has a 9 mm instead of the 8 mm length of the second generation lens. The design of the third generation lens with two 1.5 mm plates above and below prevents capture of the lens by the pupil. The other characteristics are the same for both lenses: optics are 6 mm in diameter, flexible haptics up to 14 mm in diameter. In both lenses the channels of circulation of aqueous between the posterior surface of the IOL and the anterior surface of the crystalline lens assure good aqueous humor circulation preventing a suction effect on the IOL.



The fact that after very careful consideration, he has now created a new method for the correction of high myopia based on this pre-crystalline posterior chamber IOL implant is important because of his widely respected reputation and credibility.

Description of the Barraquer Lens

The lens has evolved through three (3) generation-designs. The third generation lens has successfully overcome initial problems that presented with the first two (2) generations. The majority of the Barraquer series has been performed with the third generation lenses which began in June 1997 (120 eyes from a total of 183.)

The lens is manufactured by **Corneal W.K.** in France. It is fixated in the sulcus (Fig. 134). It has an optical diameter of 6 mm. The length of the "body" of the lens is 9 mm. It has flexible haptics up to 14 mm in diameter **(Fig. 127)** to allow adequate sulcus fixation (Figs. 132, 133). The "body" of the lens, the 6 mm diameter optic, has two 1.5 mm plates which are necessary to avoid capture of the lens by the iris when the pupil dilates. The iris glides smoothly over the plates and the optic. The periphery of the IOL remains in front of the crystalline lens and behind the iris (Figs. 133, 134).

Two lateral channels ensure communication with the posterior chamber and adequate circulation of aqueous in the space between the IOL and the anterior surface of the crystalline lens. This avoids a suction effect which could produce contact between the posterior concave surface of the myopic IOL and the anterior convex surface of the crystalline lens. The anterior surface of the IOL is slightly convex, and very smooth. The optical correction is produced by the difference in curvatures of the two surfaces of the IOL **(Figs. 127, 134)**. This design insures no interference with the normal movement of the iris and adequate separation of the implant from the anterior surface of the crystalline lens.

Advantages of the Barraquer Lens

The Barraquer pre-crystalline lens, with its 6 mm optic, prevents the patient from seeing confused images at night when the pupil dilates. Spontaneous widening of the pupil at night is particularly common in young highly myopic patients. The foldable soft lenses utilized for high myopia have a smaller central optical area and some patients seem to have problems seeing at night.

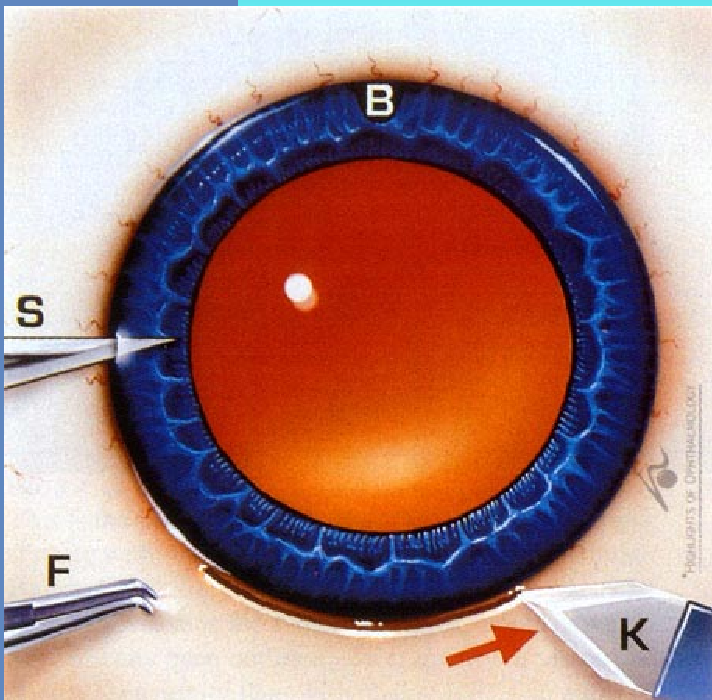
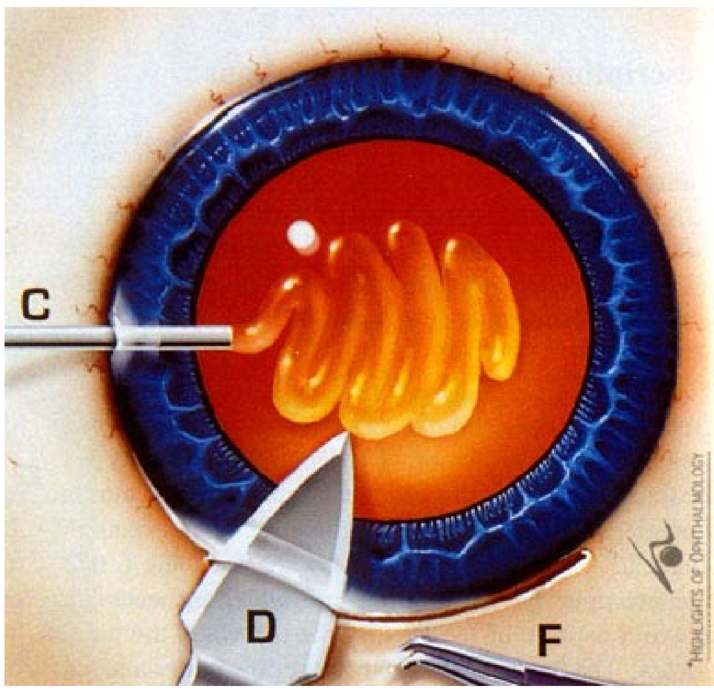


Figure 128: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Step 1

A non-penetrating perpendicular incision is performed 1mm behind the limbus with a diamond blade knife (K). The incision is shown here beginning at 2 o'clock while the blade (K) is shown at 10 o'clock. This incision is extended superiorly from 2 to 10 o'clock (arrow) for a length of 8mm. This is the first plane of the two plane incision. Fixation forceps (F). A paracentesis at the limbus is made temporally as shown with a stiletto knife (S). Note: YAG laser peripheral iridotomy (B) is performed 15 days before the operation to facilitate aqueous circulation from the posterior to the anterior chamber and avoid relative pupillary block and possible angle-closure glaucoma.

Figure 129: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Step 2

A viscoelastic substance is injected through the paracentesis via a cannula (C) to fill the anterior chamber. This will maintain the chamber depth and increase dilation of the pupil. At one end of the non-penetrating limbal incision, a horizontal beveled incision is made with a disposable keratome knife (D) shown here at 2 o'clock. This will begin the second plane of the two plane incision. Fixation forceps (F).



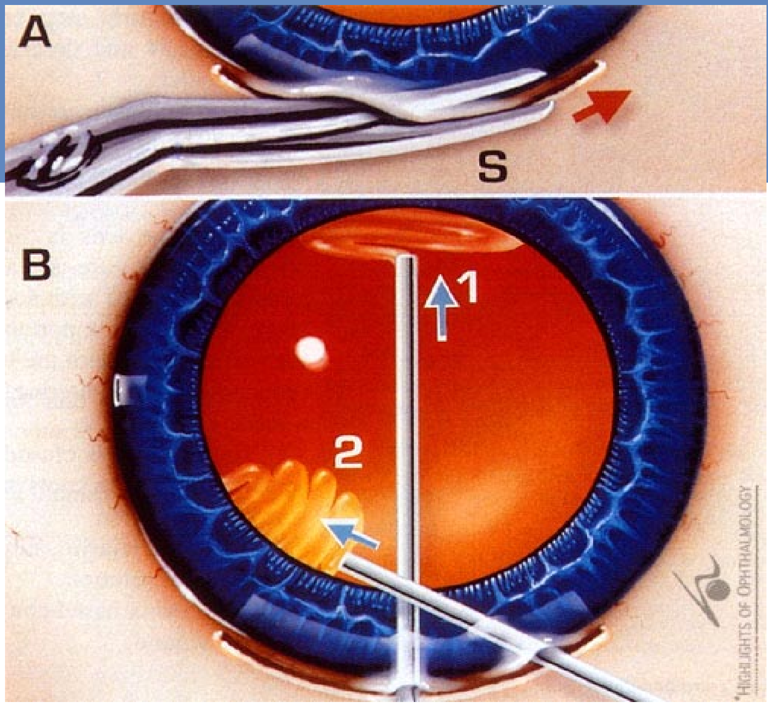


Figure 130: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Step 3

(A) The two plane horizontal beveled incision made with the keratome (D -figure 6) is completed (red arrow) with Jose Barraquer's scissors (S) in the deep layers of the groove. (B) Viscoelastic is introduced with a cannula behind the iris, in front of the crystalline lens, toward the ciliary sulcus at 6 o'clock (1-blue arrow) and then (2- blue arrow) at 2 o'clock. This will facilitate safer and easier introduction of the flexible haptics into the sulcus.

Disadvantages of the Technique

Inserting an intraocular foreign body between the posterior surface of the iris and the anterior surface of the crystalline lens certainly requires a highly skilled surgeon to prevent harming these delicate tissues. Perhaps, with time, more experience and a great deal of teaching and training of other surgeons, this technique might prove to be an important positive step in the quest for a method that is certainly much less costly than the present Excimer procedures and would be available to more surgeons and more patients.

Surgical Technique Step by Step

1) Two weeks before the lens implantation two YAG laser iridotomies are performed (Fig. 135-A).

2) Deep general anesthesia. This has been Professor Barraquer's preferred method for many years.

3) Intravenous Mannitol, in order to obtain maximum hypotony.

4) Fornix based conjunctival flap which is provisionally sutured to the sterile drape, covering the lid margin to avoid contact of instruments and the IOL with the eyelashes.

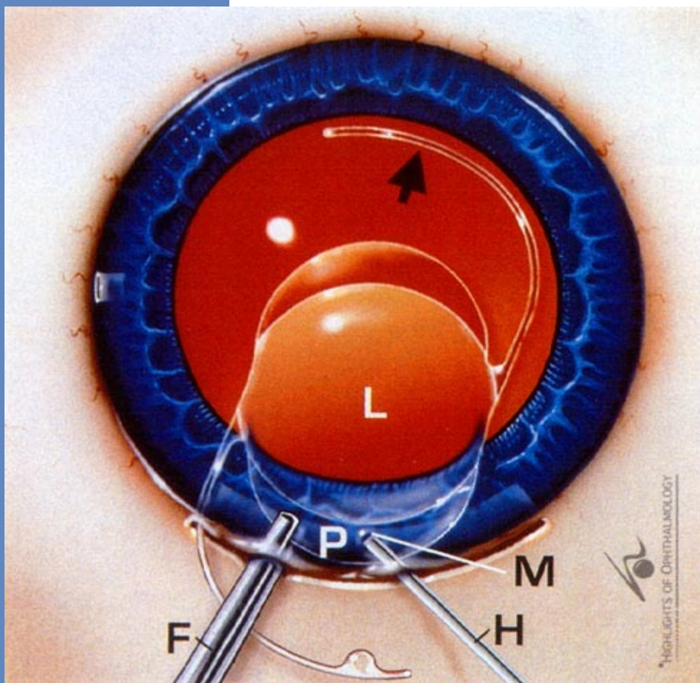


Figure 131: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Step 4

The pre-crystalline intraocular lens (L) is introduced into the eye, maintaining a plane as parallel as possible to the iris and lens planes to avoid damage to the anterior lens capsule. The intraocular lens is grasped by the peripheral plate (P) of the lens with a forceps (F), and guided with a Sinsky hook (H) placed in the manipulation hole (M) of the plate. The distal haptic is directed into the ciliary sulcus (arrow).

Figure 132: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Step 5

Once the pre-crystalline lens is inside the eye, the Sinsky hook (H) is placed through the plate manipulation hole and pushes the lens away from the incision (red arrow). At the same time, the blunt-tipped forceps (F) grasps the upper haptic at the special haptic manipulation hole. The haptic is compressed and directed behind the iris and into the ciliary sulcus (blue arrow). The Sinsky hook (H) is used to depress the optic slightly during this maneuver to assist in directing the haptic behind the iris.

5) The step by step technique is illustrated in **Figs. 128-134** and described in their respective figure legends.

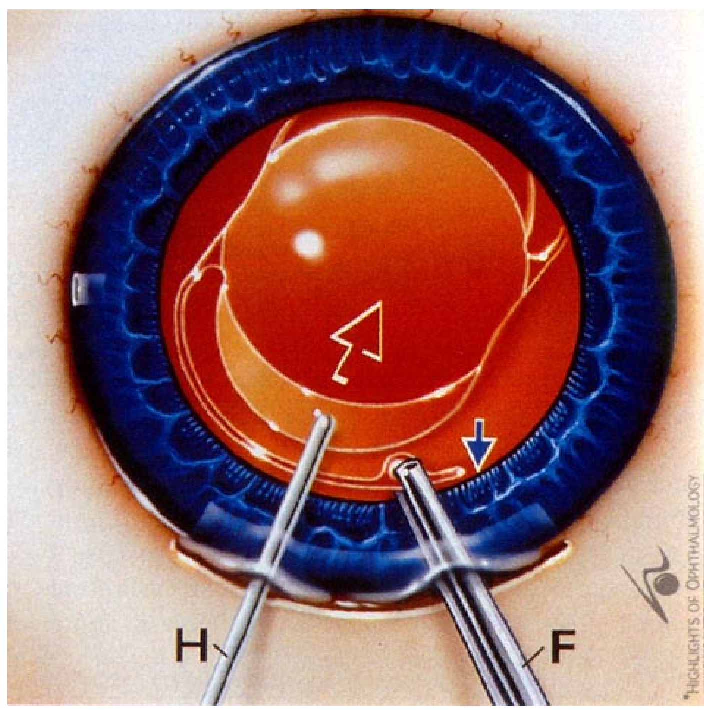
6) The viscoelastic present in the anterior chamber (Figs. 129 and 130) and behind the iris at 6 o'clock and 2 o'clock serves as a protective and anti-trauma lubricant.

7) When the lens is "in situ" (Fig. 134), one (10-0 nylon) suture is placed in the wound and miosis is obtained with acetylcholine 1%. At this stage, it is always important to carefully "depress" the anterior surface of the IOL with the cannula, in order to help in centering the IOL and obtaining miosis.

8) The incision is closed with 7 or more 10-0 nylon sutures. The knots are buried on the corneal side of the incision

9) The viscoelastic substance is replaced by balanced salt solution.

10) The fornix based conjunctival flap is sutured over the wound.



How to Order a Custom-Made Lens for Each Patient

Barraquer and **Uxo** send the manufacturer (Corneal WK) the following clinical information to obtain a lens which is custom made for each patient. This is necessary because of the very high power lenses needed.

1) Visual acuity without refractive correction.
2) Visual acuity with spectacle or contact lens correction;
3) Spectacle prescription and vertex distance.
4) Refraction with the autorefractometer.
5) Axial length.
6) Depth of the anterior chamber.
7) Keratometer readings.
8) Corneal topography.

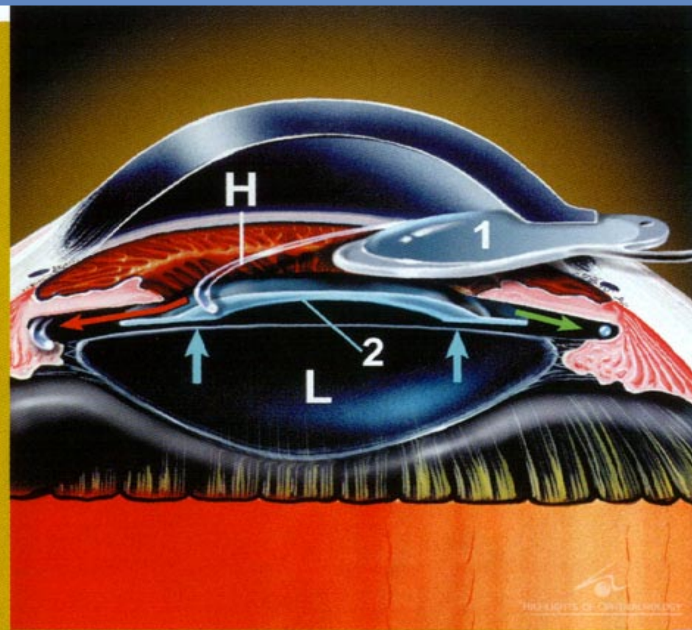


Figure 133: Side View of Implantation Maneuver of Barraquer's Pre-Crytalline Lens

The implantation technique shown in Figs. 131 and 132 as surgeon's view is presented here as a side view. It provides a graphic demonstration of how the lens glides into the very narrow space between the postgerior surface of the iris and the anterior surface of the patient's own crystalline lens. (1) Represents the lens optics, (H) the haptics being inserted to rest in the sulcus (red arrow). (2) Shows the lens finally in place with the two blue arrows pointing toward the lens. (L) is the patient's own crystalline lens. The green arrow demonstratges how the other haptic is inserted in the sulcus.

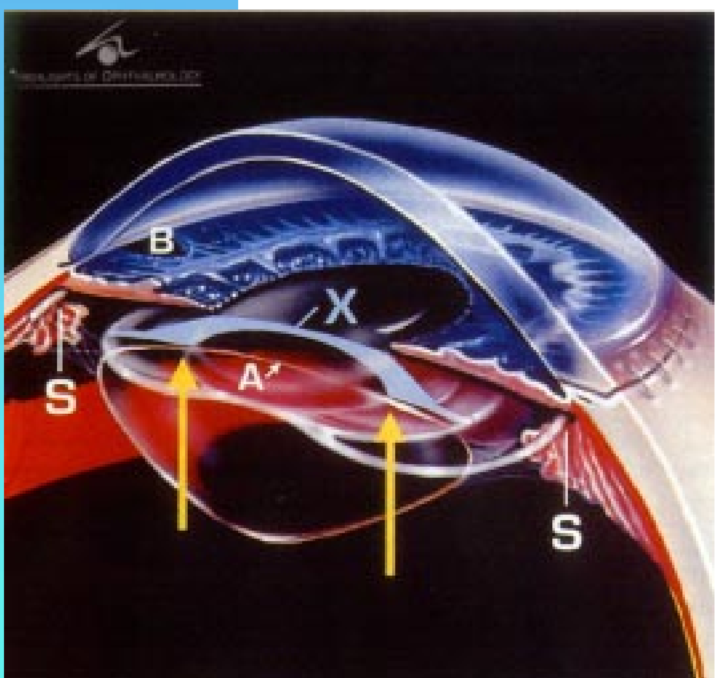


Figure 134: Barraquer's Pre-Crystalline Posterior Chamber IOL Implantation Technique - Final Configuration

This oblique cross section view shows the final three-dimensional configuration of the pre-crystalline IOL in place. Note that the incision is closed with 9 or 10 interrupted corneo-scleral sutures. A section of the IOL is shown in cross section (X) to see its relationship to the anterior capsule (A) of the natural crystalline lens. The IOL does not come into contact with the natural lens except for two small areas near the periphery (arrows). Haptics (14mm) are properly placed in the ciliary sulcus (S). Note YAG laser peripheral iridotomy (B).

Where Is the Barraquer Lens Available

This lens is available through the following company: CORNEAL, oupe W.K*.; Parc d' Activities Pré Mairie; B.P. 13; F-74371 PRINGY Cedex, France - FAX Nº: 33-04 50 27 26 89.

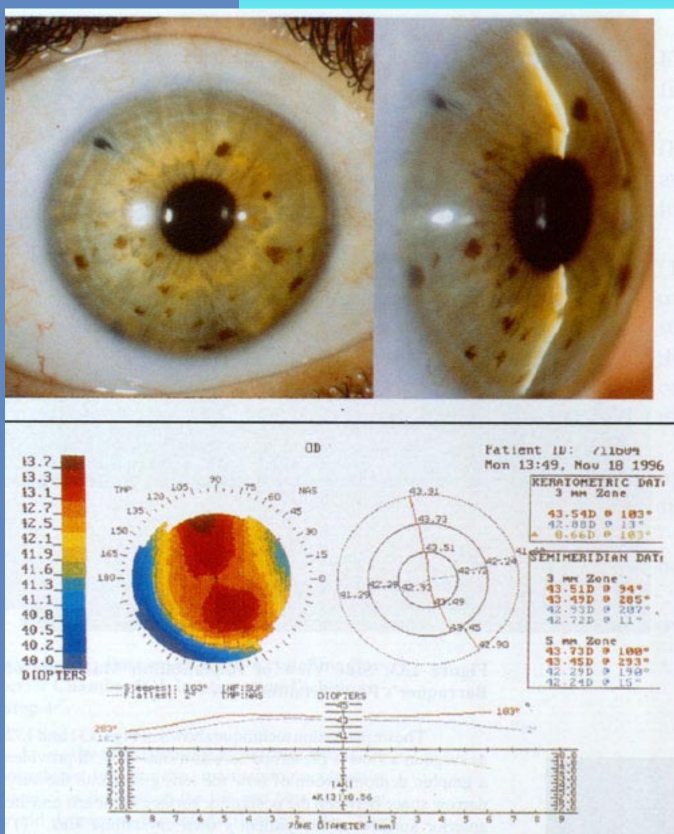


Figure 135 A-B: Postoperative Quiet Eye with Intact Pupil and Small Astigmatism Following Barraquer's Technique for Pre-Crystalline IOL Implantation

Figure 135-A (above) shows a highly myopic right eye in the preoperative stage. The patient is 39 years old, visual acuity is 0.5 (20/40) J1 with a correction of -23.00 -1.00 x 35º. A YAG laser iridotomy at 10 o'clock was performed 15 days preoperatively. Fig. 135-A (right) shows the same eye 9 months postoperatively with a visual acuity of 0.9 (20/20-) J1 with good accommodation to read without spectacles. Please observe that there are no keratic precipitates over the surface of the pre-crystalline lens nor the anterior capsule of the crystalline lens of the patient. The anterior chamber is normal. Good pupillary light reaction. Applanation tonometry 11 mm Hg. Figure 135-B (below) shows corneal topography of the same eye 40 days postoperatively with astigmatism of -0.66 D with the rule. The postoperative astigmatism 7 days postop, however, was -4.00 D with the rule. (Photos courtesy of Professor Joaquin Barraquer, M.D., F.A.C.S.)

Complications

Postoperative Lens Opacities

Using third generation lenses, subcapsular lens opacities have been observed in 3% of the 120 operated eyes. These opacities have appeared 11 to 18 months postoperatively.

The management was to remove the IOL, proceed with an extracapsular extraction of the cataract and implant a posterior chamber aphakic IOL within the bag. This resulted in excellent visual acuity.

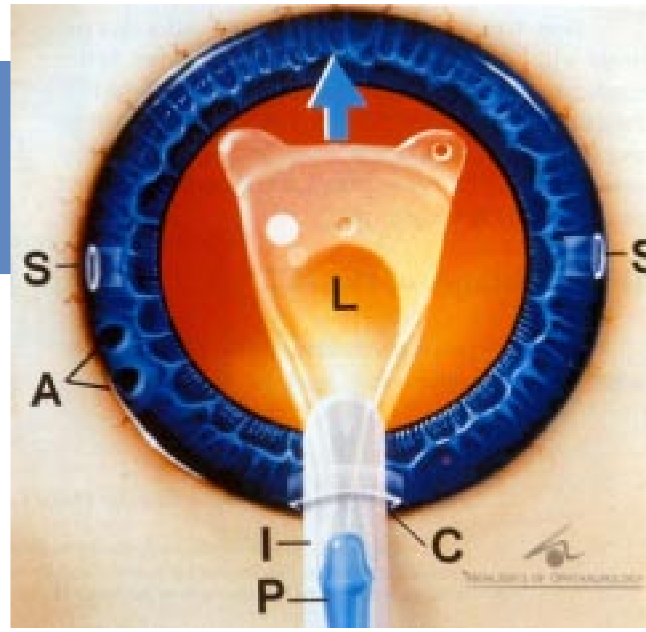
Postoperative Astigmatism

By making the incision superiorly, between 10 and 2, and placing adequate tension on the sutures, the wound is hermetically sealed. In the early stages postoperatively a -4.00 diopter with the rule astigmatism or even higher is initially seen (Fig.135-A). This astigmatism is spontaneously reduced to -0.75 or -1.00 D with the rule upon healing of the corneo scleral incision (Fig. 135-B). If the astigmatism persists, the sutures can be cut with the YAG laser 3 months postoperatively.

Joaquin Barraquer believes that the low postoperative astigmatism (Fig. 135-B) is the result of a well healed incision done in two planes at the surgical limbus (corneo-scleral), very precise suturing and eventually cutting any remaining suture causing traction 3 months postoperatively.

Figure 136: Foldable Posterior Chamber Phakic Lens (ICL) - Insertion Technique - Step 1

A double YAG laser peripheral iridotomy (A) to avoid iris blockage, is performed the week prior to lens implantation in order to avoid iris pigment deposition on the lens. Iridotomies would be very difficult to do intraoperatively because of the widely dilated pupil. First, a 3.0mm temporal clear corneal incision (C) is performed, as well as two side port incisions (S) 90 degrees away from the main incision and 180 degrees away from each other. The chamber is filled with viscoelastic material (not shown). The foldable posterior chamber lens will be placed between the iris and natural lens. The folded lens (L) is inserted into the eye via the special inserter (I) which has been placed through the corneal incision. A plunger (P) inside the inserter pushes the distal haptics of the ICL into the anterior chamber (arrow) while unfolding as shown. The lens haptics will be placed in the posterior chamber later. This illustration is shown from the surgeon's point of view as he/she is operating. The lens is implanted from the temporal side of the eye.



THE POSTERIOR CHAMBER FOLDABLE PLATE PHAKIC LENS

(The Implantable Contact Lens)

This is an ingenious development originally known as the **"Implantable Contact Lens" (ICL)** or foldable, soft pre-crystalline lens as pioneered by **Ricardo Guimãraes, M.D.,** in Brazil and **Roberto Zaldivar, M.D.,** in Argentina. It is manufactured by the Swiss company, Staar Surgical. The original name of ICL was chosen to differentiate this lens from the posterior chamber intraocular lens (PCIOL). The critical feature of this lens is the new material of which it is made: a mixture of hydrogel and collagen polymer, which is called a **collamer.** It is very permeable and hydrophilic. The ICL is placed between the iris and the natural crystalline lens.

It is soft and very thin - only 100 microns in thickness, as compared to the 1 mm required for a 30 diopter power silicone lens. Although this lens is fitted in the posterior chamber, it does not lie on the surface of the crystalline lens. A space that varies between 100 and 150 microns exists between the capsule of the crystalline lens and the new ICL (Fig. 137-B). This space allows for circulation between the two. This new lens is so thin that almost no pigment movement occurs in the eye.

Many surgeons refer to this lens now as a posterior chamber **foldable** phakic lens, to avoid confusion by the term "implantable **contact** lens."

Indications

Guimarães recommends this lens for the young adult patient with myopia higher than -10 diopters as the first option and for every case of hyperopia over +3 D.

Zaldivar, who has limited his practice to refractive surgery and has extensive experience with all refractive procedures prefers its use for patients with more than 10 diopters of myopia or more than 4 diopters of hyperopia. With this lens **Zaldivar** can correct up to 20 diopters of myopia and up to 12 diopters of hyperopia.

ICL vs LASIK

Both **Guimarães** and **Zaldivar** consider that patients with myopia less than -9 D diopters are better candidates for laser in situ keratomileusis (LASIK). Patients with more than -10 D myopia suffer from glare and have poor contrast sensitivity after LASIK. They prefer to use ICL rather than LASIK in the group of patients with high ametropias.

Disadvantages of the ICL

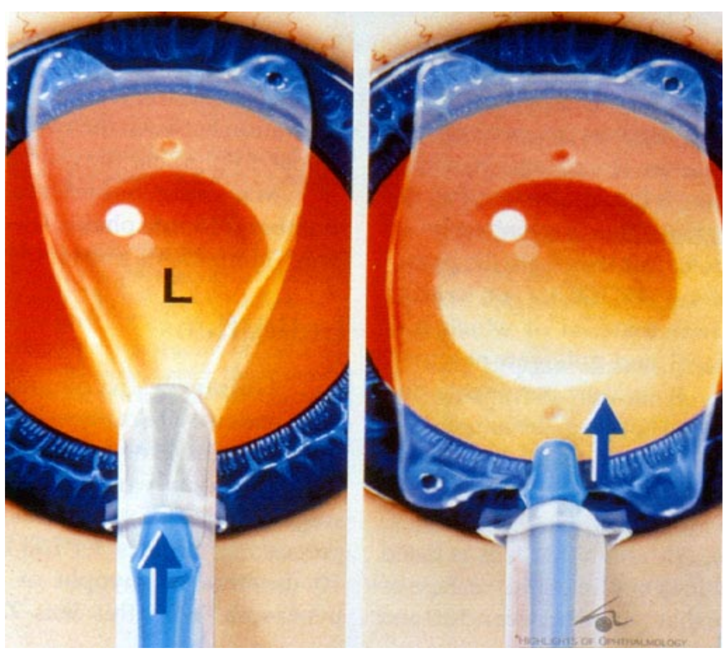
There are two main disadvantages: 1) it is a somewhat risky procedure and must be done by a very experienced surgeon so as to avoid harming vital surrounding tissues, especially the crystalline lens (Figs. 137-B and C; 138-B, 139) and; 2) it has high cost. The lens itself, which is manufactured in Switzerland, costs about $700. The final cost of dispatching and courier not including import tax is about $800. Obtaining the lens from the manufacturer takes about 1 month.

Description of the Lens

It is identified by Staar Surgical as the IC 2020. It has a flat, very delicate plate (optics) with very thin haptics and a 5 mm meniscus optic (Figs. 137 B-C). It is **foldable** (Figs. 137 A-C). It is inserted through a 3 mm wide, temporal clear corneal incision with an internal corneal valve.

Figure 137 A: Foldable Posterior Chamber Phakic Lens (ICL) - Insertion Technique - Step 2

The lens (L) is shown unfolded further as the plunger pushes (arrow) the lens out of the inserter and into the anterior chamber. This illustration is shown from the surgeon's point of view as he/she is operating. The lens is implanted from the temporal side of the eye as shown in Figs. 137-B and C.



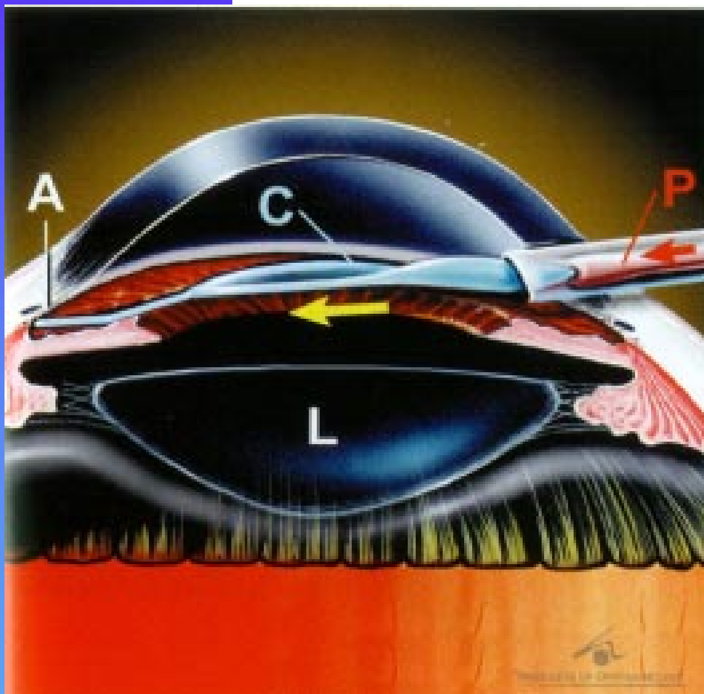
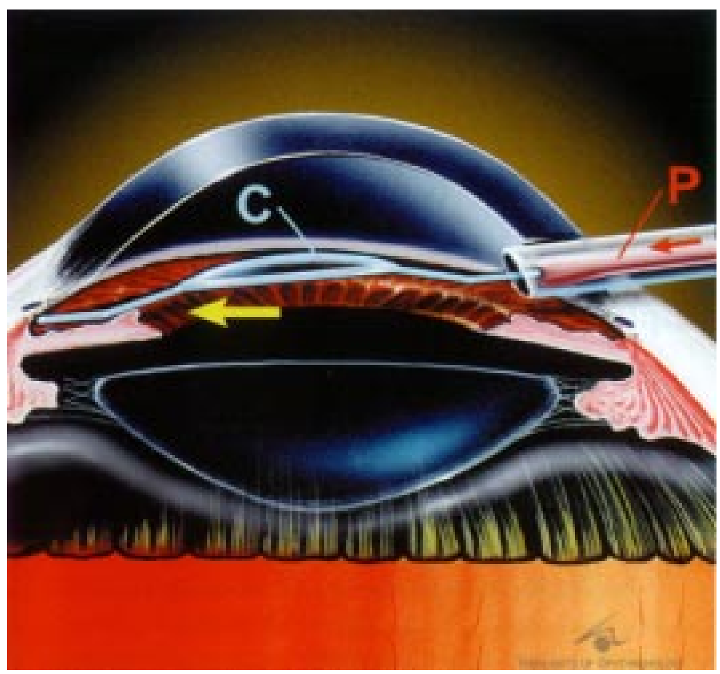


Figure 137 B: Insertion Technique of the Foldable Posterior Chamber Phakic Lens (ICL) - Cross Section View Step 2

With a viscoelastic present, a foldable posterior chamber phakic IOL (C) is placed into the anterior chamber via a special injector placed through a small corneal incision. A plunger (P) within the injector pushes the IOL out into the anterior chamber with the distal haptic directed toward the angle (A). Some surgeons add a piece of microsponge to act as a softer pusher. Note the position of the IOL (C), as it unfolds, in relation to the natural lens (L).

Figure 137 C: Insertion Technique of the Foldable Posterior Chamber Phakic IOL - Cross Section View - Step 2

The plunger (P) continues to push (arrow) the IOL (C) out of the injector until the entire unfolded lens rests on the iris in the anterior chamber. The injector is removed from the incision.



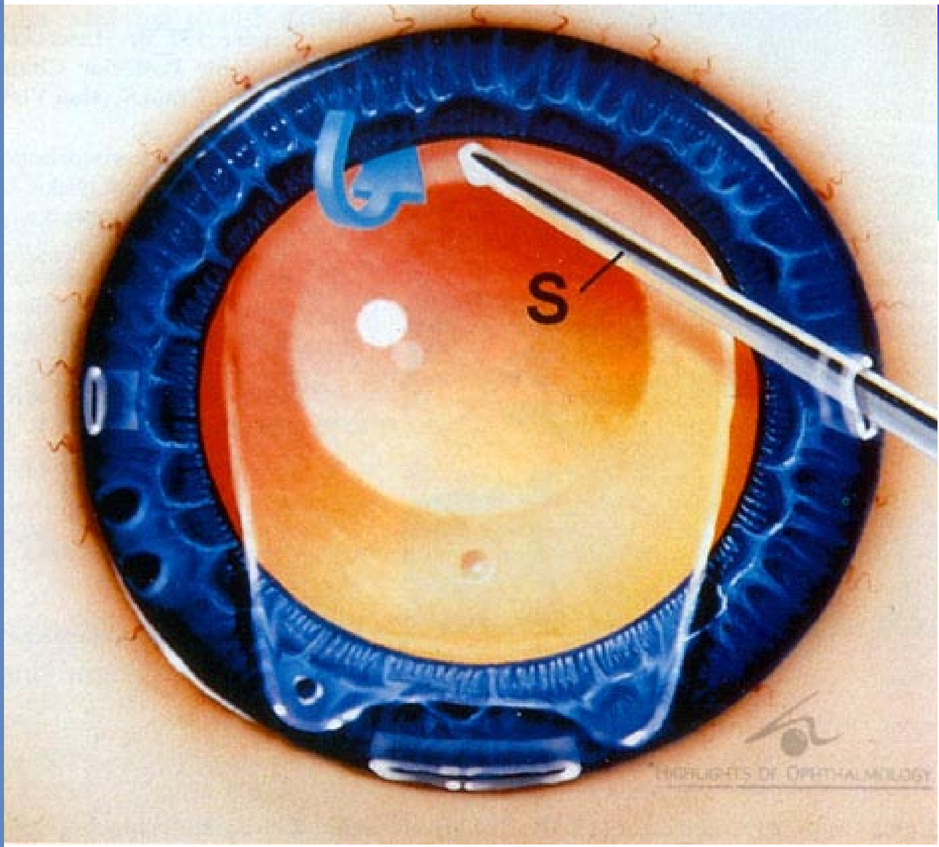


Figure 138 A: Foldable Posterior Chamber Phakic Lens (ICL) - Insertion Technique - Step 3

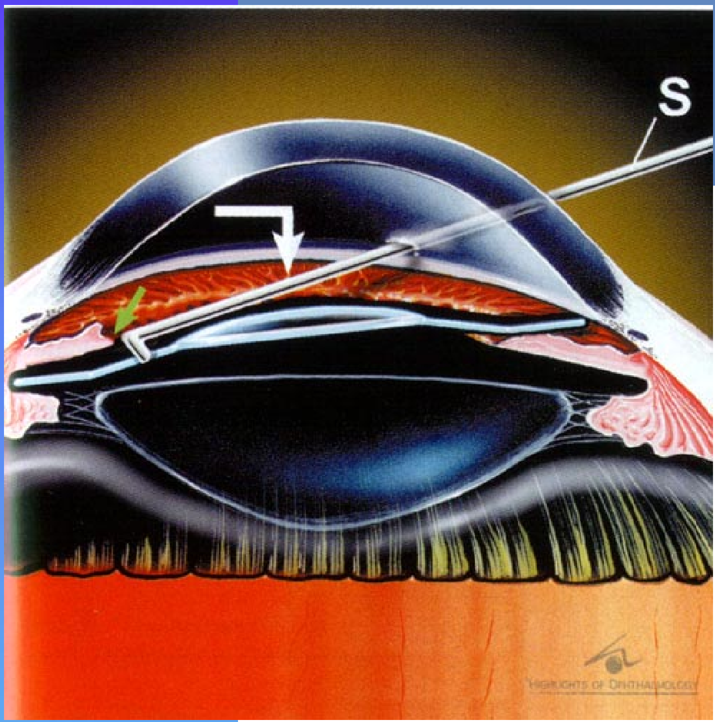
The distal haptics of the ICL are placed in behind the iris before the proximal haptics. With a spatula (S), inserted through one of the side ports, the distal extremity of the ICL is gently pushed (arrow) into the posterior chamber, to the ciliary sulcus. The same movement is used to place the proximal haptics into the posterior chamber. This illustration is shown from the surgeon's point of view as he/she is operating. The lens is implanted from the temporal side of the eye as shown in Fig. 138-B.

Implantation Technique

One week previous to the surgery, two peripheral iridectomies are performed using the YAG laser, to avoid pupil blockage (Fig. 136). They are done one week before surgery because they are difficult to do intraoperatively when the pupil is dilated. The iridectomies are performed very close to 12 o'clock.

Implanting the lens requires a 3 mm temporal clear corneal incision (Fig. 136). The lens is so thin that it can be folded and inserted through this very small incision (Fig. 137 A). The surgical technique must be very smooth. A temporal corneal tunnel incision is made followed by two paracentesis. Then the chamber is filled with viscoelastic. The pupil must be very dilated. The lens must be folded in a special cartridge and injected very slowly inside the eye (Figs. 136, 137 A-C).

The recently redesigned lens injector has a sponge attached to the plunger that facilitates insertion, prevents air bubbles and allows better lens positioning. Insert the plunger and release the lens. Place the haptics beneath the iris with a spatula without applying any pressure to the optic (Figs. 138, 139).



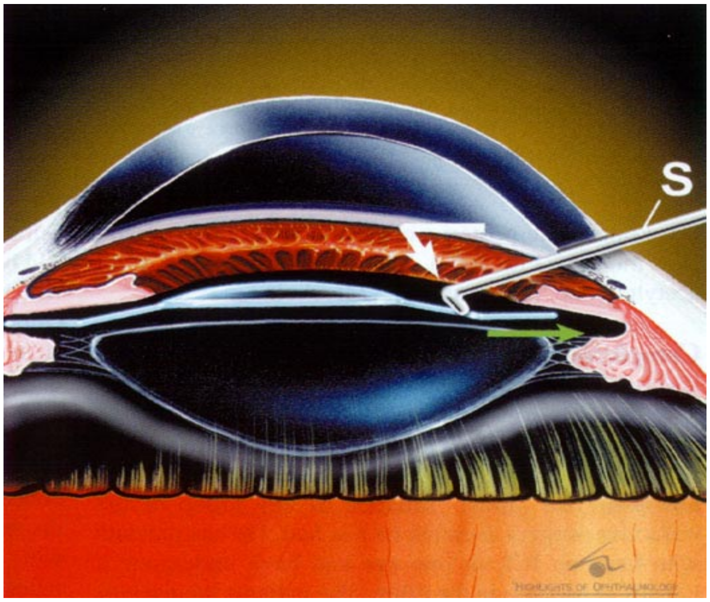
As the lens is injected, it slides on the surface of the crystalline lens because the iris is very dilated. The lens unfolds (Fig. 137 A). When the lens is floating on the viscoelastic on the surface of the crystalline lens, the surgeon must introduce the four small haptics or footplates behind the iris and in the sulcus (Fig. 138 A, B). When the haptics are in place behind the iris (Fig. 139), the pupil is constricted, leaving the lens lying in the posterior chamber, and the viscoelastic is removed (Fig. 140). The pupil is treated with acetylcholine. **Zaldivar** uses Miochol.

Figure 138 B: Insertion Technique of the Foldable Posterior Chamber Phakic Lens (ICL) - Cross Section View - Step 3

A special spatula (S) is inserted through one of the prepared side ports and engages the distal footplate of the IOL. The spatula (white arrow) pushes the distal footplates directly behind the iris (green arrow) and into the ciliary sulcus.

Figure 139: Insertion Technique of the Foldable Posterior Chamber Phakic Lens (ICL) - Side View - Step 4

The special spatula (S) then engages the proximal footplates of the IOL. The spatula (white arrow) pushes the proximal footplates directly behind the iris (green arrow) and into the ciliary sulcus.



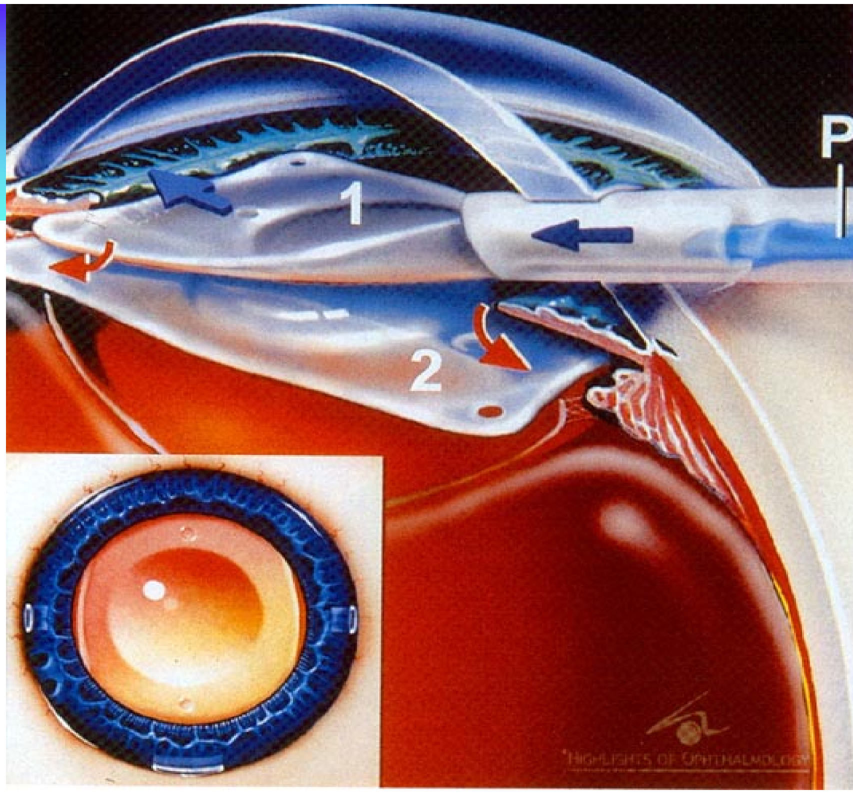


Figure 140: Conceptual Cross Section of All Stages for Implantation of a Foldable Posterior Chamber Phakic Lens (ICL)

This conceptual cross section shows the insertion and unfolding of the (ICL) compared to the final configuration of the ICL in position behind the iris and in front of the crystalline lens. (1) The plunger (P) inside the inserter pushes the distal haptics of the ICL into the anterior chamber (blue arrows) while unfolding as shown. (2) In separate maneuvers, the haptics are then placed (red arrows) into the posterior chamber behind the iris and into the ciliary sulcus. The iris will then be constricted. The inset shows a surgeon's view of this final configuration.

This illustration is a section of the eye taken from 3 to 9 o'clock, as the ICL is inserted through the temporal approach.

Complications

In a group of 160 human eyes (patients), operated by Guimarães there have been no complications from the ICL. In fact, he has observed that this patient group has been the most satisfied of any group of the refractive surgery patients he has had. He has patients who have an ICL in one eye and have undergone a LASIK procedure in the other. The patients themselves can compare the results. Even though the correction using the ICL was much higher, patients said they had better vision in the eye with the ICL than the one on which the corneal refractive procedure was performed. Guimarães considers that the ICL is reliable because it is reversible and offers predictability and high quality.

Zaldivar began to work with this lens in 1993. After 4 years of follow-up, no patient from the original group has developed cataracts. At first **Zaldivar** was concerned about the possible development of pigment dispersion glaucoma because of the contact of the iris with the lens, but the first lenses of this type were redesigned and improved. This new lens is so thin that almost no pigment movement in the eye occurs.

CHAPTER 6

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Surgical Management of Hyperopia

CHAPTER 7

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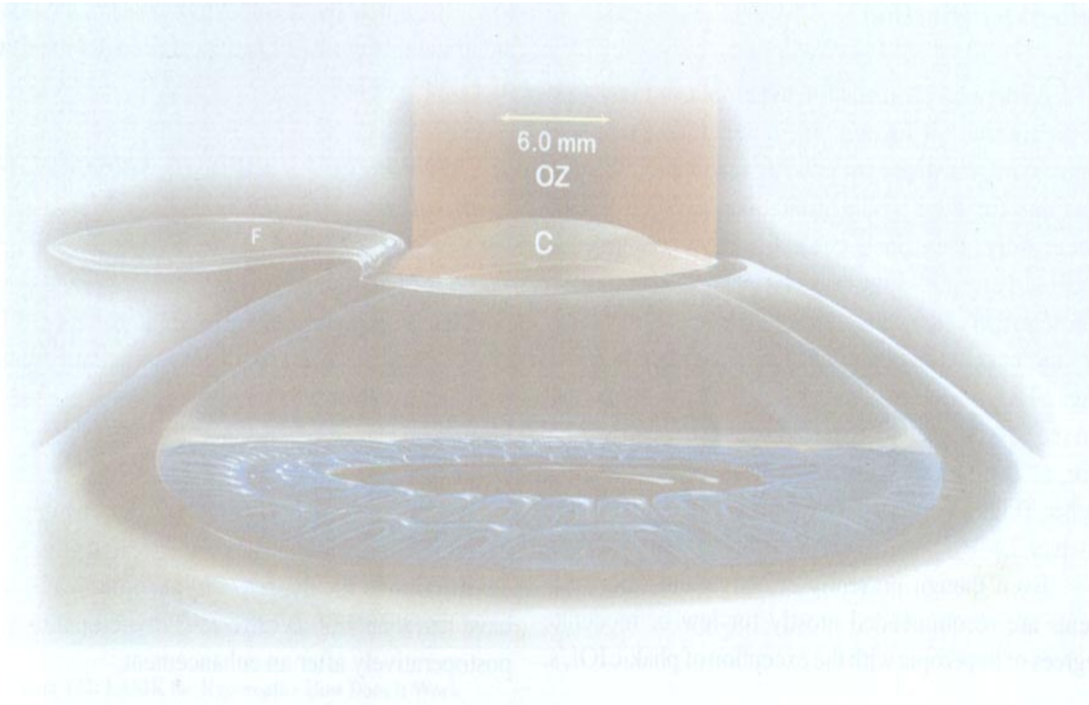
HIGHLIGHTS OF OPHTHALMOLOGY



HYPEROPIA: EFFECTIVE SOLUTIONS

Hyperopia has been one of the two refractive errors traditionally resistant to effective and lasting surgical treatments. The results until recently were unpredictable and treatment was frequently followed by regression or gradual loss of effects. The other "resistant" refractive error is presbyopia.

Most Accepted Options

The methods most accepted at present for surgically managing hyperopia are:

1) **LASIK** (Excimer laser), which is the first choice in low to moderate hyperopia from +1 up to +5 D. It is recommended not to go above +5 D because thereis los in quality of vision.

2) **PRK** in low and moderate hyperopia from +1 to +4 D.

3) **Phakic Intraocular Lenses,** particularly the **Artisan** lens, in hyperopias of +4 to +10 D and the **ICL** (posterior chamber plate lens) from +3 to +10 D.

4) **Laser Thermokeratoplasty,** from +1 D to +2 D (Fig. 147). This procedure is still in stages of evaluation but **looks promising**.

Richard Lindstrom, M.D., also considers viable the use of:

5) **ICRS (INTACS)** in low hyperopia (+1 to +2 D) (Figs. 81-86). Although the ICRS is proven to be effective and is approved by the FDA for **myopias** of up to -3 D, its use in low hyperopias is still under evaluation but **looks promising**.

6) **Clear Lensectomy** and posterior chamber aphakic IOL implantation within the capsular bag in hyperopias higher than +10 D. This often requires the implantation of two or even three piggyback IOL's (Fig. 148).

Patient Satisfaction

Although treatment for hyperopia is much less advanced than for myopia, the ophthalmic surgeon is happy to manage these patients because we finally have solutions for their visual limitations. When treated successfully, they do become the most grateful and satisfied patients. **Figure 141** clearly presents why. Before surgery, the patient cannot adequately focus for far nor near without spectacles or contact lenses (Fig. 141-A). Following effective therapy, the patient can see without glasses both for far and at times even for near, as if a multifocal effect had been created in the cornea (Fig. 141-B in this chapter, and Fig. 23-E in Chapter 2.)

Even though presently effective and safe treatments are recommended mostly for low or moderate degrees of hyperopia with the exception of phakic IOL's, this is not a factor of major concern because the significant majority of patients fall under the category of +3.50 D or less.

Important Points to Consider Upon Counseling

Machat recommends some important points to consider when counseling hyperopic patients:

1) Since many patients (particularly **younger** patients) with lower degrees of hyperopia can see 20/40 uncorrected, it is best when speaking to them to talk about final refractive results.

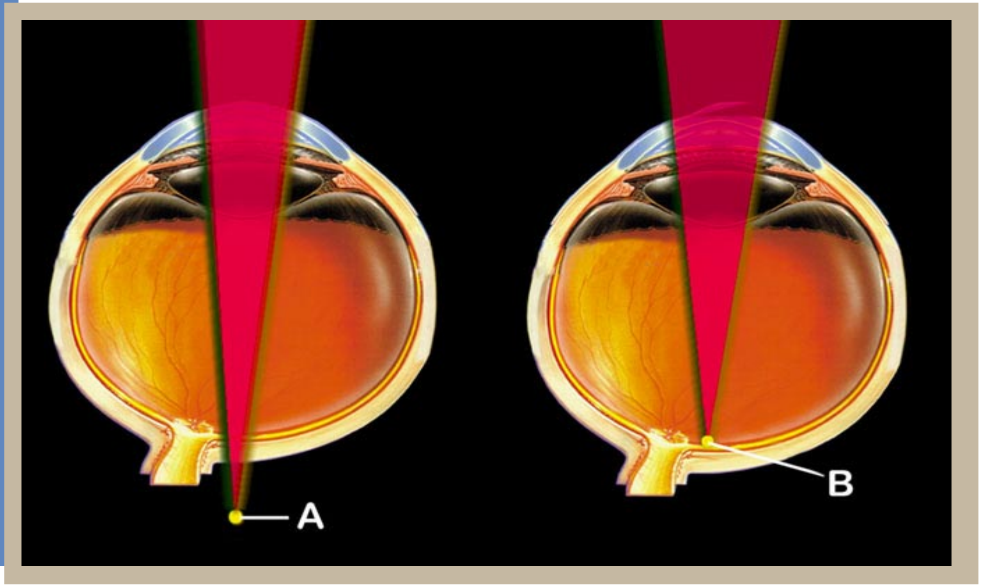
2) For patients with more severe degrees of hyperopia, one should discuss the treatment in terms of a **reduction in the degree of hyperopia.** The goal is to have less than 1.00 D of residual hyperopia remaining postoperatively after an enhancement.

3) Enhancements are typically performed earlier

Figure 141: Hyperopia - Optical Mechanism of How Vision is Surgically Corrected

The pre-op view on the left shows the patient with hyperopia when light rays (red) are focused (A) beyond the retina. The patient cannot adequately focus for far or near.

Following surgical correction (right), the steepened central corneal curvature with increased dioptric power enable the light rays (red) to be focused on the retina or even in front of the retina (B), enabling the patient to now focus well for distance and often for near.



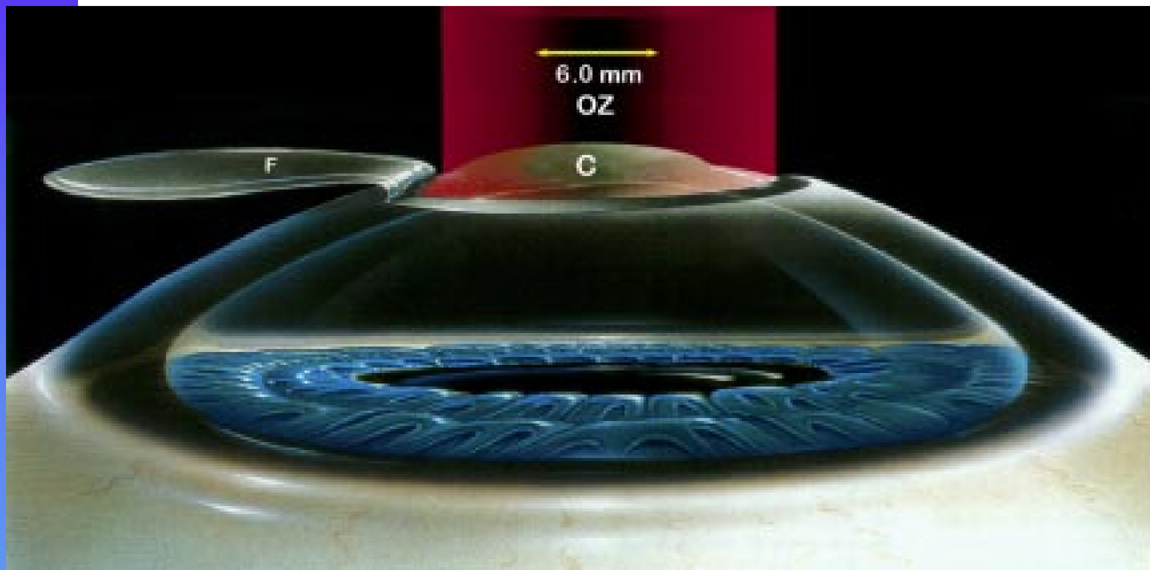


Figure 142: LASIK for Hyperopia - How Does It Work

The ablation done with the excimer laser beam, shown in red, is performed in the mid-periphery and periphery of the cornea. It is in this area that the laser subtracts or ablates tissue. The area shown in black and identified in arrows as 6 mm within the red beam is actually the central optical zone (OZ) which must be 6 mm or larger, and never less than 5.75 mm. The excimer ablation into the periphery of the cornea **begins** where the limiting diameter of the 6 mm optical zone is located. The elevated zone in the center shown in light pink and green (C) actually represents the steepening of the central cornea created by the ablation of the mid-periphery and periphery, leading to correction of hyperopia. Flap (F).

than with myopic patients, usually 6 weeks following the primary procedure.

4) We can often produce monovision, creating 1.00 D of myopia typically in the non-dominant eye, so long as the total degree of hyperopia treated does not exceed +6.00 D spherical equivalent.

LASIK IN HYPEROPIA

The treatment of hyperopia with LASIK is positively evolving and most promising. This had not been successful until recently. New computer programs and better excimer lasers are making predictable hyperopic LASIK possible. Among the surgeons who have the largest experience in managing hyperopia with excimer laser is **Carmen Barraquer, M.D.,** from Bogota, Colombia. She has developed truly effective techniques.

Fundamental Principles for Hyperopic Correction

The fundamentals of **Carmen Barraquer's** technique are based on the principle of using the laser to subtract or ablate tissue from the **mid-periphery and periphery of the cornea**. **The ideal optical zone is larger than 6 mm in diameter (Figs. 142 and 143).**

At present **Barraquer** and her colleagues are working with optical zones of 6.5 mm and 7 mm for hyperopic correction **(Figs. 142, 143).** With the 7 mm optical zone, up to 5. 5 diopters of hyperopia spherical equivalent can be corrected. With a 6.5 mm optical zone, 8 diopters spherical equivalent can be corrected.

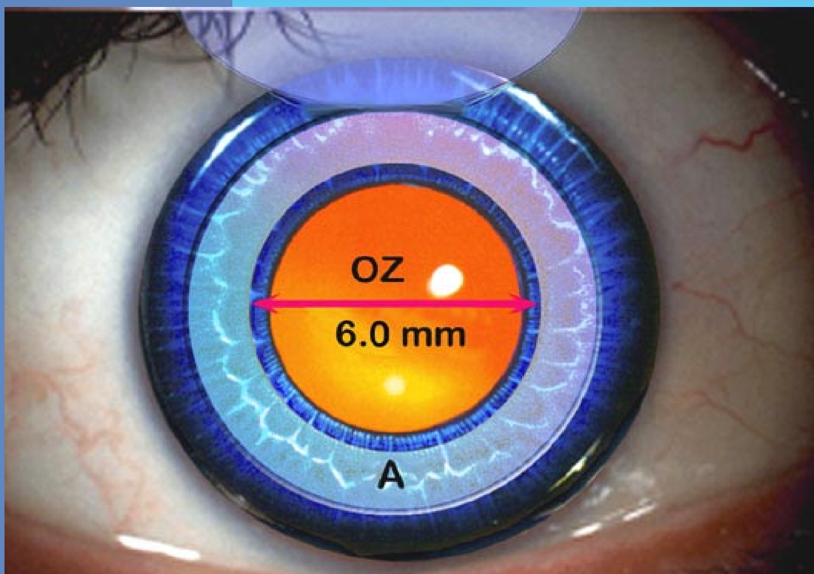


Figure 143: LASIK for Hyperopia - Ablation of Peripheral and Mid-Peripheral Cornea

The corneal flap with superior hinge has a diameter of 9.5 to 10.0 mm, certainly much larger than the flap performed with LASIK for myopia. This is now possible through more sophisticated microkeratomes.

The optical zone in the center identified by the red arrow is 6.0 mm in diameter. It always must be 6 mm or **larger**. The mid-peripheral and peripheral zone identified as "A" is the area of stromal ablation where tissue is removed with the excimer laser. The ablation of the cornea into this area "A" begins where the limiting diameter of the six millimeter optical zone is located (red arrow).

(This high correction is not, at present, recommended - Editor.) The ablation into the periphery of the cornea begins where the limiting diameter of the six millimeter optical zone is located. **The smaller the optical zone, the larger the correction obtained in hyperopia.** You can even go to a 5.85 or 5.75 millimeter optical zone if it is needed for very high corrections such as 9 diopters, but **never less than 5.75 mm** because then the patient will have poor quality of vision.

Enrique Suarez, M.D., (Caracas, Venezuela), has extensive experience with LASIK and is a pioneer in the new techniques leading to better results with LASIK in hyperopia. He considers that one of the clues to success lies on the equipment used: 1)microkeratomes that allow a **larger diameter resection of the corneal flap** and still be able to maintain the hinged disc-shaped flap reflected to expose the corneal stromal bed beneath. This corneal bed is then treated with the excimer laser (Fig. 142). 2) The much improved excimer lasers that allow such ablation in larger diameter optical zones (Figs. 142, 143, 144). With previous equipment, if the surgeon attempted to ablate farther into the periphery, he/she would sever the hinged flap, leading to serious complications.

Hyperopia vs Myopia

Major Differences in Excimer Ablation

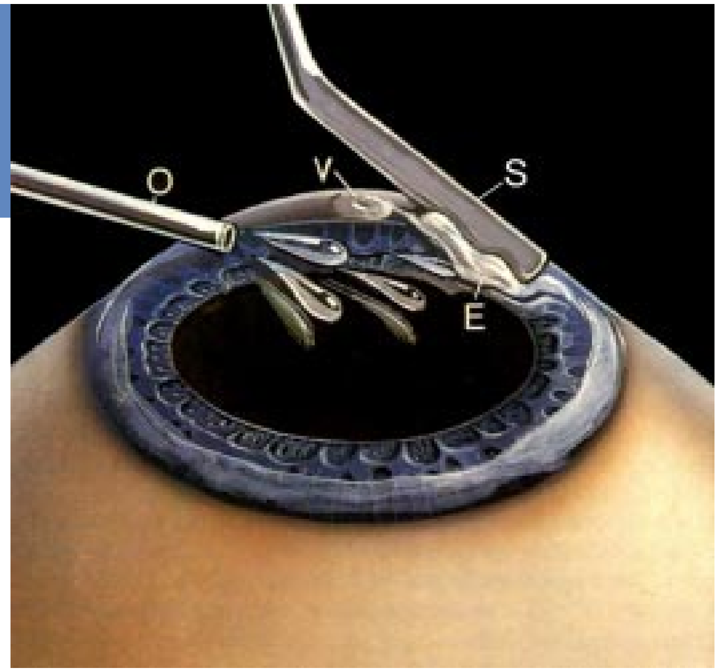
There are several key differences in the surgical principles of treatment with excimer laser between hyperopia and myopia.

1) The excimer ablation in **hyperopia** is performed in the mid-periphery and periphery (Figs. 142 and 143). The ablation into the periphery of the cornea begins where the limiting diameter of the six millimeter optical zone is located (Figs. 142, 143).

2) The excimer ablation in **myopia** is performed **within** the central optical zone 6 mm in diameter (average) (Figs. 56, 57, 58, chapter 4). Figures 59 and 60 show side by side the different characteristics of excimer laser ablation between myopia vs hyperopia.

3) The result of the excimer laser ablation in **hyperopia** is an **increased curving or steepening** of the central cornea as shown in Figs. 142, 144 and 60. This leads to correction of the hyperopia.

4) The result of the excimer laser ablation in **myopia** is an increased **flattening** of the central cornea as shown in Figs. 56, 57, 58, 59.



PRK IN HYPEROPIA

PRK may be utilized for hyperopia between +1.00 to +3.00 D, maximum +4.00 D. It is really a second choice when compared with LASIK because of the patient´s ocular discomfort associated with the procedure and the slow visual recovery.

PRK may be the procedure of choice, however, in a good number of aphakic eyes that have a tendency to be small and may be deeply set in the orbit with somewhat tight lids. This makes it almost prohibitive to use the microkeratome for LASIK.

Figure 145: PRK for Hyperopia - Removal of Corneal Epithelium

The first step in PRK is to remove the corneal epithelium (E). This is done mechanically (no chemicals) with a blunt spatula (S) and frequent irrigation with BSS (O) is done in order to maintain the stromal bed clean and uniform at the time of the laser application and tissue ablation.

In PRK the entire surface of the corneal epithelium is debrided because the diameter of the laser ablation is done precisely on the mid-peripheral and peripheral areas of the cornea, as shown in Figs. 142, 143, 145 and 60. Visual axis (V).

Surgical Technique

As in all PRK's the first step involves mechanical removal of the corneal epithelium (Fig. 145). Because the corneal ablation with excimer is located in the mid-periphery and peripheral areas of the cornea, the epithelium must be removed in the entire cornea.

Figure 144: LASIK in Hyperopia - Steepening Effect on Cornea Leading to Correction of Hyperopia

This shows in cross section what took place in Fig. 142. The central cornea has become steepened (A) following the mid-peripheral and peripheral ablation performed with the excimer laser (red). The darkened center within the red beam corresponds to the optical zone from which the ablation into the periphery begins. Dotted lines shows previous curvature.

This is followed by the corneal stromal ablation itself (Fig. 146). The parameters for excimer ablation in PRK hyperopia are the same as previously discussed for LASIK (diameter of optical zone, location of ablation in mid-periphery and periphery (Figs. 142, 143, 144, 60).

PHAKIC INTRAOCULAR LENSES IN HYPEROPIA

The significant developments with phakic intraocular lenses have been amply discussed in Chapter 6 and presented in Figs. 107 - 140 for the correction of **myopia.**

The lenses mostly used for hyperopia are the **Artisan lens** (Figs. 108-118) and the **ICL** or posterior chamber phakic foldable plate lens (Figs. 136-140). Because this is an intraocular procedure with consequent higher risks, the present trends lean toward implantation of phakic IOL's in the higher ranges of hyperopia from +3 D to +10 D.

The surgical technique is the same as that presented in Chapter 6 but there is an important change in the power of the lens, from minus to plus.

We also need to consider that many of these eyes are rather small and more difficult to operate.

LASER THERMAL KERATOPLASTY (LTK) IN HYPEROPIA

This is perhaps the first choice in low hyperopias of +1 D to +2 D. This procedure, however, still remains under evaluation.

Although thermal keratoplasty for hyperopia has been available for more than a decade, until recently, results were disappointing. New developments, however, make LTK a promising technique. The procedure has evolved from using various types of contact devices to utilizing lasers to deliver the light energy that is converted to heat. The heat results in contraction of the tissue with consequent steepening of the central cornea. (**Dr. Antonio Mendez G.** from Mexico was pioneer several years ago on the use of heat to treat hyperopia through his method "Corneal Radiodiathermy." Like most techniques for hyperopia, however, the diminution of the refractive error was not lasting because of regression - Editor).

Although a number of different lasers have been investigated, the vast majority of clinical work has been performed with the holmium:YAG laser. Two types of delivery systems are available for the holmium:YAG: 1) a contact probe holmium laser, which is the Technomed laser that is under study by Professor Jean and others in Germany and 2) a non-contact slit-lamp delivery system, as developed by Sunrise Technologies, Inc in the United States.

What Is this New Laser?

Douglas Koch, M.D., a highly credible clinical investigator at the Cullen Eye Institute, Baylor College of Medicine in Houston, has reported promising results with the **Corneal Shaping System** manufactured by Sunrise Technologies. This **non-contact** holmium YAG laser is a unique device with a slit lamp delivery system that delivers eight spots simultaneously (Fig. 147). As a result, symmetrical effects can be achieved. This attribute has made it possible to eliminate some of the problems like irregular astigmatism, which plagued the procedure when other devices were used.

The Sunrise Corneal Shaping System differs from other lasers being used in refractive surgery. It is an infrared laser that works at 2.1 microns. A separate laser unit is connected to a slit lamp delivery system with a fiberoptic cable. The patient places his or her chin in the slit lamp delivery system. The patient looks at a red light, and then the laser energy is delivered. **Koch** usually treats with two rings; each ring requires seven pulses, which takes only 1.4 seconds (Fig. 147). The procedure is extremely rapid.

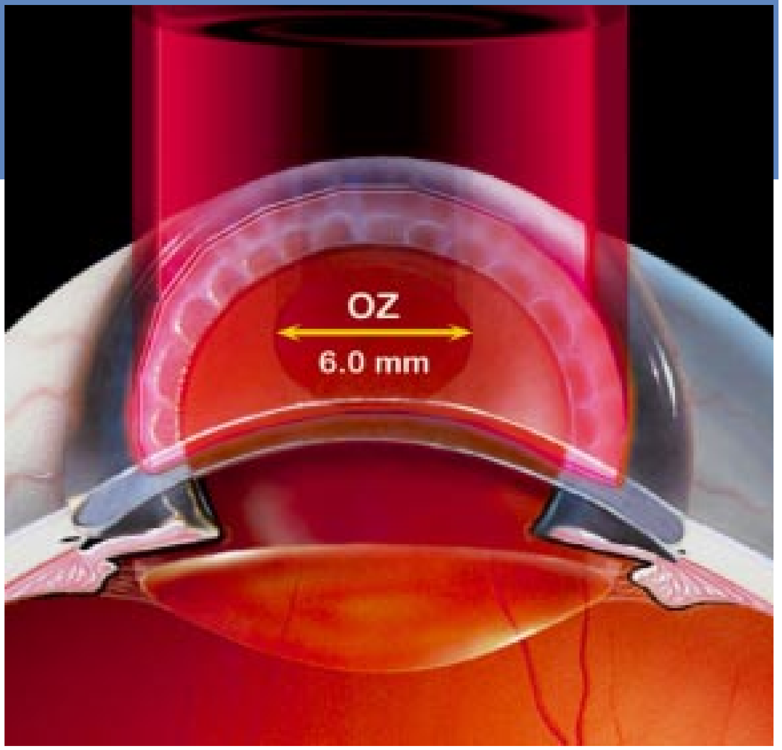


Figure 146: PRK for Hyperopia - Laser Ablation

The excimer laser beam (red) actually ablates tissue in the mid-peripheral and peripheral areas of the cornea, as opposed to laser ablation in myopia which is done in the central optical zone. The area shown in black extending through an optical zone of **no less** than 6.0 mm within the red beam is the central optical zone (OZ). Just as in LASIK, the excimer laser ablation into the periphery **begins** where the limiting diameter of the 6.0 mm optical zone is located (yellow arrow).

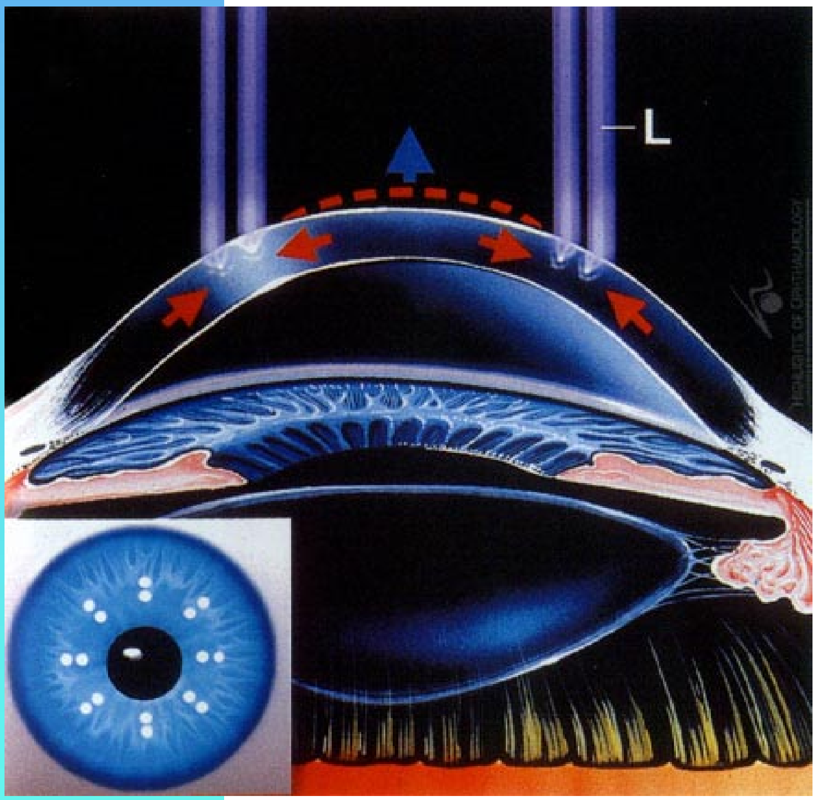


Figure 147: Concept of Noncontact Laser Thermal Keratoplasty (LTK)

Noncontact laser thermal keratoplasty for treatment of hyperopia involves delivery of holmium:YAG laser energy into the corneal stroma as spots within

Reasons for Favorable Results

Extensive work on laser thermal keratoplasty has shown that three factors help to explain the new, favorable results. **First,** most hyperopia is low hyperopia— +2 or +2.50 or less. **Secondly,** hyperopia becomes much more symptomatic as patients reach their 40's. Patients with hyperopia have different experience with refractive errors than most people. They have had excellent vision throughout their youth and through the early adult years. Then they develop premature presbyopia in their 30's (Fig. 141). All of a sudden in their 40's they also lose their distance vision. The aging of the visual function is therefore much more difficult for people with hyperopia than for people with myopia, who at least retain useful near vision. A **third** factor is that the laser seems to work much better in patients over age 40.

The fortuitous confluence of these three factors leads to favorable results. **Koch's** studies (performed in conjunction with **Peter McDonnell, M.D.,** at Doheny Eye Institute) in the U.S. have shown that, after 3 **years follow-up levels of 1.5 to 1.75 diopters of hyperopia have been corrected with the Sunrise laser. Very little regression has occurred after 6 months.** In **Koch's** and **McDonnell's** patients there was only 0.4 diopter of regression between 6 months and 2 years, and almost no regression between 1 and 3 years.

Limitations of LTK in Hyperopia with Astigmatism

In the management of low degrees of hyperopia, for which LTK seems to be quite effective in the range of +1 D to +2 D, we must keep in mind that it does not correct any important amount of astigmatism that may be present with the hyperopia.

Patient Satisfaction with LTK

Patients over 35 years of age are really "presbyopic hyperopes." They have been gradually losing vision for several years. Consequently, a return of vision with such a simple procedure as LTK is most welcome and leads to much patient satisfaction.

VERY HIGH HYPEROPIA

Clear Lens Extraction and Piggyback IOL's

Virgilio Centurion, M.D., has clarified that the piggyback intraocular lens was primarily designed for the correction of patients with high hyperopia and cataracts, especially over 30 diopters. Ophthalmologists are now using this lens system to correct patients with very high hyperopia as well.

The piggyback lens solves the problem of having to implant a lens of over 30 diopters on a very short eye. First it is almost impossible to find a manufacturer of lenses with such high power. Secondly, they yield a great optical aberration. For that reason, 3 years ago Dr. John Gayton implanted the first piggyback lens. Now we know that one, two, three, or even four intraocular lenses can be implanted inside the capsular bag because the capsular bag in normal eyes has a thickness of about 4.5 mm (Fig. 148).

Centurion has treated 12 patients with high hyperopia over 28 diopters using two implants. With the two lenses, the quality of their vision improved, with an average gain of one or two lines compared with best corrected vision before the surgery. For some reason that is not yet clear, these patients with more than one lens can correct for near vision as well, sometimes to a level of J3 or J4.

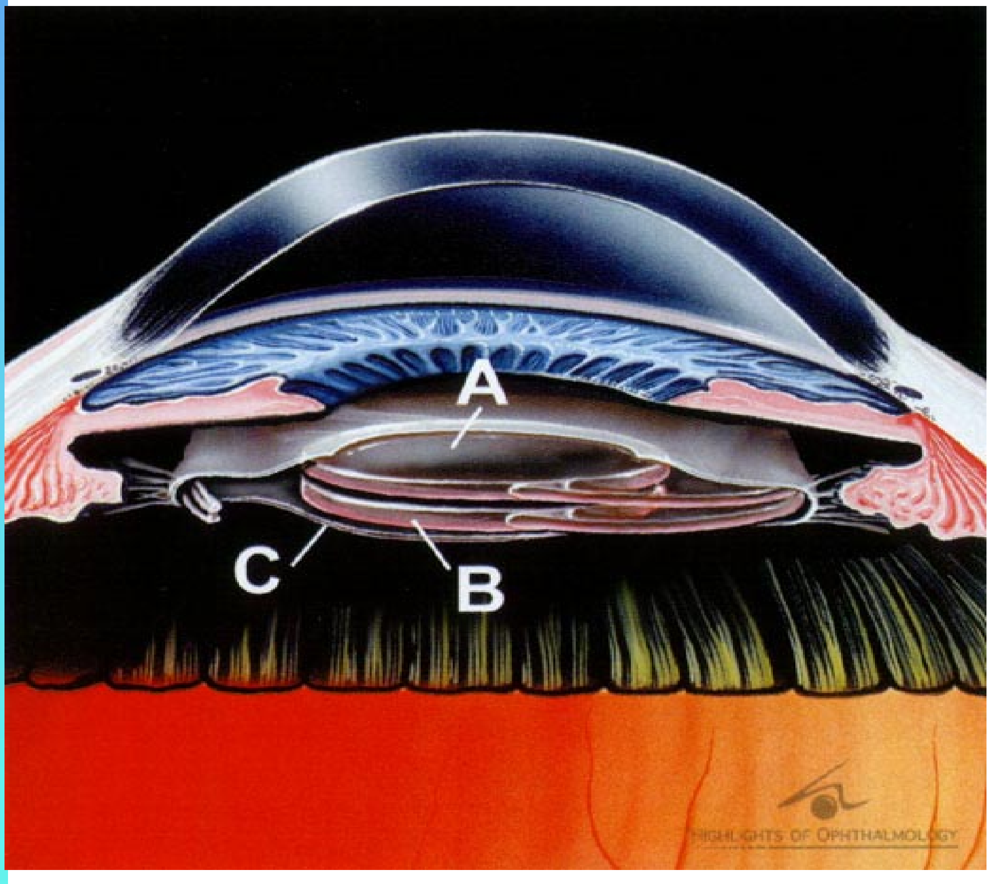
Professor **Joaquin Barraquer, M.D.,** has had similar successful experiences with piggyback lenses and extracapsular lens extraction in patients with very high hyperopia.

Gayton, pioneer in this procedure, now strongly recommends the use of PMMA lenses as the type of lenses of choice for primary piggyback procedures.

There may be technical problems with the operation because usually these are very small eyes. The main difficulties relate to making the capsulorhexis and adequate placement of the second (or third) piggyback lens in the bag.

Figure 148: Concept of the Piggyback High Plus Intraocular Lens

In cases of very high hyperopia, a clear lens extraction can be done combined with the use of piggyback high-plus intraocular lenses. One (A), two (B) or three intraocular lenses can be implanted inside the capsular bag (C). This piggyback implantation technique solves the problems of having to implant a lens of over +30 diopters with its consequent optical aberration.



CHAPTER 7

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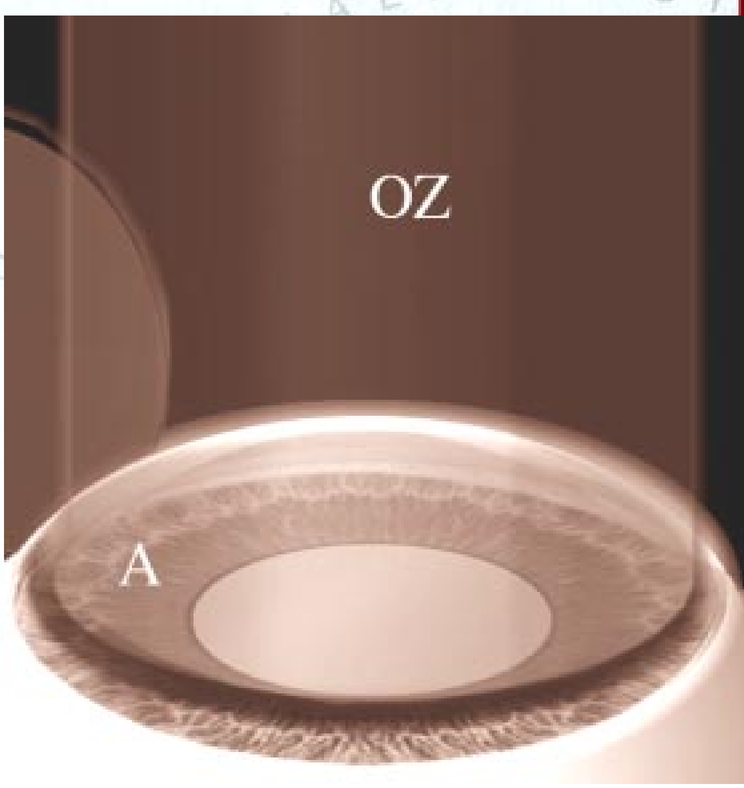
Surgical Management of Astigmatism

CHAPTER 8



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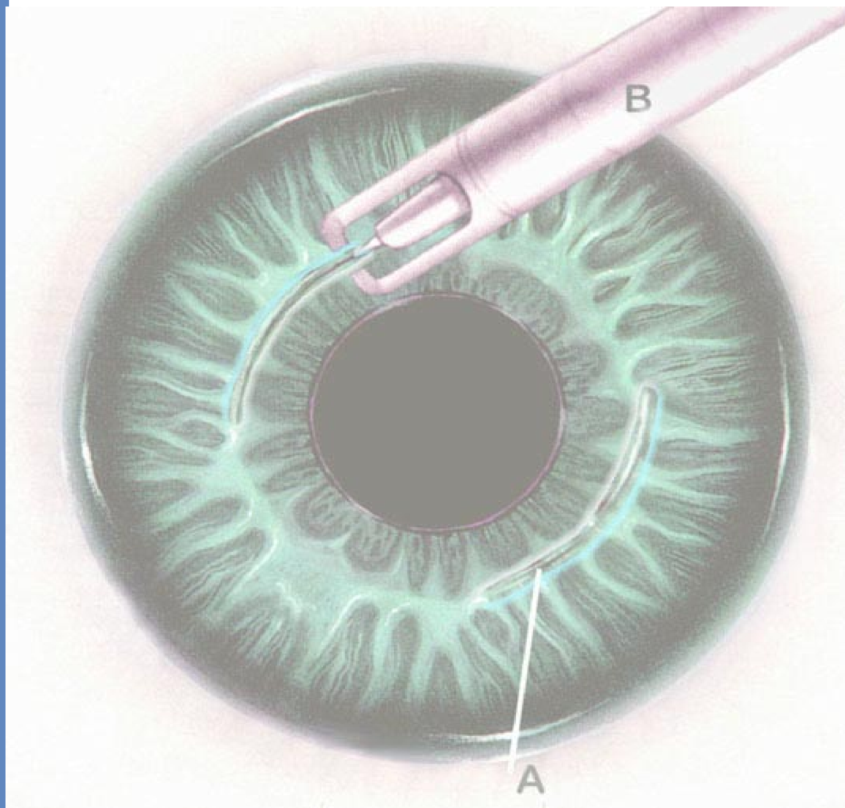


The Significant Role of Astigmatism

In Chapter 1 of this Atlas we discussed the highlights of our present understanding of astigmatism and defined a common terminology. We presented concepts that are important when referring to different types of astigmatism and when identifying in which specific axis the surgical correction must be made (Figs. 8, 9, 151, 154, 155.) We also presented the different combinations of astigmatism (Fig. 12) and defined the clinical significance of with-the-rule and against-the-rule astigmatism (Figs. 10, 11, 155, 156.)

Stephen Slade, M.D., has pointed out that our understanding of astigmatism lags behind that of myopia and even hyperopia.

This Chapter's aim is to concentrate on what astigmatism represents to the patient in his/her vision, the limitations it may give rise to in the patient's quality of life and how to treat this condition which is characteristically diverse.

How It Affects Daily Quality of Life

Patients with astigmatism cannot accommodate or "correct" for it as patients can with hyperopia. They may complain of ghost images or even diplopia. Patients having **with-the-rule astigmatism** (Fig. 10) complain less, as most letters and objects in our environment are vertically elongated. This is **one** of the reasons why surgeons have always attempted to leave a patient with an astigmatism with-the-rule (Fig. 10) instead of against-the-rule (Figs. 11 and 157) in surgical procedures that lead to postoperative astigmatism such as large incision cataract surgery and penetrating keratoplasty.

Visually Significant Astigmatism

About 10% of the population can be expected to have visually significant astigmatism of **greater than** 1.00 diopter. At this level, the quality of uncorrected visual acuity might be considered unsatisfactory. The amount of astigmatism that is troublesome to a patient is variable, but usually around 0.75 D.

Astigmatism greater than 0.50 to 1.00 D generally requires some form of optical correction. **Lindstrom** points out that an astigmatic refractive error in the range of 1.00 to 2.00 D might be expected to reduce uncorrected visual acuity to the 20/30 - 20/50 range, and 2.00 to 3.00 D might reduce uncorrected visual acuity to the 20/70 - 20/200 range.

Visually significant astigmatism is also quite common after surgery. After extracapsular cataract extraction, astigmatism greater than 1.00 D is quite common, with astigmatism greater than 3.00 D present in as many as 20% of cases. High astigmatism after penetrating keratoplasty is even more common, with astigmatism greater than 1.00 D basically being the norm. **Troutman** and **Swinger** estimated that nearly 10% of all clear penetrating keratoplasties are complicated by high postoperative astigmatism. **Troutman** was the pioneer of the techniques to reduce such astigmatism with his classical "relaxing incisions" and "wedge resections."

Selecting the Patients for Surgery

We must keep in mind the following principles:

1) As emphasized by **Slade,** spectacle lenses are poorly suited for astigmatism correction as they may cause aniseikonia, especially for newly corrected astigmatism patients. Because refractive surgery can change the asphericity of "forgiveness" of the cornea, astigmatism may be best treated with surgery instead of spectacles.

2) The surgical correction of idiopathic astigmatism is considerably more predictable than the surgical correction of postkeratoplasty or postcataract astigmatism, in which individual wound healing may affect the outcome.

3) All patients being considered for surgery of astigmatism must undergo the very careful preoperative diagnostic evaluation discussed in Chapter 3 for **all refractive surgical procedures.** This includes stable refractions. Patients younger than 21 years old may not have a stable refraction.

Computer assisted corneal topography maps are important to help ascertain which patients might be poor surgical candidates because of preclinical keratoconus, irregular astigmatism, or some other corneal abnormality.

4) Younger patients must be aware that older people end up with more surgical correction for the same amount of surgery when astigmatic keratotomy is performed (Figs. 154 - 156). Thus, smaller optical zones and more incisions may be necessary in the eyes of younger patients which increases the risk of possible side effects.

5) **Miles Friedlander,** an expert on astigmatism, points out that not all astigmatism has to be surgically corrected. **Sometimes** even a moderately high degree of astigmatism is not disabling to a patient.

6) **Friedlander** also emphasizes that it is important to be sure that the decrease in visual acuity is due to the astigmatism. Sometimes the patients' poor vision is due to cystoid macular edema following cataract surgery rather than to astigmatism. A simple way to make this assessment is to use the pinhole test. Usually if a patient's vision can be improved with a pinhole, then the cause is in the anterior portion of the eye. If the pinhole does not improve the vision, then other causes should be explored.

7) Among the most important **objective criteria for surgical correction of astigmatism** used by **Miles Friedlander, M.D., F.A.C.S.** and his close collaborator, **Nicole S. Granet, B.A.,** the following are fundamental: 1) The corneas must be healthy; 2) The astigmatism must be symptomatic; 3) When combined with radial keratotomy, correct astigmatism greater than 0.75 D if the RK is 4-cuts; correct astigmatism greater than 1.50 D if the RK is 8 - cuts (Fig. 157).

Some of **Friedlander's** most important **subjective criteria** are: 1) Awareness on the part of the patient and the surgeon of the limitations of the surgery recommended. 2) Awareness of the range of results.

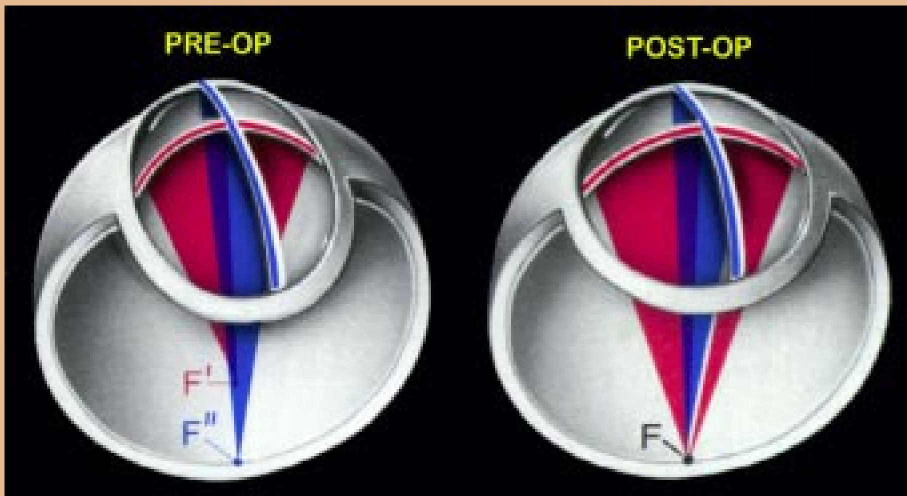
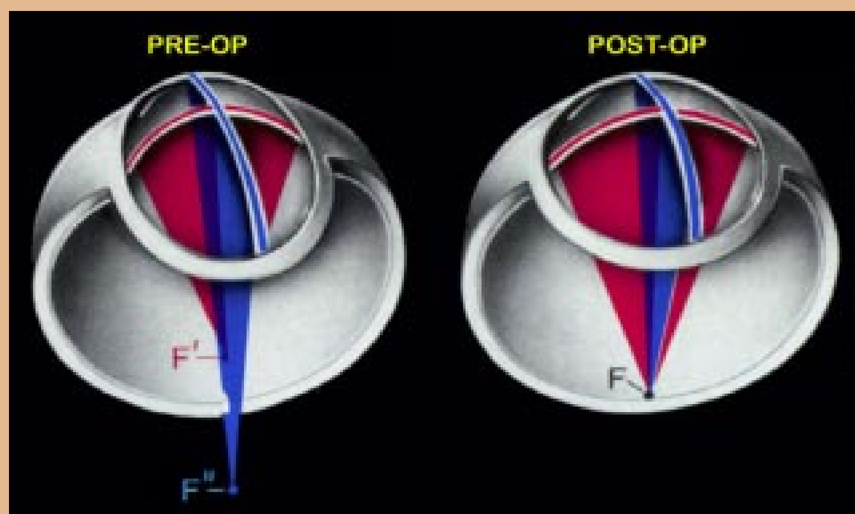


Figure 149: Goals and Principles of Myopic Astigmatism Correction

Pre-op view (left) shows the preoperative optical mechanism of myopic astigmatism. The horizontal (red) meridian projects light rays in front of the retina (F^1). Light rays through vertical meridian (blue) are focused (F^{11}) on retina. Cornea is oval shaped. Post-op (right) shows how the corneal curvature flattens in the astigmatic meridian (horizontal red arc). Compare with high horizontal curvature pre-op (red). Results: cornea now round. Light rays through horizontal meridian (red) now focused (F) on retina as well as the light rays coming from the vertical meridian (blue).

Figure 150: Goals and Principles of Hyperopic Astigmatism Correction

Pre-op view (left) shows the optical mechanism of hyperopic astigmatism. Light rays through the horizontal meridian are focused (F^1) in front of the retina (red) shown in red. Cornea is oval. Light rays through vertical meridian (blue) are focused (F^{11}) beyond the retina. Post-op result (right), the vertical meridian has been steepened (compare steepened blue area of vertical meridian post-op and pre-op). Light through vertical meridian (blue)now focused (F) on retina. The same surgical procedure flattens the pre-op steep horizontal meridian (red). This combined effect is known as "coupling". Preoperatively this was an against-the-rule astigmatism. Light through the horizontal meridian now focused (F) on retina (red area). Cornea now round.



TREATMENT OF ASTIGMATISM

The treatment of the spherical refractive errors (myopia and hyperopia) have progressed significantly in contrast with the treatment of astigmatism which has lagged behind. No one technique may be considered as really advanced (Figs. 151 - 160). This may be related to the diversity of the condition as shown in Fig. 12, Chapter 1, which includes how the different types of astigmatism are combined with spherical errors resulting in multiple combinations and consequent complexity on how to plan treatment for each individual patient.

Goals and Principles of Treatment

The **goal of treatment** is to even up the axes, modify the differing focal lines in the eye, and bring the focus to the retina (Figs. 149 and 150).

To accomplish this aim, the surgeon flattens the steep axis in patients with **myopic astigmatism** (Fig. 149). The light rays or image previosuly focused in front of the retina are focused back on the retina as the converging power of the flattened meridian is reduced (Figs. 149, 151 and 154).

On the other hand, in **hyperopic** astigmatism, the **flat axis is steepened** thereby bringing forward the image previously focused behind the retina to focus on the retina (Fig. 150). This steepening of the flat axis is obtained by removing more tissue from the mid-periphery and periphery as in the ablation for hyperopia but at the pre-determined axis (Figs. 152, 153).

Alternatives for Treatment

There are two alternative methods for treatment of astigmatism. They are:

1) The **Excimer Laser Procedures** (LASIK and PRK) of which LASIK is the procedure of choice when not contraindicated (Figs. 151, 152, 153).

2) **Astigmatic Keratotomy** which may be through **arcuate** corneal incisions (Figs. 154, 155,) or **transverse** corneal incisions (Fig. 157 - (inset), 160).

Indications for Each Alternative

Lindstrom recommends the following:

1) **Astigmatic Keratotomy for:**

a) Postkeratoplasty astigmatism (Figs. 154-155).

b) Refractive cataract surgery the cataract patient with astigmatism (Fig. 160).

c) Mixed astigmatism such as +1.00 -3.00 at 90º (fig. 156).

d) When excimer not available.

In addition to **Lindstrom's** indications, we may add that present trends tend toward performing astigmatic keratotomy in small degrees of primary astigmatism and for enhancements. For nomogram to perform astigmatic keratotomy, see Figs. 159, A-C.

2) **Astigmatic PRK (Fig. 153) for:**

a) When the patient has a superficial scar with basement membrane dystrophy and,

b) When unable to perform a microkeratome flap for LASIK. This usually occurs in patients with very narrow eyelid fissures. Such a problem may be overcome by performing a small canthotomy at the lateral canthus followed by stretching of the speculum.

3) **LASIK (Figs. 151 and 152): Lindstrom** considers this to be the best operation in most cases.

4) **INTACS (ICRS):** Work is underway to treat astigmatism two ways: 1) one way is to rotate the incision (being studied now with very encouraging results), and 2) with product modifications using variable thickness INTACS, as described by **Belfort.**

INTACS as available today is being investigated outside the US for use in the treatment of keratoconus (Colin et al), the treatment of undercorrected LASIKS (Kritzinger), and in combination with LASIK for high degrees of myopia allowing for the future adaptation to presbyopia (various). Studies are underway outside the US on the use of radially place INTACS for the treatment of hyperopia. These differ from the normal 150 degree arc design and utilize PMMA segments of only 1 mm in width. In all applications the central optical zone is untouched and the positive asphericity of the cornea is maintained.

The present limitation of INTACS is the cost of the equipment. Although the per eye cost of INTACS is $500, the instrument kit which includes two sets of instruments (for a bilateral procedure) and a vacuum pump retails for $36,000.

LASIK FOR ASTIGMATISM

LASIK can correct astigmatism effectively. It is usually reserved for treating astigmatism of moderate and higher degrees. As described by **Doane** and **Slade,** astigmatism is corrected by differential removal of tissue in the frontal plane of the cornea in one of the two major meridians. Actual tissue removal can occur by flattening the steep axis or steepening the flat axis (Figs. 151, 152).

Carmen Barraquer clarifies that the early algorithms to perform astigmatic corrections with excimer laser were developed based on myopic defects; for this purpose elliptical and/or cylindrical ablations centered on the cornea were performed (Fig. 151). **Carmen Barraquer** and her colleagues began to correct **myopic**

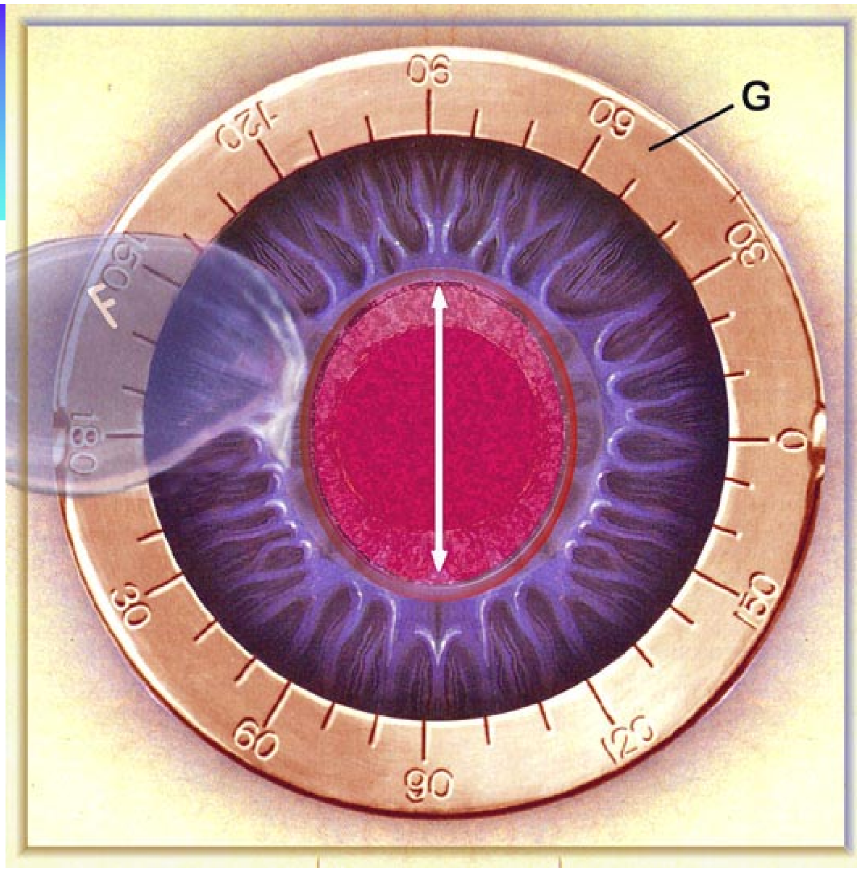


Figure 151: LASIK for Myopic Astigmatism

This surgeon's conceptual view is shown to orient the surgeon on the type of excimer laser ablation done in LASIK for myopic astigmatism. Corneal flap (F). Gauge (G) outlining the degrees of the circumference shown peripherally. The white vertical arrow within the vertical oval pink area as seen through the laser microscope shows where the laser is performing the ablation at the 90º meridian. The darker red represents the pupillary area. Through this mechanism the laser corrects both the astigmatic and part of the spherical refractive error simultaneously.

astigmatism with LASIK technique in 1994 at the Barraquer Clinic in Bogota (Fig. 151). They have found that it is possible to correct up to 6.0 D of astigmatic defect with good predictability.

The algorithms for **hyperopic** astigmatism correction were developed around 1996. In this ametropia both the cylinder and spherical defects must be corrected at the corneal **periphery (Fig. 152)**. In these eyes the cornea must be **steepened in all meridians.** At the Barraquer Clinic in Bogota, Colombia they began to correct hyperopic astigmatism in 1997. The current results in hyperopic astigmatism correction have 80% predictability, which is very good. The experience with this type of ametropia is not widespread: only few lasers have predictable algorithms for this defect.

Myopic astigmatism is treated effectively with the "minus cylinder format" in which the laser beam passes over the center of the cornea, flattening not only the steep meridian but also some of the myopia (Fig. 151). This can be completed by large area ablation lasers or flying spot lasers (Figs. 17, 18, 19, Chapter 2) passing the laser spot parallel to the minus cylinder axis or flat

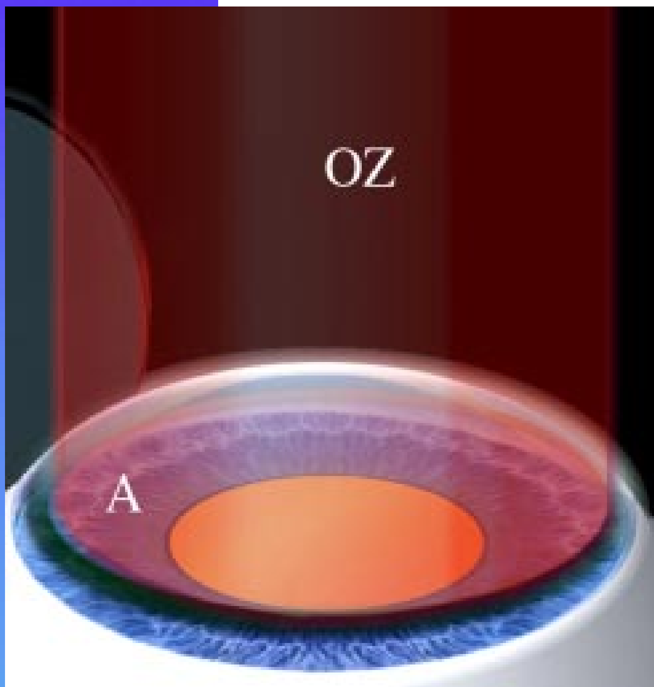


Figure 152: LASIK for Hyperopic Astigmatism

This is a side view of the principles of how excimer laser acts to ablate a hyperopic astigmatism. The excimer ablation is wide (red beam), somewhat oblique (A). It extends as far as 9.0 mm to ablate the mid-peripheral and peripheral areas of the cornea in the axis involved. The central cornea is shown elevated (steepened). The optical zone (OZ) shown in dark shade within the red beam of the laser should not be less than 6.0 mm wide. If smaller, the patient will develop visual aberrations.

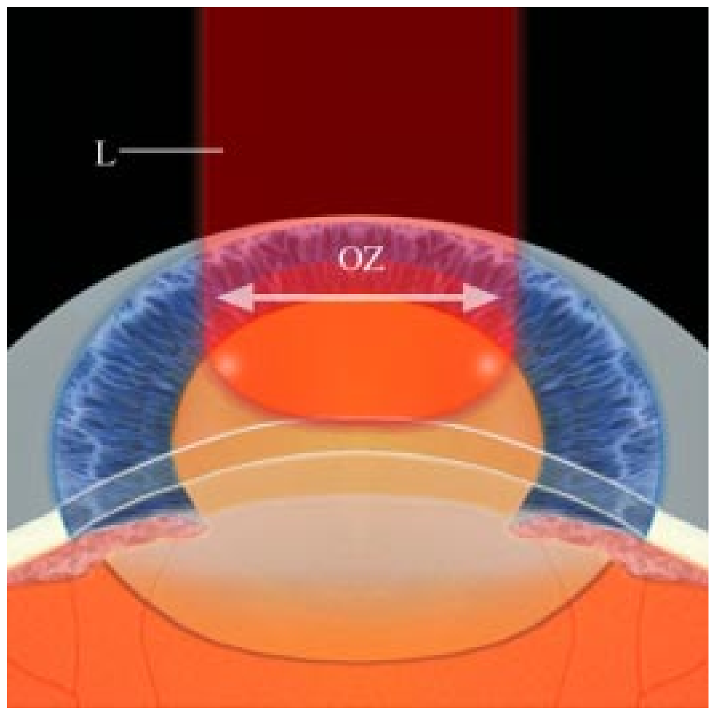


Figure 153: PRK to Correct Astigmatism

The entire corneal epithelium has been debrided. This lateral view, shows the excimer laser beam (L) over the debrided cornea with a central optical zone (OZ) of 6 mm (white arrow). The ablation is oblique, to correct the spherical as well as the astigmatic element, specifically oriented toward the pre-determined axis. The mid-peripheral and peripheral ablation results in steepening of the central cornea in the treated axis, thereby correcting the hyperopic astigmatism.

When treating **hyperopic astigmatism,** the surgeon may use the "plus cylinder format." With the laser he creates steepening of the flat axis best treated with **scanning** spot lasers (Figs. 16-19) by removing tissue paracentrally parallel to the minus cylinder axis or flatter axis on keratometry (Fig. 152).

PRK FOR ASTIGMATISM (Fig. 153)

Upon using PRK, when indicated as previously outlined, all the laser parameters described for LASIK in astigmatism are the same. The only part of the technique that is different is the one related to the differences between PRK and LASIK.

ASTIGMATIC KERATOTOMY

These techniques are still very much used, particularly for correction of primary low astigmatism, enhancements and in refractive cataract surgery (patients with cataract and some primary astigmatism, when the surgeon wishes to correct both conditions during the same operation session) (Fig. 160).

PRINCIPLES OF ASTIGMATIC KERATOTOMY

Types of Keratotomy Incision

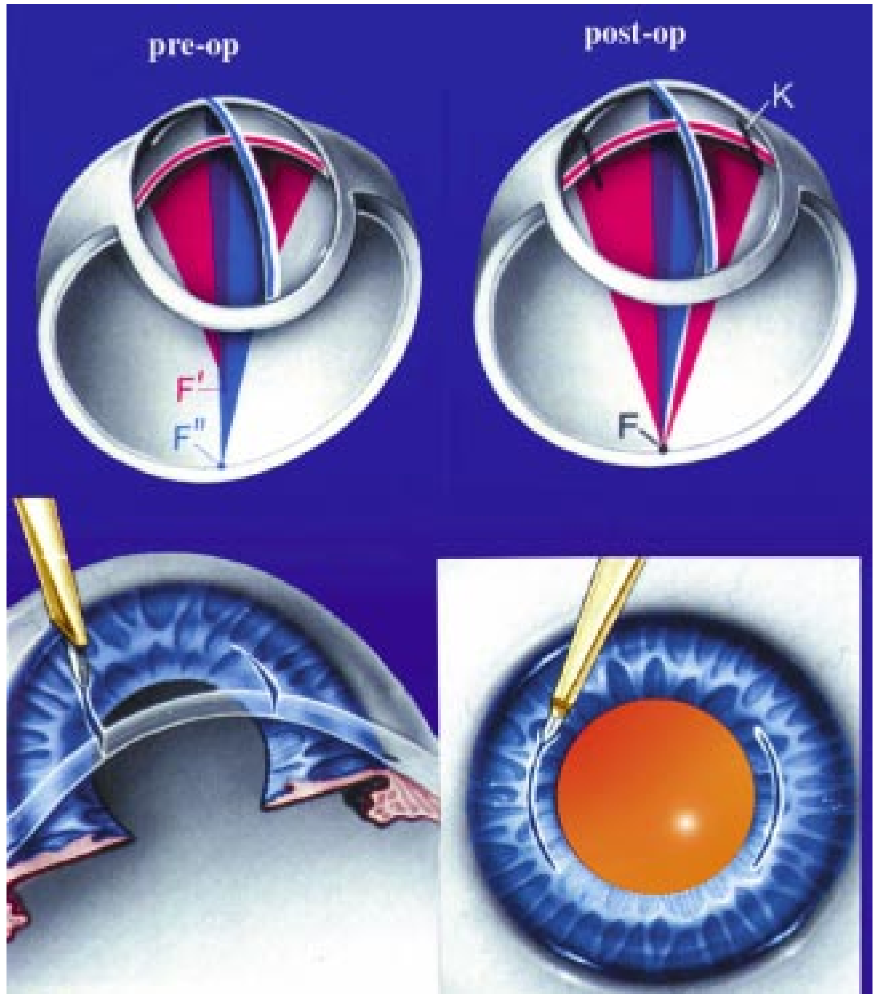


Figure 154: How Astigmatic Keratotomy Corrects Astigmatism

(Top Left) Pre-op view. Myopic astigmatism is shown in the horizontal meridian (red) with light rays (red) focused in front of the retina (F[1]). Light rays through the vertical meridian (blue) are focused on the retina (F[11]). (Top Right) Post-op view. The relaxing incisions (K) of the arcuate keratotomy shown below, (left and right) flatten the corneal curvature in the astigmatic horizontal meridian (horizontal red arc). Results: cornea now round. Light rays through horizontal meridian (red) now focused on the retina (F).

There are **two types** of astigmatic keratotomy used for reduction of astigmatism. They are: 1) **Arcuate** incisions (Figs. 154 and 155) and; 2) The **transverse** keratotomy (Inset in Fig. 157). The latter were previously known as the T-cuts.

How Keratotomies Work

- The incisions are placed in the axis of the steeper meridian, which is the axis of the plus cylinder and has the greatest power on central keratometry (Fig. 155). As pointed out by **Slade,** keratotomies work in a different way from excimer ablations for astigmatism. **Any keratotomy incision will flatten the cornea under the**

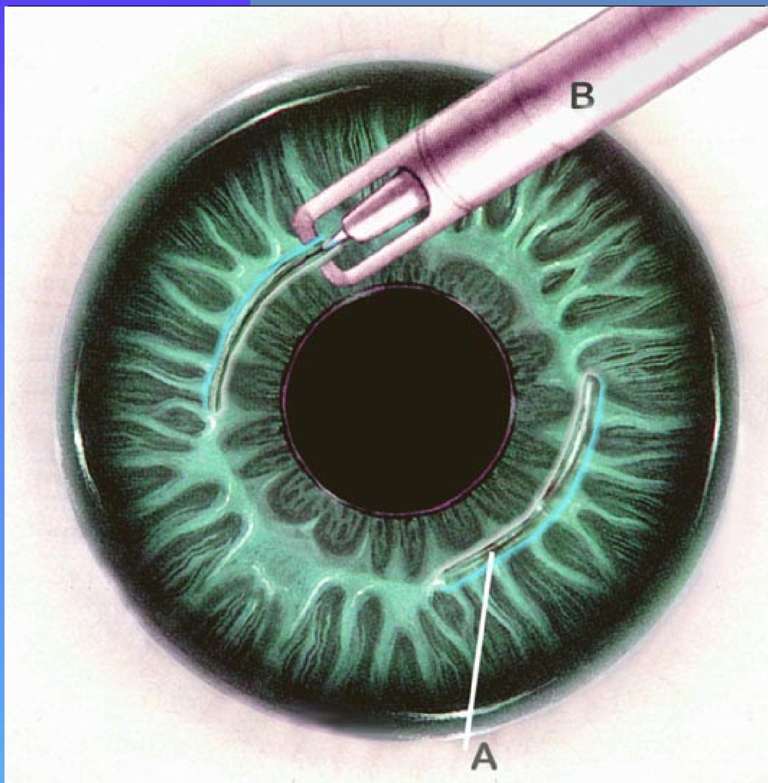


Figure 155 A: Performing the Two Arcuate Incisions

This superior surgeon's view shows how to perform the arcuate relaxing incisions (A). They are performed at the 145º axis where the steepest meridian is present as shown in Fig. 155 B. They are placed face to face equidistant to each other by means of the diamond knife (B).

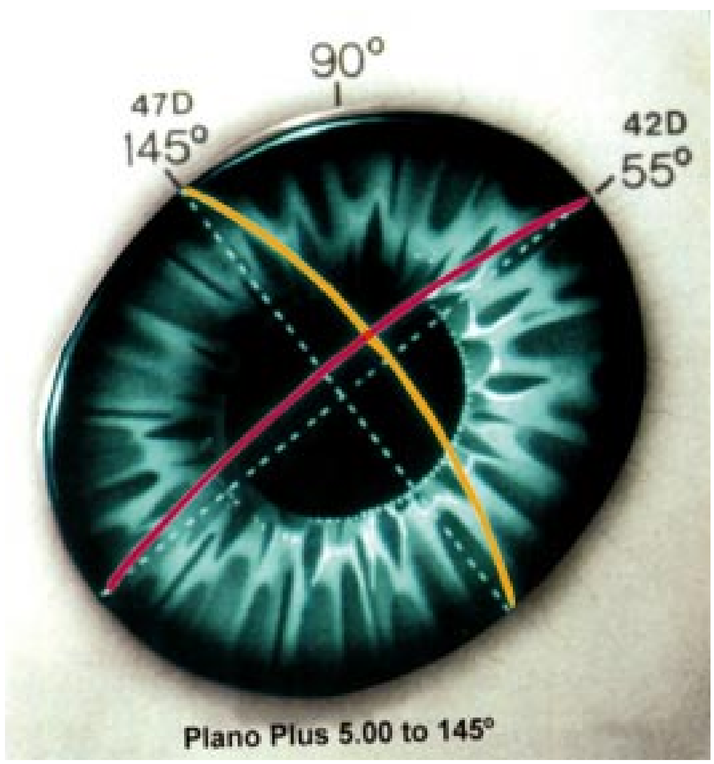


Figure 155 B: Steeper Axis at 145º

The steeper axis shown here at 145º is being corrected with the arcuate incisions shown in Fig. 155 A.

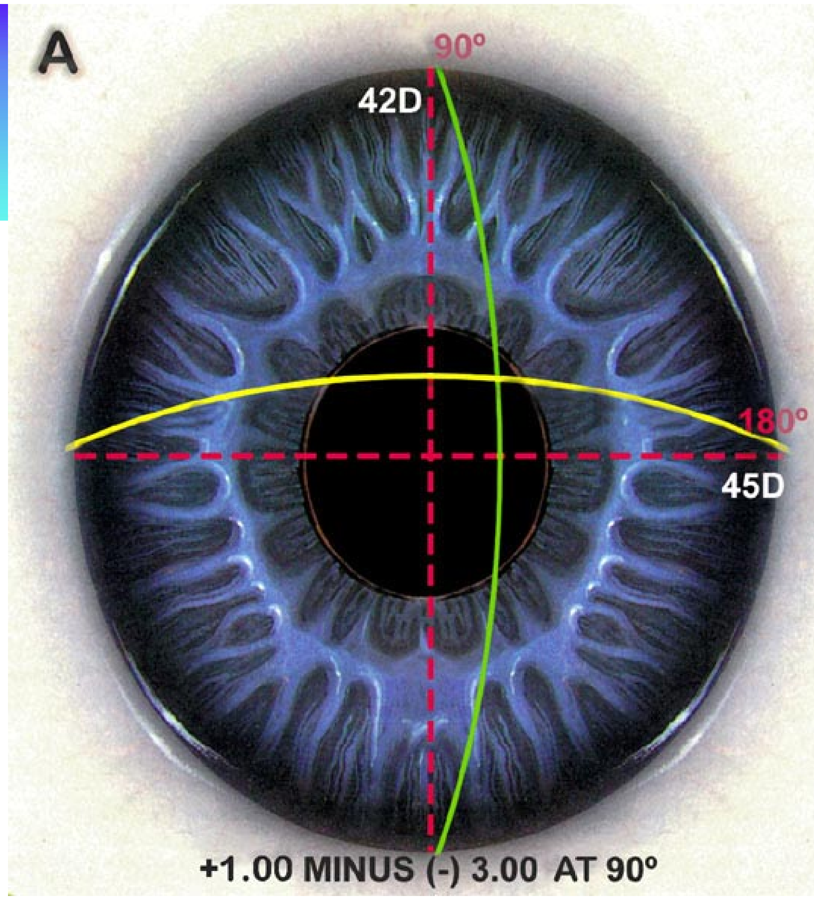


Figure 156: The Coupling Effect of Astigmatic Keratotomy

This conceptual view presents the steepest curvature shown in yellow with 45 diopters at 180° in the horizontal axis and the flatter vertical meridian shown in green with 42 diopters at 90°. An astigmatic keratotomy placed at the steepest axis (180°) corrects the -3.00 astigmatism at 90° and the spherical error of +1.00 D.

incision. The incision flattens the cornea immediately adjacent to it and at the meridian that is perpendicular to the cut itself (Fig. 155 A and B). The other meridian, **unlike an excimer ablation,** is also affected. While the steep axis perpendicular to the cuts is flattened (Fig. 149), the flat meridian is slightly steepened. **This is the coupling effect.** In a myopic patient with a hyperopic opposite meridian, this is obviously beneficial. An example would be a patient with +1.00 -3.00 at 90° (Fig. 156). This patient might be best treated with astigmatic keratotomy because the coupling would correct the 1 D of hyperopia.

- The maximum efficacy per unit length incision for a straight or arcuate keratotomy incision occurs when the incision is placed coincident with a 5 to 8 mm diameter zone. For the effects caused by incisions placed at different optical zones, see Figs. 159 A-C (Nomograms).
- Incisions at an optical zone that is less than 5 mm are contraindicated because of irregular astigmatism and glare.
- Most of the effect of transverse or arcuate incisions is achieved with the first symmetric pair of keratotomy incisions (Figs. 154, 155, 157 - inset). This accounts for about two thirds of the effect. Placement of an additional

pair of incisions will increase efficacy 25% to 33%. No additional incisions are effective nor recommended.

Younger patients tend to achieve a lesser result than older patients. Therefore the nomogram must be adjusted according to the patient's age. (See Nomograms in Figs. 159 A-C).

Determining a Surgical Plan

In general, plan to slightly overcorrect against-the-rule or steep at 180º, and to undercorrect with-the-rule. Patients having with-the-rule astigmatism often have a better range and depth of vision than spherical patients.

Make sure you consider the fellow eye. If the fellow eye has astigmatism, especially oblique astigmatism that the patient likes, consider leaving matching oblique astigmatism alone.

Friedlander considers that the shape of the keratotomy cut is not in itself important to the amount of correction as is its proximity to the optical center. Any point on an **arcuate incision** is at the same distance from the optical center (Fig. 155 A). Conversely the **T incision** will be closest to the optic center only at its mid-point (Fig. 157 - Inset). Other points located on a T cut are farther away from the center than the mid-point. Therefore, given the same optical zone and incision length, **Friedlander** considers that the arcuate cut is more effective than the transverse incision in reducing astigmatism. The least effective is the radial incision.

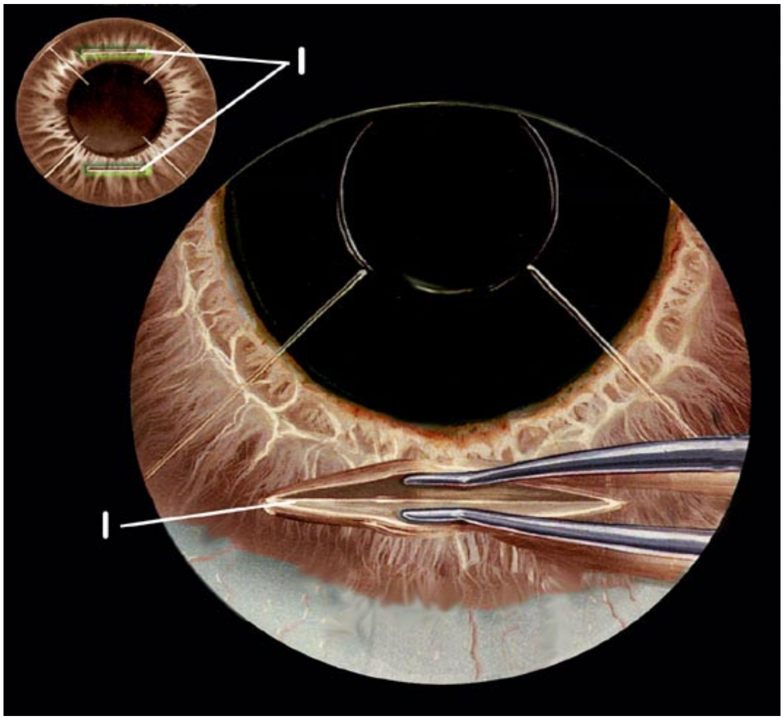


Figure 157: Transverse Keratotomy Incisions in Correction of Astigmatism

Transverse incision shown in inset (I) are used more often to correct low astigmatism and for enhancements. This surgeon's view shows two transverse incisions (I - inset) placed between two radial incisions. In this case, the surgeon is treating myopia and astigmatism combining two transverse incisions with four radial incisions for RK.

In the larger figure, the surgeon is inspecting the incision to evaluate its depth and length and to observe that no debris is remaining. The transverse incisions shown above and below in the inset are facing each other and are equidistant, in order to obtain the best corrective effect.

Surgical Technique of Astigmatic Keratotomy

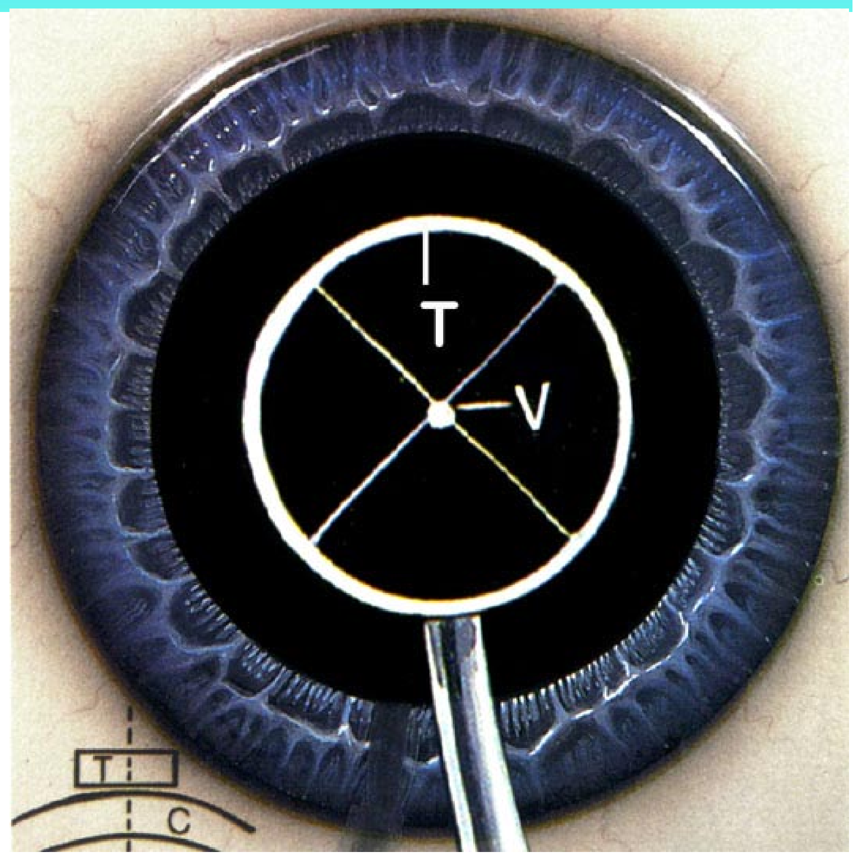


Figure 158: Marking the Central Optical Zone in Astigmatic Keratotomy

Following the marking of the visual axis (V) and steep meridian, the optical zone, which will remain free of any incisions, is delineated with this optical clear zone marker (Fig. 158). The size of the optical zone (T) is determined by the data specific to each patient's required correction as found in the nomograms in Figs. 159 A-C.

Instrumentation

The main surgical instrumentation you need is as follows: 1) **Pre-Incision**, wire speculum and Pachymeter. Pachymetry is performed either adjacent to the central optical zone mark (Fig. 158) or directly over the area to be incised. 2) **Sterile Portion:** Sinskey hook, a peripheral ring marker indicating the degrees of circumference of the cornea to mark the steep meridian (shown in Fig. 151 with LASIK), an optical clear zone marker (Fig. 158), a diamond micrometer knife for making the incision (Fig. 97), solid blade locking lid speculum, gentian violet or skin marking pencil, angled Kremer fixation forceps, wound spreader (Fig. 157) and irrigation needle.

Arcuate Keratotomies

These are relaxing incisions. They tend to be reasonably stable because they involve fewer incisions (Figs. 154-155). The basic principle for relaxing incisions to correct astigmatism was pioneered by **Richard Troutman, M.D.** The effects are related to the diameter of the optical zone utilized which is marked with a special marker (Fig. 158) and the length of the incision. A common choice is a 7 mm optical zone both for ease of creation and to avoid visual aberrations with a smaller optical zone. The effect of these arcuate relaxing incisions is titrated by the length of the incision (45, 60, and 90 degrees) with depth held constant at 80-90% (Figs. 94 and 97, Chapter 5.)

The specific nomograms for using a 6, 7, 8-9 mm optical zone are presented in Figs. 159 A-C as advised by **Lindstrom**. The optical zone **should not be** less than 5.5 mm. The step-by-step technique based on the original technique of **Miles Friedlander** (New Orleans) is as follows:

The patient is centered under the operating microscope and the eye is positioned perpendicular to the microscope.

Anesthetize the eye with topical anesthetic of your preference and mark the limbus with a marking pencil at the 12:00, 6:00, 3:00 and 9:00 o'clock positions. The lids are separated with a lid speculum. Additional anesthetic drops are instilled. The patient fixates on the operating microscope light, which is turned to a low level, or a red fixation light mounted on the microscope. The conjunctiva and cornea are dried with an absorbent sponge. The center of the pupil is marked with a **Sinskey** hook which has been painted with Gentian violet. A 7 mm (or the diameter previously selected) optical zone marker (Fig. 158) is centered over the pupil and pressed down. The axis of the steepest meridian is identified. Place two marks, 180° apart, at the axis of the steepest meridian on the 7 mm marker (Fig. 155-B). The steeper meridian is marked with a skin-marking pen using preoperative landmarks and an axis marker. Refer to the nomogram to determine the diameter of the optical zone and length of arcuate incisions (Fig. 159). Position a blade over the steep axis and mark the position of the blade to the immediate right and to the immediate left. Do this at the steep meridian at the 7 mm zone 180° apart. Make one or two arcuate incisions following the 7 mm zone (Fig. 155-A). The wound is inspected (Fig. 157 shows inspection of wound in transverse cut). The incisions are irrigated.

Transverse Astigmatic Keratotomies

These incisions are more indicated to correct small primary astigmatism, postoperative enhancements and combined in refractive cataract surgery (Fig. 160).

Figure 159-A

ARCUATE AND TRANSVERSE ASTIGMATIC KERATOTOMY

ARC - T 6 mm (Optical Zone) Nomogram (after Lindstrom)

Surgical Option

AGE	1 x 30°	1 x 45° (2 x 30°)	1 x 60°	1 x 90° (2 x 45°)	2 x 60°	2 x 90°
21-30	0.62-0.75	1.23-1.50	1.85-2.25	2.44-3.00	3.69-4.50	4.92-6.00
31-40	0.77-0.90	1.52-1.80	2.30-2.70	3.04-3.60	4.59-5.40	6.12-7.20
41-50	0.92-1.05	1.82-2.10	2.74-3.15	3.66-4.20	5.49-6.30	7.32-8.40
51-60	1.07-1.20	2.13-2.40	3.20-3.60	4.26-4.80	6.39-7.20	8.52-9.50
61-70	1.22-1.35	2.43-2.70	3.65-4.00	4.86-5.40	7.29-8.00	9.72-10.80

Find patient age group, then move right to find a result closest to refractive cylinder. To calculate the size of the transverse incision (when indicated) as compared to the amount of degrees of the Arcuate Keratotomies outlined above, you may use the following equivalents:

30° arc= 2.0 mm **45° arc**= 2.5 mm **60° arc**= 3.0 mm **90° arc**= 3.5 mm

Surgical Technique

The same measures are taken than when preparing the patient for arcuate incisions as outlined above. The difference is as follows:

If a 3 mm straight transverse keratotomy is selected (Fig. 157) a 3 mm zone marker can be placed over the 6 or 7 mm optical zone marker in the steeper axis to delineate the incision length. Alternatively, 3 mm transverse markers are also available.

Another alternative is, if using a 7 mm clear zone to set the surgical calipers to 3.5 mm (the distance from the center of the pupil to a transverse cut mark will be 3.5 mm). Place one point of the caliper at the center of the pupil and the other along the steepest meridian. Make a mark on the steepest meridian with this caliper tip. Then rotate the caliper 180º and place a second mark along the steepest meridian in the opposite direction. Take pachymeter readings at these points and determine the thinnest reading.

The Nomograms for both transverse cut and arcuate keratotomies are presented in Figs. 159 A-C.

Figure 159-B

ARCUATE AND TRANSVERSE ASTIGMATIC KERATOTOMY

ARC - T 7 mm (Optical Zone) Nomogram (after Lindstrom)

Surgical Option

AGE	**1 x 30º**	**1 x 45º (2 x 30º)**	**1 x 60º**	**1 x 90º (2 x 45º)**	**2 x 60º**	**2 x 90º**
21-30	0.41-0.50	0.82-1.00	1.23-1.50	1.64-2.00	2.46-3.00	3.28-4.00
31-40	0.51-0.60	1.02-1.20	1.53-1.80	2.04-2.40	3.06-3.60	4.08-4.80
41-50	0.61-0.70	1.22-1.40	1.83-2.10	2.44-2.80	3.66-4.20	4.88-5.60
51-60	0.71-0.80	1.41-1.60	2.13-2.40	2.82-3.20	4.26-4.80	5.64-6.40
61-70	0.81-0.90	1.61-1.81	2.43-2.70	3.24-3.60	4.86-5.40	6.48-7.20

Find patient age group, then move right to find a result closest to refractive cylinder. To calculate the size of the transverse incision (when indicated) as compared to the amount of degrees of the Arcuate Keratotomies outlined above, you may use the following equivalents:

30º arc= 2.0 mm **45º arc**= 2.5 mm **60º arc**= 3.0 mm **90º arc**= 3.5 mm

Figure 159-C

ARCUATE AND TRANSVERSE ASTIGMATIC KERATOTOMY

ARC - T 8-9 mm (Optical Zone) Nomogram (after Lindstrom)

Surgical Option

AGE	1 x 30º	1 x 45º (2 x 30º)	1 x 60º	1 x 90º (2 x 45º)	2 x 60º	2 x 90º
21-30	0.21-0.25	0.40-0.50	0.60-0.75	0.80-1.00	1.20-1.50	1.60-2.00
31-40	0.26-0.40	0.51-0.60	0.75-0.90	1.02-1.20	1.53-1.80	2.00-2.40
41-50	0.31-0.35	0.61-0.70	0.92-1.05	1.21-1.40	1.82-2.10	2.42-2.80
51-60	0.36-0.40	0.71-0.80	1.07-1.20	1.42-1.60	2.13-2.40	2.84-3.20
61-70	0.41-0.45	0.81-0.91	1.22-1.35	1.62-1.80	2.42-2.70	3.21-3.60

Find patient age group, then move right to find a result closest to refractive cylinder. To calculate the size of the transverse incision (when indicated) as compared to the amount of degrees of the Arcuate Keratotomies outlined above, you may use the following equivalents:

30º arc= 2.0 mm **45º arc**= 2.5 mm **60º arc**= 3.0 mm **90º arc**= 3.5 mm

Transverse Cuts Combined with RK

If transverse keratotomies are combined with RK (Fig. 157 - inset), the transverse incision **should never touch or communicate with the radial incisions.** This leads to complications.

In four incision RK, the T cut and arcuate cuts will not intersect the radial incisions. In an eight incision RK, the T cuts are on either side of the radial cut in the steepest meridian . They are 2 mm in length each and **do not cross or intersect the radial incisions**. In a combined procedure place the radial incisions first and then make the transverse incisions.

How to Manage Astigmatism at the Time of Cataract Surgery

With important improvements in the lens power calculations, cataract surgery has become a form of refractive surgery, offering significant improvement of both best corrected and uncorrected visual acuity. Astigmatism has remained the main obstacle to the achievement of excellent uncorrected visual acuity after cataract surgery.

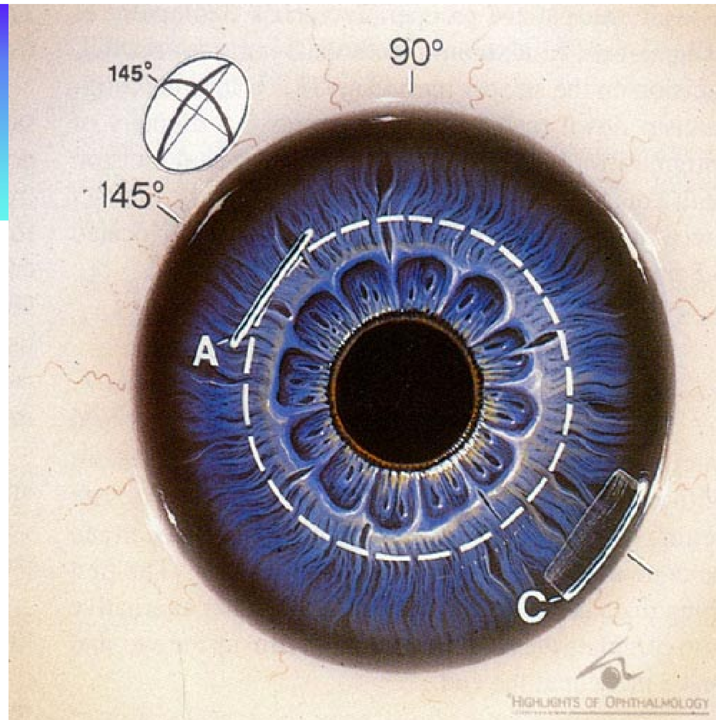
When cataract surgery is being done with the phacoemulsification technique, and astigmatism that merits surgical correction is already present, it is very definitely indicated to perform a combined procedure in order to improve on the patient's astigmatism at the time of cataract surgery.

Richard Lindstrom, M.D., at the Phillips Eye Institute and the University of Minnesota, is a strong advocate of what he calls "refractive cataract surgery". Refractive cataract surgery is indicated only when performing phacoemulsification with foldable IOL's, keeping a 3 mm incision.

In his extensive research and clinical experience, about 70% of the patients that he operates for cataract have less than one diopter of astigmatism preoperatively and about 30% have more than one. He does not make any astigmatic corrections in those that have less than one diopter. That is good enough for 20/30 uncorrected visual acuity. **Lindstrom** becomes somewhat more

Figure 160: Surgical Principles for Refractive Cataract Surgery

Lindstrom places the 3 mm cataract tunnel incision (C) in the steeper meridian to reduce pre-op astigmatism when present in a cataract patient. Further reduction of astigmatism may be obtained with a corneal incision (A) placed opposite the cataract incision in the same axis at the 7 mm optical zone (dotted line). The example shows a patient with pre-op 3 diopters of plus cylinder at axis 145º (inset). The corneal cataract incision is placed in the axis and may reduce the pre-op astigmatism by 0.50 diopters. The 3 mm straight corneal incision placed opposite the cataract incision in the same axis at the 7 mm optical zone is actually a transverse astigmatic keratotomy that should reduce astigmatism further by 2.0 diopters. The two together will reduce astigmatism a total of 2.5 diopters.



aggressive with astigmatism when there are two **diopters or more before the cataract operation.** His goal is to reduce it to one diopter, not to try to correct it all, just to get it down into a reasonable range (Fig. 160).

Lindstrom has found that when using 3 mm cataract wounds, which is possible only with **phaco and foldable IOL's,** the cornea is flattened only between 0.25 to 0.50 diopters.

Luis W. Lu, M.D., in Pennsylvania, who has extensive experience with management of cataract and astigmatism, emphasizes that we must reduce the astigmatism without overcorrecting the patient or changing the axis.

Technique for Refractive Cataract Surgery

Surgical Principles

Lindstrom's surgical principles and technique are as follows:

1) Move the 3 mm cataract tunnel incision **to the steeper meridian.** He thinks of this small wound as an astigmatic keratotomy. This will reduce the present astigmatism by 0.50 diopters. If the patient has 1 diopter of **plus cylinder** at axis 90, and a 3 mm cataract incision is made at axis 90, he/she will end up with only a 0.5 diopter of cylinder. If they have +1 diopter at 180 and the 3 mm cataract/IOL incision is moved over to the temporal side where the steeper meridian is located, they will end up with only +0.5 diopter of astigmatism at 180º which is good enough for 20/20 vision uncorrected. If they have 1.5 diopters, they will end up with 1 diopter cylinder and that is acceptable. But if they have 2 diopters to begin with, they will end up with 1.5 diopters and that is outside his goal. **Lindstrom's** outcome goal is 1 diopter astigmatism or less.

2) If more than 1.0 diopter of astigmatism would remain, **Lindstrom** applies the principles of **astigmatic keratotomy at the time of surgery. He does this very conservatively.** The cataract wound becomes one astigmatic keratotomy. On the opposite side, at a 7 mm optical zone, he will make a small 2 mm corneal incision to correct 1 diopter or a 3 mm long incision to correct 2 diopters of astigmatism in the cataract age group. This becomes a second astigmatic keratotomy.

If the patient preoperatively has 3 diopters of astigmatism, **Lindstrom** places the 3 mm cataract/IOL incision on the steeper meridian. This brings the astigmatism down to 2.5 D. If he wants 0.5 diopters of astigmatism, he makes a small 3 mm **corneal** incision with a diamond knife on the opposite side of the cataract incision using a 7 mm optical zone (Fig. 160), located 3.5 mm from the center of the optical clear zone.

Surgical Technique for Keratotomy

The depth of the diamond blade is set at 600 microns. At 3.5 mm from the center, the cornea is about 650 microns thick on the average so it is a very safe setting to avoid perforating the cornea. This incision can be done at the very beginning of the surgery. The first thing to do is make this small cut. The other alternative is to complete the cataract operation, firm up the eye, and make that cut at the end.

By using a 7 mm optical zone, the exact location of the cut is 3.5 mm from the center of the cornea (Fig. 160). The diameter of the cornea is 12 mm. The limbus is 6 mm from the center.

With this technique we try to make the operation safe and better for the patient, not perfect, to avoid doing any harm. This means trying to bring a patient from 3.5 diopters of astigmatism down to one, in order **to improve** the quality of his/her vision. The surgeon can enhance the results to the point where about 85% to 90% of patients will have 1 diopter or less of astigmatism. Most of them will wear spectacles anyway, because they need a bifocal, unless they have a trifocal IOL implanted.

These tiny incisions programmed as outlined here are a very powerful tool and seem to be very safe. Major complications such as poor wound healing, infection or perforation have not been observed.

This combined operation is **contraindicated** in the presence of a large cataract incision.

Combining ECCE and astigmatic correction can result in bad irregular astigmatism, macroperforations and overcorrections.

CHAPTER 8

SUGGESTED READINGS

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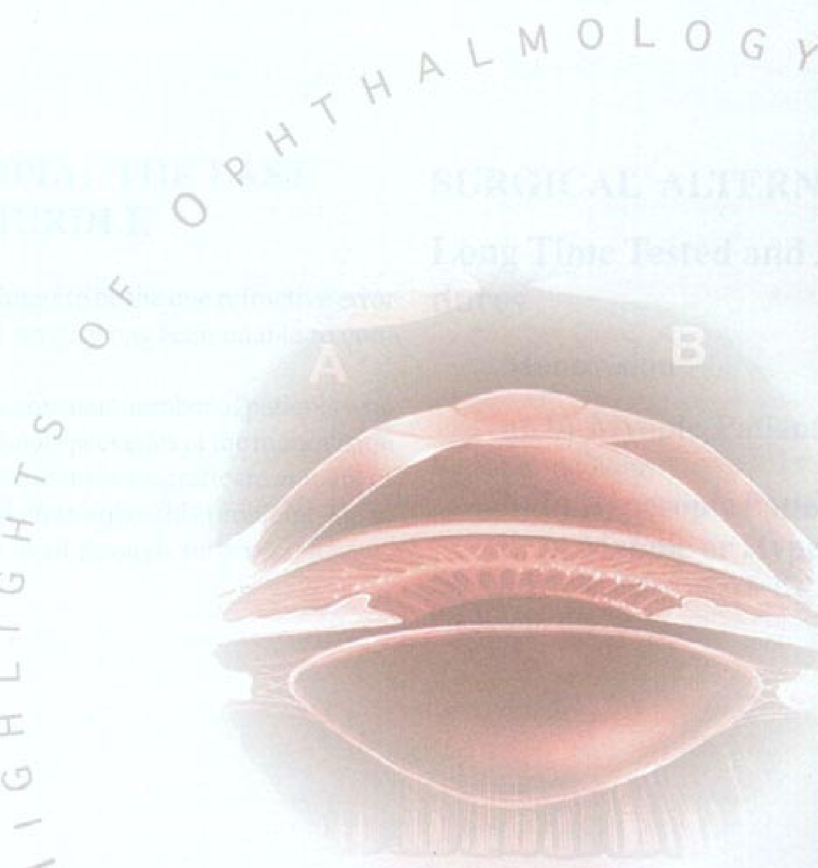
Surgical Management of Presbyopia

CHAPTER 9



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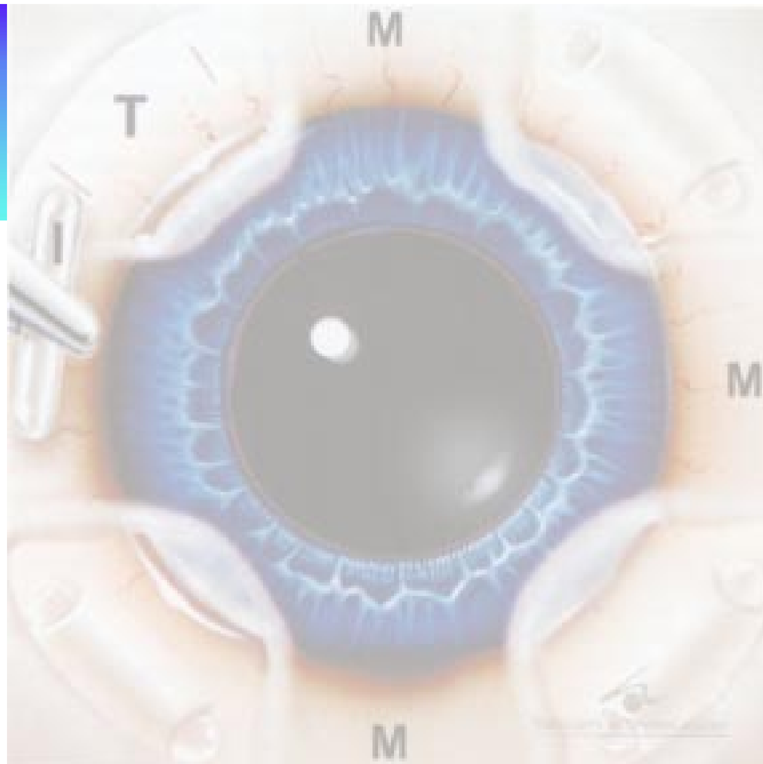


PRESBYOPIA: THE LAST HURDLE

Presbyopia continues to be the one refractive error that modern refractive surgery has been unable to conquer.

Considering the enormous number of patients who would want to read without spectacles or the monovision system of contact lenses, there is a significant amount of research being undertaken to solve this problem. Up to now there has been no avail through surgery.

SURGICAL ALTERNATIVES

Long Time Tested and Accepted Procedures

Monovision

a) In Myopic Patients: LASIK, PRK and Radial Keratotomy.

b) In Hyperopic Patients: LASIK and PRK.

c) In Myopic or Hyperopic patients: refractive IOL's: either phakic IOL's or clear lens extractions with IOL's.

Experimental Procedures Under Evaluation

a) Laser Thermokeratoplasty
b) Multifocal Cornea Sculpted with Excimer Laser (LASIK)
c) Intacs (ISCRS)
d) Scleral Expansion with Scleral Implants Over the Ciliary Body (SEB) and Scleral Slits Incisions over ciliary body to "restore accommodation."

LONG TIME TESTED AND ACCEPTED PROCEDURES

These are all based on the **system of monovision,** which has been used successfully for years with contact lenses.

Surgical Monovision in Myopic Patients

The first choice is to attain this with LASIK (Figs. 55-56). LASIK is the method preferred by most surgeons because of its stability and rapid visual rehabilitation. The other procedures that may be used are PRK as second choice and RK as third choice. Phakic IOL's are a logical alternative.

How Monovision Works

When correcting myopia with LASIK, in patients over 40 years of age a residual myopia is left in one eye on purpose so that the patient can read for near. How much residual myopia depends on the age of the patient; usually -2.00 D in order to keep comfortable vision and prevent anisometropia.

Usually the non-dominant eye is selected for the residual myopia, but this is up to the surgeon's best judgment.

It is important to test this method with contact lenses for several days before surgery in order to determine the patient's tolerance to this change in visual function. Not all patients tolerate monovision. If they do not, then they are informed they will need to wear spectacles for reading.

Surgical Monovision in Hyperopic Patients

The first choice again is LASIK. PRK is a second choice.

The patient is overcorrected by an average of 2.0 D in the selected eye. This renders that eye myopic. As with other LASIK corrections for hyperopia, a multifocal effect is sometimes obtained so the patient may regain 50% of near vision and still see rather well for distance. This multifocal effect, however, cannot be guaranteed nor predicted for individual patients.

The surgical technique consists of performing the conventional LASIK procedure for hyperopia (Figs. 142-144), instructing the computer to add the desired overcorrection. If the spectacle prescription is +1.50 D in both eyes, the laser computer is instructed to remove 1.50 D in one eye and 3.50 D in the other eye.

EXPERIMENTAL PROCEDURES UNDER EVALUATION

1) Laser Thermokeratoplasty

Of the four techniques now being tried for the surgical correction of presbyopia, non-contact laser thermokeratoplasty with the Sunrise Corneal Shaping System as described by **Douglas Koch, M.D.,** principal investigator, is the one most tested and most advanced in its laboratory and clinical work (Fig. 147).

This technique, developed primarily to manage low hyperopia as described in Chapter 7, may be also used to treat presbyopia. This is achieved through a monovision approach by inducing some myopia in an

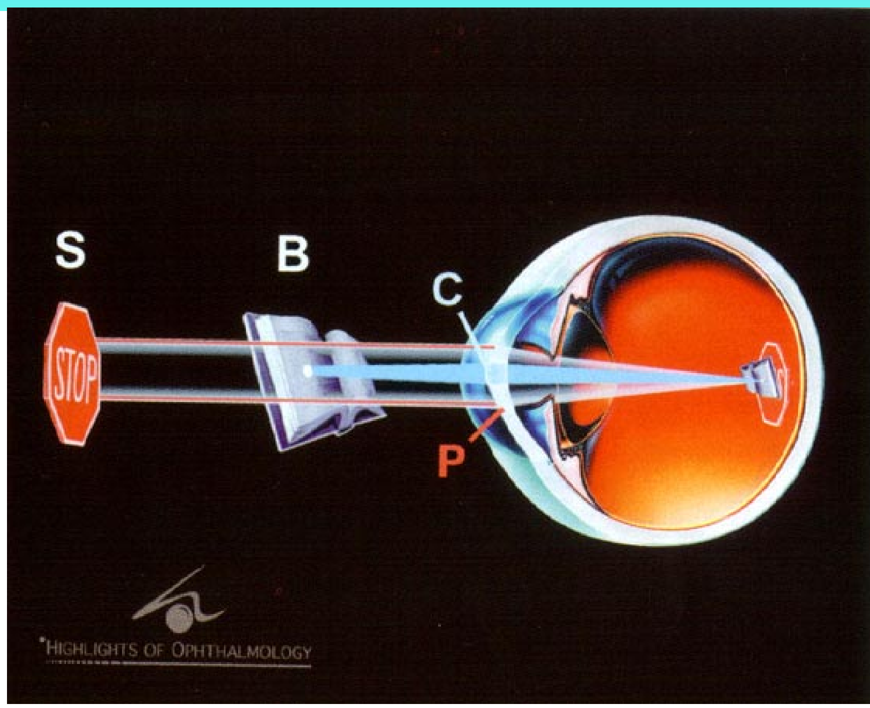


Figure 161: Improving Presbyopia by Sculpting a Multifocal Cornea

A scanning excimer laser beam might sculpt a multifocal cornea for the correction of hyperopia and presbyopia.

emmetrope. This works much like a monovision contact lens.

2) Multifocal Cornea Through LASIK

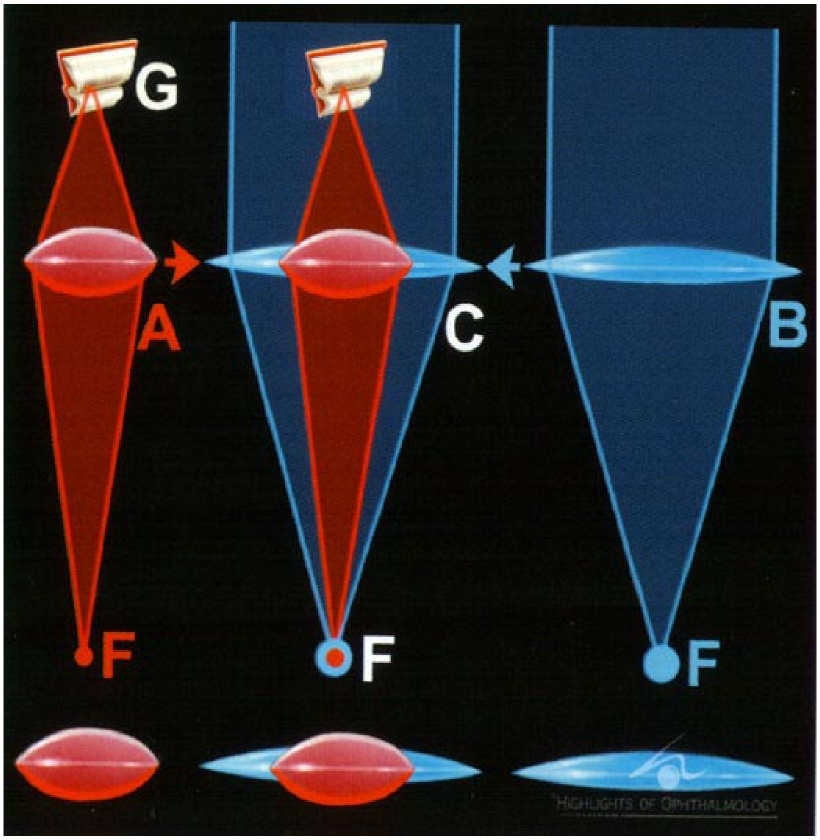
Another approach to compensate presbyopia by using corneal refractive surgical procedures, is by using LASIK to attempt to produce a multifocal effect in the cornea **(Fig. 161).** The surgeon attempts to reshape the corneal surface so there may be different regions within the cornea that have different powers. When successful, this allows simultaneous vision at distance through the flatter part of the cornea and at near through the steeper part of the cornea (Figs. 162, 163). This effect occurs in patients with a so-called central island after laser surgery, a central corneal area that was not ablated as much as the peripheral part of the cornea (Fig. 163). This small area, 2 mm or 3 mm in diameter in the central cornea may be steeper by 2 or 3 diopters than the peripheral surrounding cornea. Such a central island can allow patients to regain reading vision (Fig. 163).

The surgeon attempts to obtain these different curvatures by placing different sized masks over the cornea during ablation. The trade-off is that these patients often have visual confusions, decreased contrast sensitivity, and glare at night because of the simultaneous images, one of which is out of focus for the distance they are trying to see. The problem with this procedure is that we are not yet able to predict what long-term visual complications the smaller and non-uniform central optical area may create for the patient in front of us.

Carmen Barraquer, M.D., has very definite concepts about the strategy utilized for correction of presbyopia involving changes of different degrees in the corneal curves. She describes the three methods currently in development but emphasizes that **none of them is predictable enough yet to meet current standards for refractive surgery.** 1) LASIK to create a multifocal cornea, placing a mask over the stroma and ablating a bifocal lens (Figs. 162, 163). Although this technique may work, it requires critical centration. **Even a slight decentration can result in confused images and bad vision.** 2) LASIK and aspheric ablations used in certain algorithms to correct hyperopia, with a slight inferior decentration. This method can be applied in adult patients who need hyperopic surgery. Although they

Figure 162: Concept of Multifocal Corneal Shaping for Near and Far Vision

To understand the concept of a multifocal cornea providing correction for both near and far vision, lenses are shown to represent the multiple refractive powers of such a cornea. Assume that a small, high power lens (A) with focal length (F) for objects at reading distance (book (G)) is combined inside a larger, low power lens (B) with the same focal length (F) for distant objects. This combination is a multifocal lens (C).



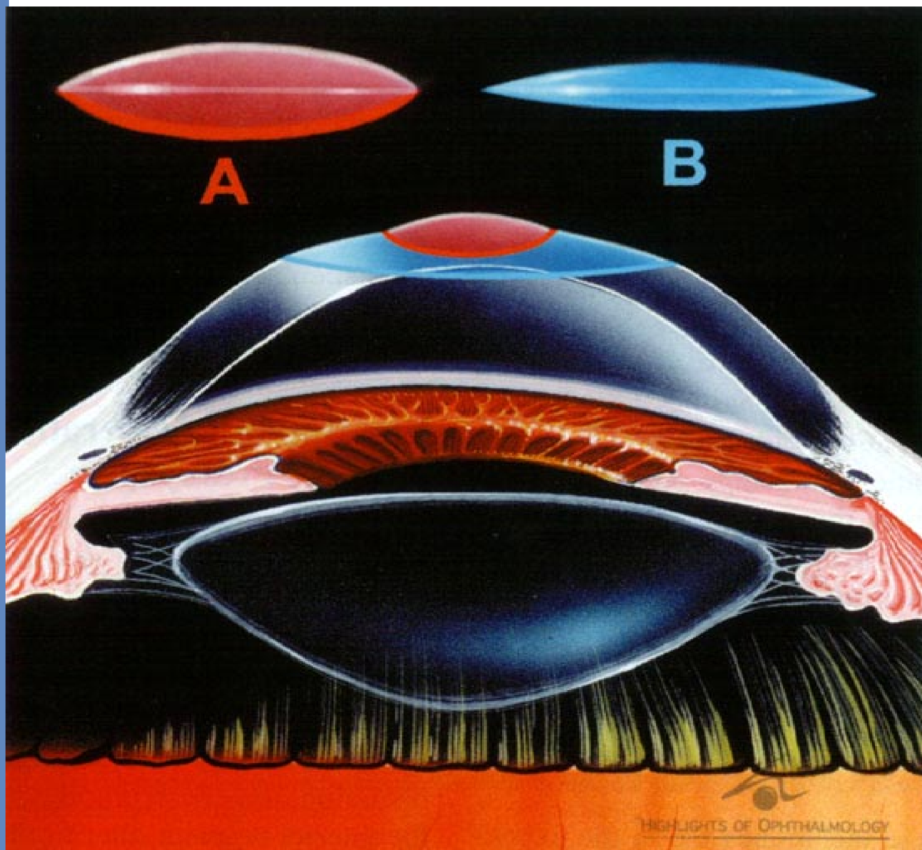


Figure 163: Concept of Multifocal Corneal Shaping for Near and Far Vision

In a similar fashion as lenses, one high power (A) and one lower power (B), a multifocal cornea with steep central curvature (red area) and flatter peripheral curvature (blue area) will focus close objects through the central portion and far objects through the peripheral cornea, simultaneously on the retina. The representational lenses of varying power are shown related to the multifocal corneal shape. The curvatures of the cornea are exaggerated for clarity.

may obtain good reading vision, the result is neither predictable nor quantifiable. 3) The third method entails creating a central area with positive power using the LASIK technique. The procedure aims to create a central 3 mm island of positive power over the pupil; hopefully the patient will use the peripheral cornea for distance and the central island for near vision, as is done with some bifocal contact lenses (Figs. 162, 163). Again, this technique is neither predictable, nor quantifiable. Of ten (10) patients operated on, five (5) are not happy. At present, the standard we try to meet in refractive surgery is a correction within + or - 0.5 diopters of the desired result. **Carmen Barraquer strontly believes that up to now, none of the current methods for correcting presbyopia by multifocal reshaping of the cornea reach these standards.**

Waring also feels that current **corneal refractive surgery cannot be used to manage presbyopia predictably.** Many patients after age 40 have developed both good distance and reading vision after radial keratotomy, PRK, LASIK, or an intrastromal corneal ring procedure. The reason for achieving this is the development of an **effectively functioning multifocal cornea.** This cornea works like a multifocal intraocular lens

(Figs. 162, 163). Some portions focus well for distance and other portions focus well at near. In some patients, the brain can suppress the unneeded information and use only the needed information. Currently, patients who have presbyopia but good distance and near vision **have it by fortunate accident. There is no way at present to reliably *create* a multifocal cornea that can focus at distance and near with sharp visual acuity,** and at the same time, ensure that the patient will be free of the problems of glare and loss of contrast sensitivity, and multiple images. **Waring** also emphasizes that, unfortunately, for every happy patient with a multifocal cornea, there are dozens of patients unhappy with multifocal corneas functioning less than optimally. Therefore, **Waring advises against using current techniques to intentionally create a multifocal cornea** until more research has been done.

Operations on the Sclera to Improve Presbyopia

Even though these techniques are in the experimental stage and in the process of evaluation, we present them here, illustrated step by step, in order to provide you with a clear understanding of the concepts and procedures involved. They have created a significant amount of controversy, including rejection of the theory of accommodation traditionally recognized through the years (Helmholtz). These operations are based on a new theory of accommodation described by the initiators of these techniques. Recent studies have contended that this theory, on which the surgical techniques are based, is incorrect.

Carmen Barraquer describes two strategies now used to correct presbyopia by operating on the sclera and the limbus. The first is to work over the ciliary body to increase the distance between it and the lens. Small segments of PMMA are placed in the sclera in quadrants like small scleral buckles 2.5 mm behind the limbus to pull the ciliary body outward (Figs. 164-169). The second approach is to perform radial incisions in the limbal sclera with the aim of relaxing it and changing the shape of the anterior segment (Figs. 170-171). Although the patient can read in the immediate postoperative period, it seems that this artificial accommodation is lost as soon as the scleral incisions heal.

Description of Operations on the Sclera to Improve Presbyopia

Changing the Anatomy of the Anterior Segment

These surgeries are based on the theory that loss of accommodation is a problem of geometry rather than of muscle atrophy or hardening of the lens with age. Two operations have been proposed to change the anatomy of the anterior segment, altering the relative positions of the ciliary muscle and the lens. An operation on the sclera may possibly change the biomechanical dynamics in the anterior segment to restore accommodation (Figs. 164-171).

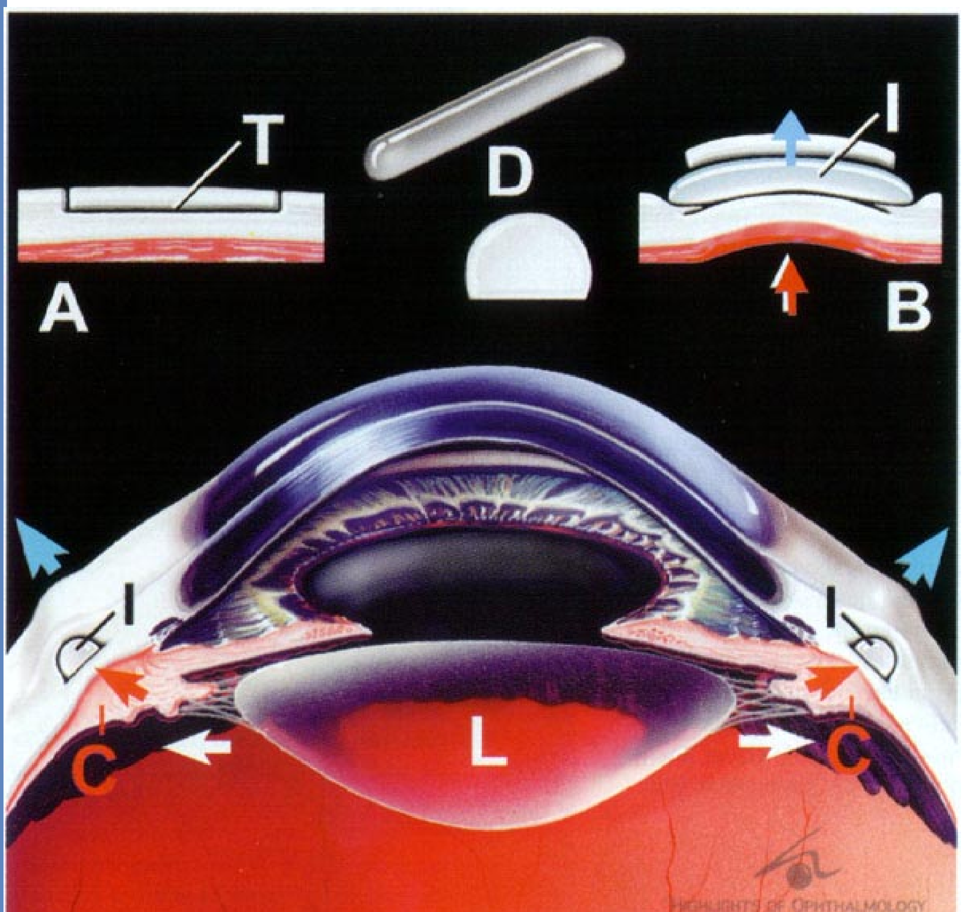
THE SCHACHAR PROCEDURE

One approach, spearheaded by **Ronald Shachar, M.D., Ph.D** from Texas, involves placing four small circular ring implants in the sclera like scleral buckles over the ciliary body to lift the ciliary body away from the lens (Figs. 164-169). These small buckles consist of small segments of polymethylmethacrylate (PMMA) in each quadrant. Although this surgery has been reported to restore accommodation and reading vision in some patients, data are still incomplete, and no published peer reviewed scientific studies have taken place.

Dr. McDonnell points out that **Dr. Richard Yee** from Houston, Texas has reported initial results in nine patients who had this surgery by him, with generally good results in terms of accomodation. Some of these patients, however, developed anterior segment ischemia, a significant complication, presumably due to interruption of the anterior ciliary arteries. The procedure definitely needs to be better explored and understood.

Figure 164: Concept of Scleral Implant Technique for Correction of Presbyopia

This method under investigation for the correction of presbyopia involves the implantation of four small scleral implants (I) directly over the ciliary body (C). These have the effect of pulling (blue arrows) the ciliary body out (red arrows) and changes the distance between the ciliary body (C) and lens (L), possibly increasing ability of zonular fibers to exert traction (white arrows) on lens capsule and change shape of lens. Inset (A) shows a section of the tunnel (T) made in the sclera before the implant changes the shape of the sclera. Inset (B) shows the implant (I) in place within the scleral tunnel and its affect on bulging the sclera outward (blue arrow) and thus pulling the ciliary body out (red arrow). (D) shows a view of an implant and its cross section.



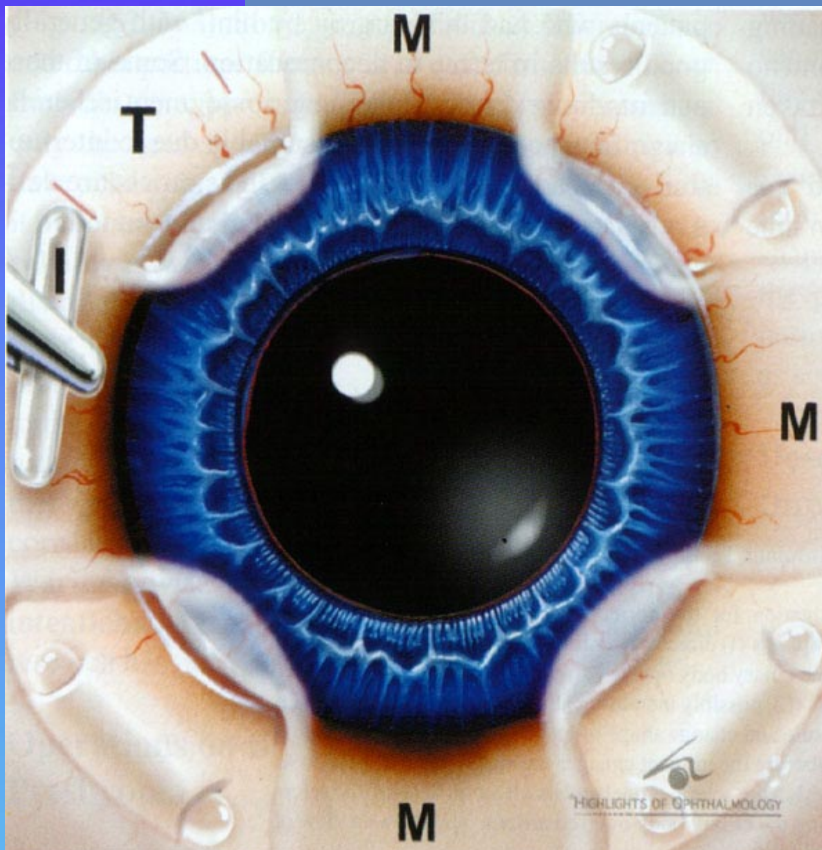


Figure 165: External Configuration of Scleral Implants for Correction of Presbyopia

This external view of the eye shows shows the location and size of the four scleral implants placed in the area between the extraocular muscles (M). One implant (I) is shown just before implantation into the scleral tunnel (T).

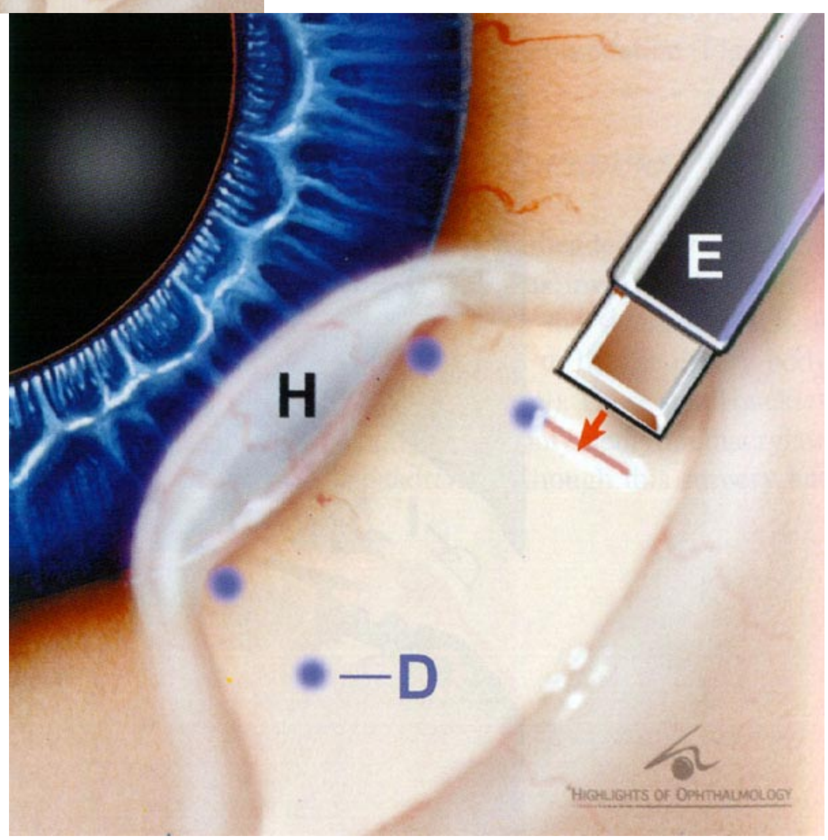


Figure 166: Scleral Implant Surgical Technique for Correction of Presbyopia - Step 1

The procedure shown is performed in each of the four quadrants of the anterior sclera between the positions of the extraocular muscles. The conjunctiva is reflected (H) in the four quadrants. Two small parallel vertical slits are made with a short diamond blade knife (E) at 2mm posterior to the limbus, premarked with dye (D).

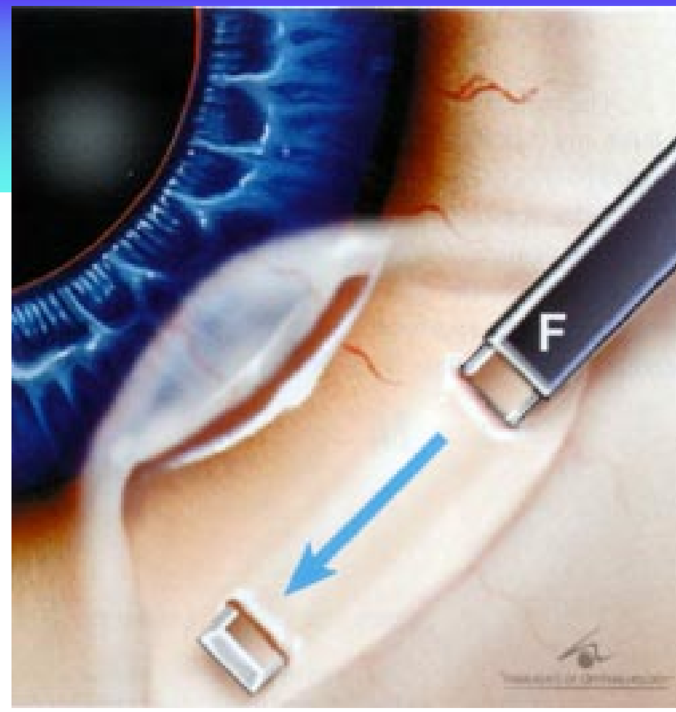


Figure 167 (above right): Scleral Implant Surgical Technique for Correction of Presbyopia - Step 2

A long diamond knife (F) is used to create a scleral tunnel (arrow) between the two vertical slits.

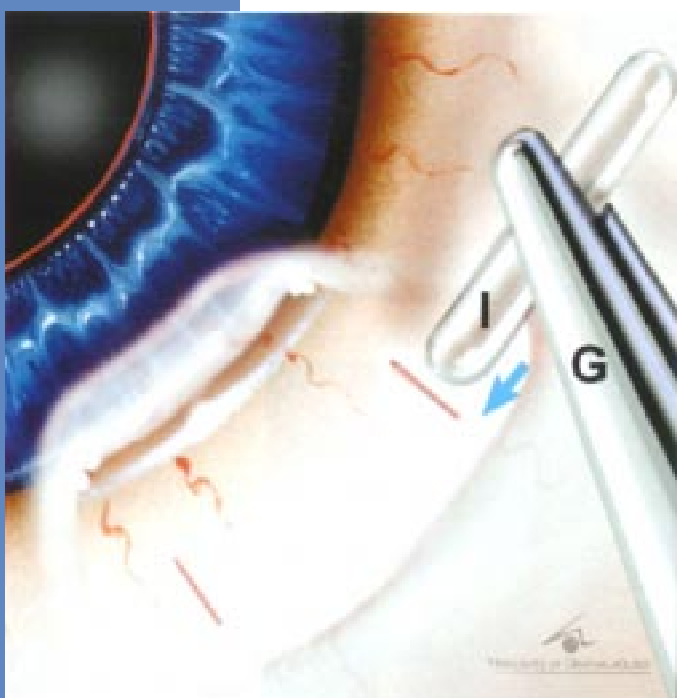


Figure 168 (center): Scleral Implant Surgical Technique for Correction of Presbyopia - Step 3

The tubular implant (I) is inserted into the scleral tunnel with forceps (G).

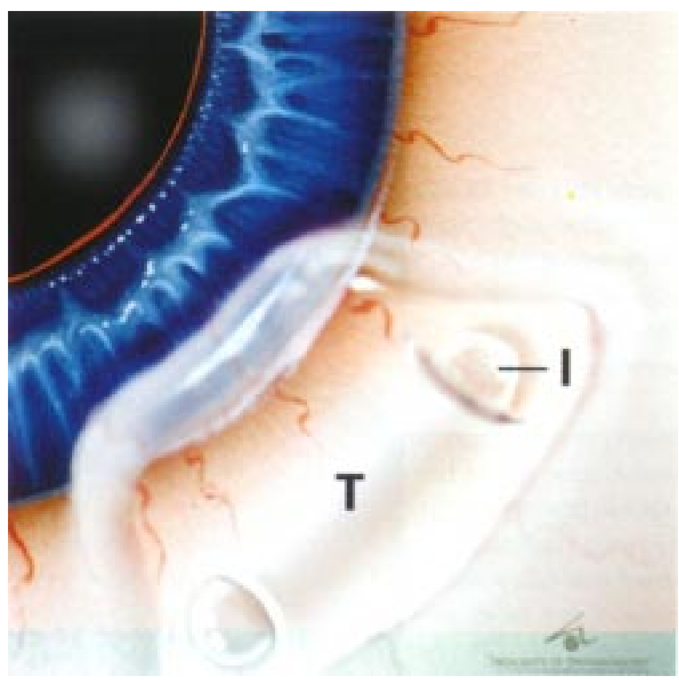


Figure 169 (below right): Scleral Implant Surgical Technique for Correction of Presbyopia - Step 4

This magnified view of one quadrant shows the final position of the scleral implant (I) within the scleral tunnel (T).

THE RADIAL SCLEROTOMY TECHNIQUE

The other approach involves creating radial sclerotomy incisions in the sclera over the ciliary muscle (Figs. 170-171). These incisions cause expansion of the sclera in the region of the ciliary muscle, which changes the biomechanical forces and restores accommodation to some degree. **Dr. Spencer Thorton,** who has been investigating this approach, has found that it helps restore reading vision in some patients.

Mechanism of Presbyopia - Intense Interest

Study of the mechanisms of presbyopia is currently an area of intense interest and research focus. **Steven Mathews, OD, Ph.D,** from the Department of Ophthalmology and Visual Sciences, Texas Tech University Health Science Center, Lubbock, Texas, concludes, after very careful scientific study published in *Ophthalmology* 1999;106:873-877, that if presbyopic patients read smaller letters at near than they were able

Figure 170: Concept of Scleral Slits Technique for Correction of Presbyopia

This method under investigation for the correction of presbyopia involves the use of a series of small scleral slits (S) over the area of the ciliary body (C) to induce a shift of the ciliary body out (red arrows). This changes the distance between the ciliary body (C) and lens (L), possibly increasing ability of zonular fibers to exert traction (white arrows) on lens capsule and change shape of lens. Notice the change in shape (blue arrow) of the sclera in the area of the slits (S).

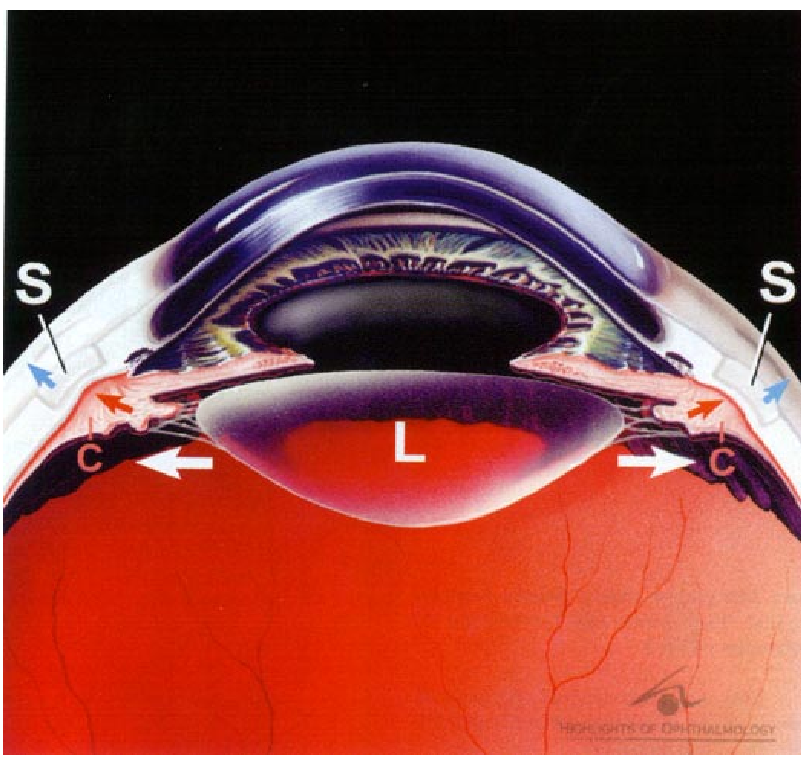


Figure 171: External Configuration of Scleral Slits Technique for Correction of Presbyopia

This external view of the eye shows shows the location, size and number of slits (S) placed in the area between the extraocular muscles (M), for the treatment of presbyopia.

to read prior to scleral expansion surgery (Figs. 164-171), then an explanation **other than** the restoration of accommodation needs to be found. The results of **Mathews'** scientific analysis show that scleral expansion surgery did not restore accommodation in the group of presbyopic human subjects studied. According to **Mathews,** there is no scientific indication that scleral expansion surgery restores accommodation in human presbyopia.

The rationale behind scleral expansion surgery is essentially based on **Schachar's** theories of accommodation.

Mathews points out that according to Schachar's theories of accommodation and presbyopia, the surgery restores the zonular tension lost to normal lens growth and allows accommodation to function again. **Dr. Schachar's** theorizes that presbyopia occurs because normal lens growth, as a result of age, increases its equatorial diameter and, as a result, the lens equator moves closer to the ciliary muscle, rendering the contracting muscles less capable of steepening lens curvature.

These notions contradict the commonly accepted mechanisms of accommodation and presbyopia, essentially based on **Helmholtz** theory of the physical mechanism of accommodation. The latter essentially conveys that a combination of zonular relaxation and lens hardening prevents the ciliary muscles from functioning adequately as patients approach their 40's and later on in life.

Helmholtz formally stated that the ciliary muscle is relaxed when the eye is focused for distance. The relaxed ciliary muscle maintains the zonule under tension to flatten the crystalline lens for distance viewing. When the eye focuses on a near object, the ciliary muscle contracts and releases tension on the zonule. The release of zonular tension allows the crystalline lens to become more curved due to elastic forces in the lens.

Also, contrary to **Schachar's** theory, the study of **Glasser** and **Campbell** strongly supports the classical theories of presbyopia based on the crystalline lens becoming unmalleable with age. Another cornerstone of **Schachar's** theory of accommodation and presbyopia is that the lens diameter increases with accommodation. A group of recent studies show, using various imaging techniques, that the crystalline lens diameter decreases with accommodation, as the classical literature maintains and contrary to **Schachar's** contention.

Although the surgical approach to presbyopia made by Schachar, Yee and Thorton, is indeed quite innovative and ingenious, it is quite evident that further verification of the efficacy of scleral expansion surgery would be prudent. The reported evidence showing improvement in the human accommodative amplitude is based solely on subjective measures.

Improving Our Understanding of Accommodation

Peter McDonnell believes that the ultrasound biomicroscope and other scientific advances are providing an improved understanding of what happens in the ciliary muscle during accommodation. A better understanding of the anatomical and physiological changes that lead to presbyopia should help scientists learn to correct it.

McDonnell predicts that our knowledge in this area will explode over the next few years. Better techniques would result in a major improvement in quality of life for patients. Many of these people are executives or professionals who rely on and are strongly motivated to correct their near vision as well as distance vision. **McDonnell** believes that restoring accommodation should be our ultimate goal in working with patients with presbyopia.

The currently available artificial techniques to counterbalance the problem of presbyopia, including the creation of a multifocal cornea or monofocal vision, carry with them significant limitations.

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Enhancements (Retreatments)

CHAPTER 10

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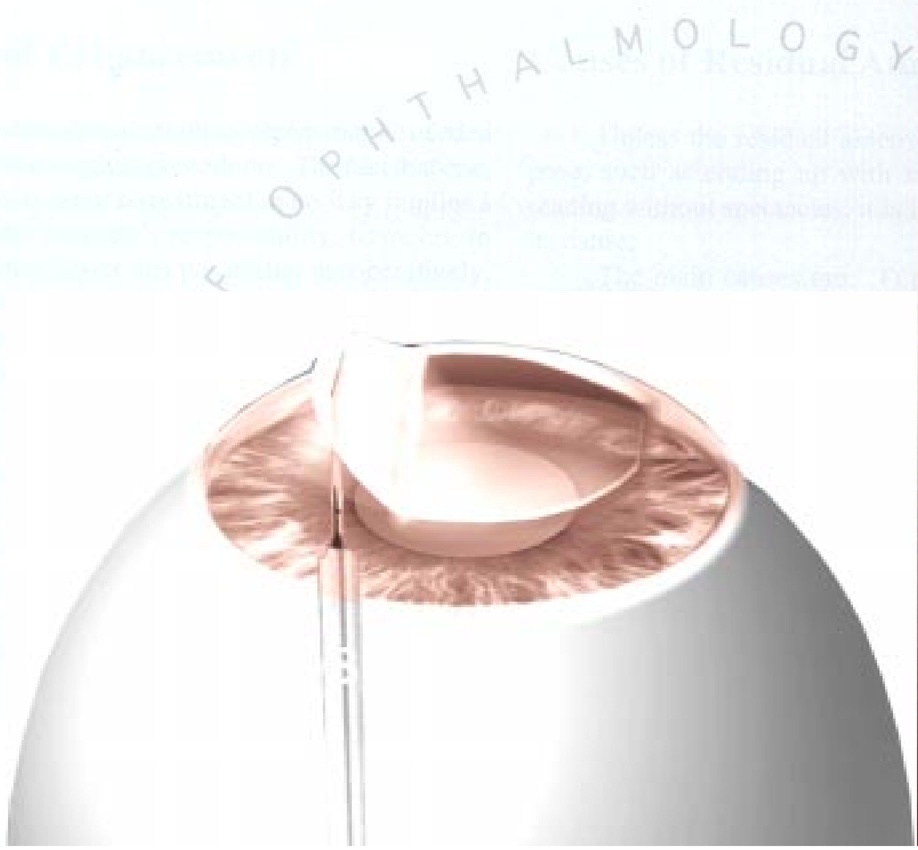
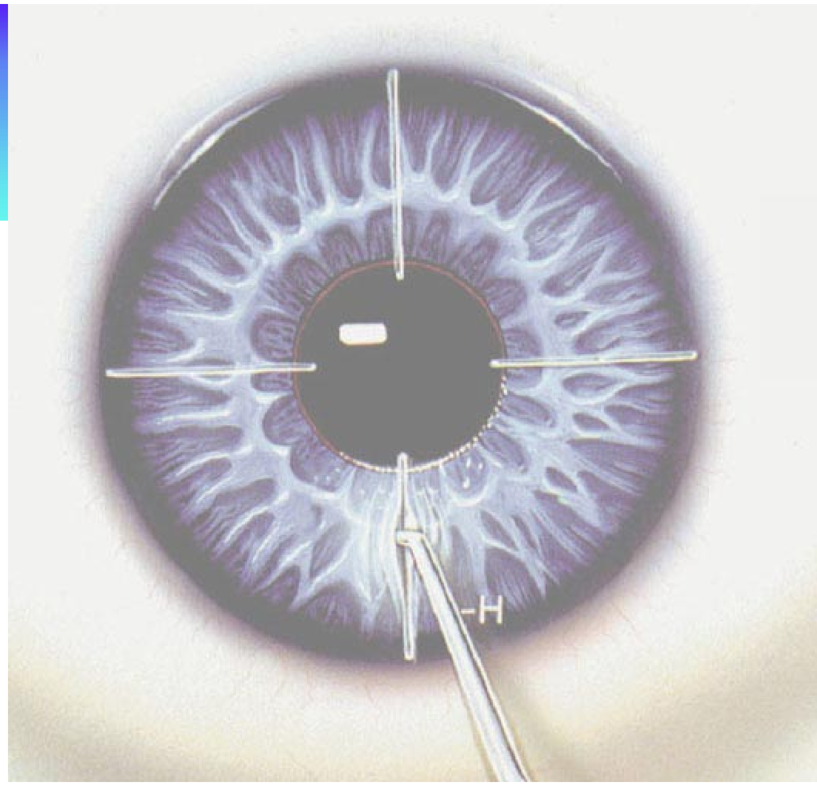




The Role of Enhancements

A retreatment or enhancement may be needed with all refractive surgical procedures. The fact that one, or both eyes, may need retreatment in no way implies a failure. It is the surgeon's responsibility, however, to inform the patient about this possibility preoperatively. It is wise in telling the patient to use phrases such as "sometimes the surgery is done in two or more stages", may need "enhancement" or "touch-up", etc. As a matter of fact, the need for enhancements may be interpreted as a prudent and responsible way to manage a refractive error, particularly in cases of high ametropias.

The end result of the first operation may also be selected to meet the patient's visual goal and needs. Some patients prefer to see more sharply at far and others at near. Of course, everyone desires to see very well far and near but in some cases, this may not be possible.

Causes of Residual Ametropias

Unless the residual ametropia was done on purpose, such as ending up with small myopia to allow reading without spectacles, it is important to determine its cause.

The main causes are: 1) postoperative unstable refraction with changes in the spherical and cylindrical correction; 2) a poorly calculated or misdiagnosed ametropia preoperatively; 3) inexact calibration of the different parameters in the excimer laser computer; 4) a slightly humid stromal bed at the time of ablation with the excimer laser; 5) insufficient depth of the cuts with diamond knife or the use of non-optimal optical zone in cases operated with RK or astigmatic keratotomy; and 6) each patient has his or her own biological variables and responses independent of the refractive procedure performed.

ENHANCEMENTS WITH LASIK

When a patient has undergone a LASIK primary procedure and there is residual ametropia that the surgeon wishes to retreat or enhance, it is important to delay the second LASIK procedure until 2-3 months after the primary operation to allow for accurate corneal stability.

Preoperative Evaluation Before Enhancement

The post-op refraction and corneal topography must be stable before proceeding with the LASIK enhancement (Figs. 172, 173). It is also fundamental that adequate corneal thickness remains to allow performing another LASIK procedure. 250 microns residual tissue below the LASIK flap is essential, after either the primary or the enhancement procedure; or a total of 410 microns, minimal.

In some cases, corneal topography (Chapter 3) may help us in determining if the patient's remaining ametropia is due to a significant amount of residual ametropia or to an anomaly or deficiency in the primary operation as in the case of a decentration.

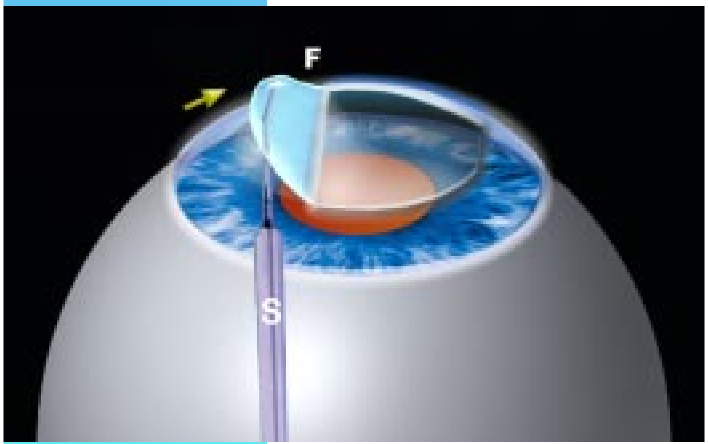


Figure 172: Enhancement with LASIK - Step 1

The inferior or the temporal border of the previously performed LASIK corneal flap (F) is lifted (yellow arrow) using a fine spatula (S), accompanied by irrigation with BSS.

Indications for LASIK Enhancements

The main indications are:

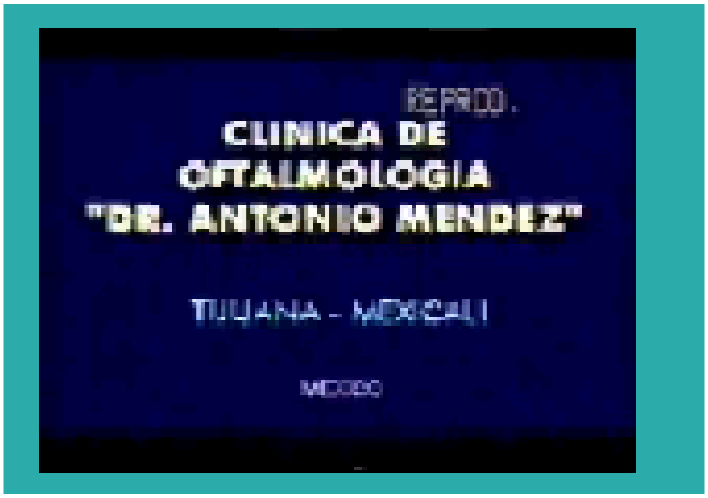
1) Residual myopia or hyperopia larger than 1 D.
2) Residual astigmatism larger than 1 D.
3) Visual acuity less than 20/40.

If the primary LASIK procedure is unsuccessful because of a decentration, or a patient unhappy with glare or with the correction obtained, the remaining options are limited.

Surgical Technique for LASIK Enhancements

This depends on each surgeon's preferences. The standard procedure is to lift the inferior or temporal border of the flap with a fine spatula and BSS irrigation. This is done very delicately to prevent migration of epithelial cells under the flap toward the center of the stromal bed (Figs. 172, 69, 70, 71, 72).

The stromal bed is dried with a sponge and additional pulses with the excimer are applied to obtain the ablation previously calculated, that will accomplish



Hyperopic **LASIK** After RK in Overcorrections (click over videoclip)

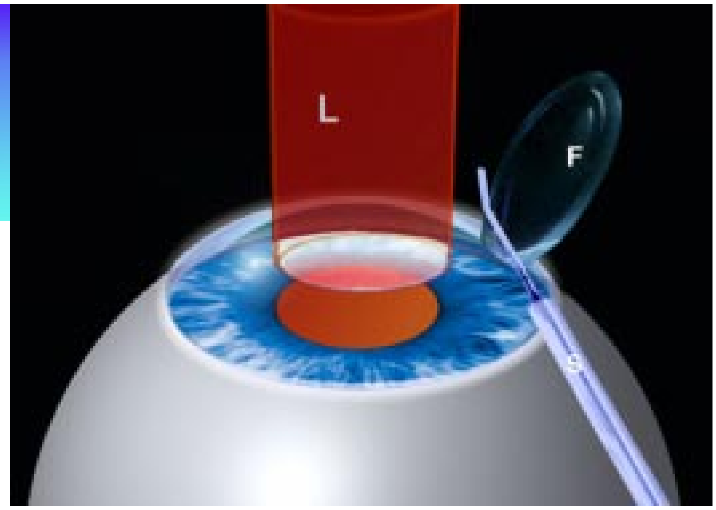


Figure 173: Enhancement with LASIK - Step 2

After lifting the flap (F), the stromal bed is irrigated with BSS to eliminate any epithelial cells that may have moved in when lifting the flap. The stromal bed is then dried with a sponge. After adequate centration and calibration of the laser, the excimer laser beam (L) is applied to obtain the desired ablation.

the correction the patient desires.

During and after the ablation it is important to maintain the corneal interface clean by means of a flat cannula with BSS irrigation (Fig. 173). With large undercorrections, the flap may be lifted earlier than 2-3 months and the stroma ablated. In most cases after 4 months, re-cutting the flap is preferable because a smoother surface is created and the risk of epithelial ingrowth is less (Figs. 69 - 72).

LASIK Enhancement Following an Unsatisfactory RK

Undercorrections following radial keratotomy (RK) may be due in some cases to insufficient depth of the incisions, or when incisions were made too short to correct the myopia. Hypercorrections, on the other hand, may be related to very deep incisions or more incisions than necessary, particularly in cases of low myopia.

The modern approach to these cases is to perform either a myopic LASIK or hyperopic LASIK as shown in Fig. 174 in which a standard LASIK flap and stromal ablation with excimer is done.

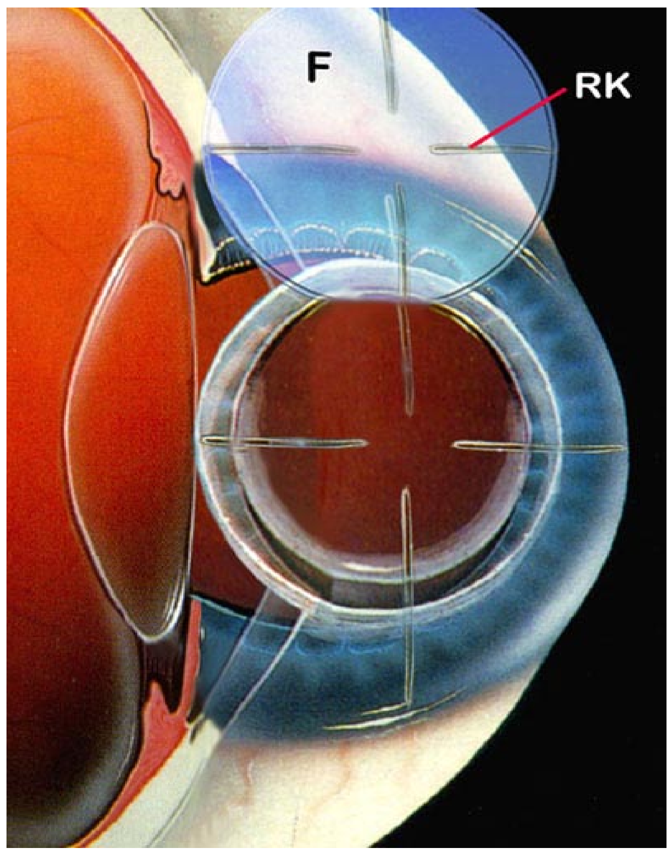


Figure 174: Enhancement with LASIK Following Unsatisfactory RK

The LASIK corneal flap (F) is elevated on its hinge. The scars from the previous RK incision are clearly seen both in the flap as well as the stromal bed.

Risks Following LASIK Enhancements

As in all operations, there may be risks. The following need to be taken into consideration:

1) Overcorrections
2) Epithelial ingrowth (Figs. 69-72)
3) Flap striae
4) Infection

Postoperative Care

In the specific case of LASIK, we must always be observant for a possible epithelial ingrowth. And, of course, determine the refractive outcome.

ENHANCEMENTS WITH PRK

The technique for corneal epithelial debridement (Fig. 75) in patients undergoing a second operation with PRK has given rise to some controversies. Some surgeons prefer to perform epithelial debridement directly with the excimer laser to prevent somewhat the reappearance of haze (Fig. 77). Whether this really works remains controversial. Other surgeons prefer to perform the conventional mechanical epithelial debridement with a spatula (Fig. 75) and proceed with the stromal ablation with excimer (Fig. 76).

It is highly recommended to wait from 3-6 months post PRK before doing an enhancement with the excimer laser. This will allow you to perform the PRK enhancement on a stable cornea.

ENHANCEMENTS WITH INTACS (ISCRS)

Daniel Durrie, M.D., who has extensive experience with **INTACS,** emphasizes that if a myopic or hyperopic enhancement after LASIK is indicated, and if the cornea's thickness remaining is too thin to perform a second LASIK, INTACS can be implanted to treat low, residual myopia or hyperopia. This is another important, new and safe procedure highly useful for enhancements.

Patient Selection

Whenever an enhancement with **INTACS** is contemplated following LASIK or PRK, the selection of patients is the same as if a primary operation with INTACS were to be done, as follows: myopia between 1 D and 3 D and astigmatism of less than 0.75, maximum 1 D.

Surgical Procedure for Enhancements with INTACS

The surgical technique for residual myopia with INTACS following LASIK or PRK is the same as if the primary INTACS operation were being performed (Figs. 83-86).

Enhancements Following an Insufficient INTACS Operation

If a patient previously had an INTACS operation and the myopic correction remains insufficient and the patient is unhappy, the following procedure is advisable:

1) Remove the INTACS segments and replace them either by: a) thicker ring segments to correct more myopia, or b) thinner ring segments to correct less myopia.

The INTACS segments are available in three thicknesses: 0.25 mm (corrects -1 D to -1.75 D); 0.3 mm (corrects from -1.75 D to 2.25 D); 0.35 mm, (corrects from -2.25 D to 3.00 D).

Of course, if the patient, or the surgeon, decide not to use INTACS for enhancements, the following options remain:

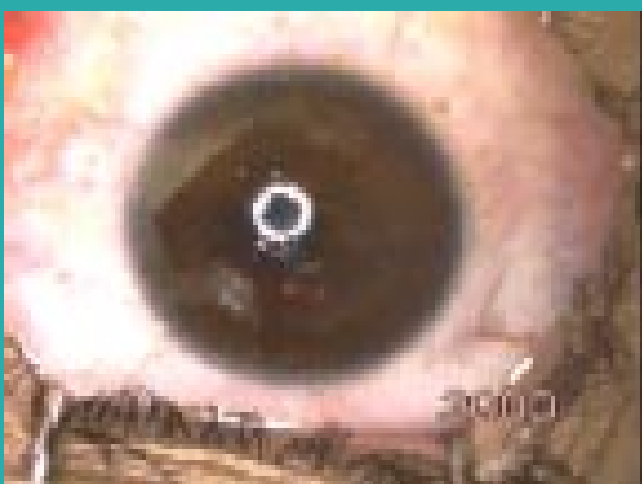
2) Remove the INTACS segments and perform another refractive procedure such as LASIK or PRK. In order to do LASIK or PRK, the INTACS first need to be removed.

3) Remove the INTACS segments, perform no other refractive procedure, and leave the patient with the preoperative refractive error, if he/she so prefers.

Enhancements with RK over LASIK

This is an unusual situation but must be considered. The indication is to correct a high myopia in patients who previously had a LASIK procedure but the full myopia was not totally corrected because of limitations in corneal thickness. Another LASIK cannot be performed. If a phakic intraocular lens is not available (Chapter 6), a four incision RK may be performed 6 months after the LASIK procedure (Fig. 175).

Enhancement of LASIK with RK
(Click Over the Videoclip)



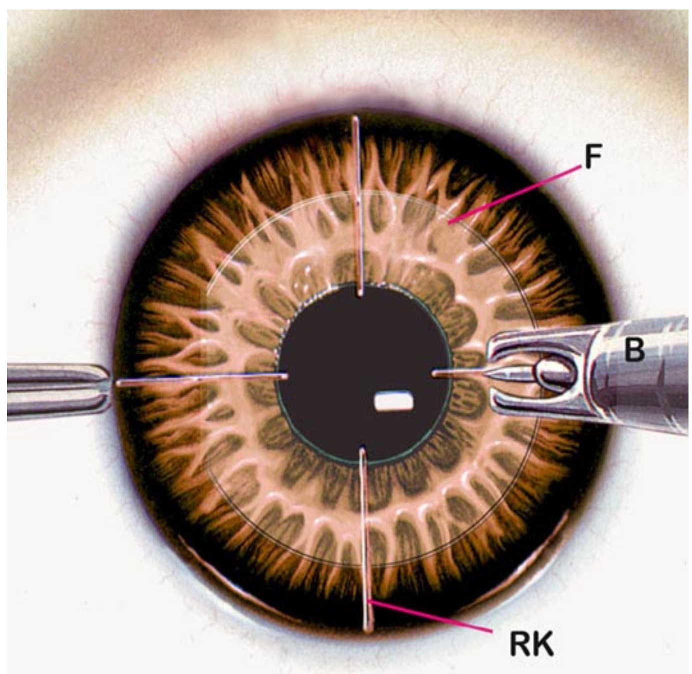


Figure 175: Enhancement of LASIK with RK

The border of the LASIK corneal flap previously performed is clearly seen in (F). A four (4) incision RK technique is made over the healed flap 6 months after LASIK. Diamond knife (B).

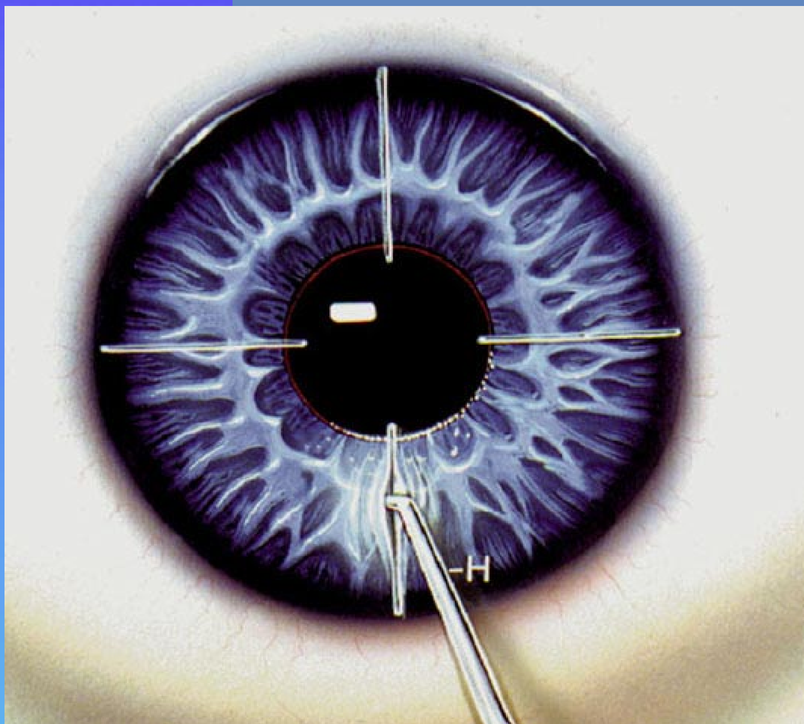


Figure 176: Enhancement for Undercorrected RK

The 4 (four) incisions from a previous RK are opened with a blunt hook (H) and the diamond knife, set to the depth of the primary operation, is inserted into the incision and moved centripetally and centrifugally in the incision until no resistance is felt. The procedure can be repeated several times with increasing effect, if necessary. Watch for any sign of perforation: the appearance of fluid in the incision.

Enhancements Following Incisional Keratotomy

Undercorrections

Buzard emphasizes that the three possible causes of an undercorrection with RK are: 1) a poorly planned operation; 2) shallow incisions; 3) a patient who under responds.

Errors in the preoperative plan can be easily checked. Shallow incisions are observed on slit lamp evaluation as incisions which do not appear to extend completely through the cornea on a thin slit beam directly adjacent to the clear central zone.

Patients who respond poorly to appropriately planned incisional refractive surgery are relatively rare and seem to be more common in the younger age group. Pregnant women have a remarkable ability to heal refractive incisions. Impending or coexisting pregnancy should be a contraindication to incisional refractive surgery.

Shallow corneal incisions are the most common cause of undercorrections and are easily corrected either in the operating room or at the slit lamp with **Buzard's** procedure (Fig. 176). Briefly, the incision is opened with a blunt hook and the diamond knife, set to the depth of the primary operation, is inserted into the incision and moved both centripetally and centrifugally in the incision until no resistance is felt. The knife is "bumped" against the paracentral end of the incision to eliminate any beveling of the incision.

The incisions are re-examined and if an undercorrection persists and shallow incisions are still present, the procedure can be repeated with a slight (0.02 to 0.03) extension of the diamond knife. If care is taken to remain within the incision(s), the procedure can be repeated several times with increasing effect. This procedure can be performed even several years after the primary procedure with good results and no corneal instability. Beware of perforation: watch for and stop if there is any appearance of fluid in the incision.

CHAPTER 10

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