Scientists have been trying to understand the basis for refractive errors since the time of Leonardo Da Vinci. Now with the latest innovations, over a period of fifty years, myopia, hyperopia and astigmatism can be treated with safety and predictability, using lasers. Extensive research has provided invaluable refinements & advancements of laser technology & diagnostic tools to develop safe & appropriate treatment options for patient with a myriad of refractive disorders. Laser – assisted in situ Keratomileusis (LASIK) is presently the most preferred elective procedure in the modern world. This review will discuss the history of refractive surgery, past and present technological advances and the future of refractive surgery.

History of Refractive Surgery
The first person to utilize incisional surgery to correct refractive error was Hjalmar Schiotz in 1885. In the 1940’s, Tatsuhiko Sato attempted to refine this technique. In 1948, Jose Barraquer of Bogota, Colombia, considered by many to be the father of refractive surgery, first performed corneal lamellar surgery to reshape the cornea. Barraquer removed a portion of the cornea, froze and reshaped it in lathe, and then sutured it to the eye with fine sutures, the precursor to LASIK surgery.

In the 1970’s and 1980’s there was a rapid infusion of new technologies for treating refractive errors including Radial Keratotomy (RK). Slava Fyodorov of Russia developed RK, a procedure in which 11-16 equally distanced incisions were made into the anterior cornea at a depth of approximately 90% leaving a clear central zone. Fyodorov noted, after treating a myopic boy who had an accidental corneal penetrating injury, that when the cornea healed, near sightedness was corrected. In 1978, the procedure was introduced into the U.S.

During the 1980’s, there was a revolutionary change in treatment of refractive errors departing from incisional to laser – assisted refractive surgery with the inception of excimer laser technology. In 1983, Stephen Trokel utilized the excimer laser to ablate the corneal tissue.

History of Lasers
The excimer laser was originally used for etching silicone computer chips in 1970’s. Working in the IBM research laboratories in 1982, Rangaswamy Srinivasan, James Wynne and Samuel Blum saw the potential of the excimer laser in interacting with biological tissue. Srinivasan and the IBM team realized that you could remove tissue with a laser without causing any heat damage to the neighbouring material. Dr. Steven Trokel performed the first laser surgery on a patient’s eye in 1987.

Basic Mechanism
Excimer laser doesn’t burn or cut material, but instead it produces energy that disrupts the molecular bonds of organized tissue; causing them to disintegrate through a process known as ablation. Ablation is the removal of material from the surface of an object by vaporization, chipping or some other type of erosive process. Excimer laser separates the bonds that hold the corneal cells together with sub-micrometer precision removing 0.25 microns of tissue with each pulse.

The term excimer is a short for “excited dimer”. An excimer laser typically uses combination of an inert gas (argon, krypton or xenon) and a reactive gas (fluorine or chlorine). The term excimer is strictly speaking a misnomer since a dimer refers to a molecule of two identical or similar parts. The correct but less commonly used name for such is exciplex laser. The wavelength of an excimer laser depends on the molecules used, and is usually between 157 and 351 nm.

Theo Sieler, a physicist and ophthalmologist from Germany performed the first excimer laser treatment on a blind eye in the mid 1980s. This was followed in 1988 in the U.S by Margaret McC Donald who performed the first treatment on a sighted eye with myopia.

Evolution of Refractive Surgery
In 1970’s Radial Keratotomy (RK) was developed in Russia. Radial cuts were made on the cornea which flattens the cornea on healing thereby reduces the myopia. In the 1970’s & early 1980’s RK was a wide spread procedure for correcting myopia. It has since been replaced by laser based refractive surgeries such as PRK & LASIK that offer improved image quality & outcome predictability.

Photo Refractive Keratectomy
Michael Gordon performed the first PRK procedure in the U.S with his Summit excimer laser in 1989. In PRK, the epithelium is removed and then the excimer laser removes bowman’s membrane and a few microns of anterior stroma (depending on the degree of myopia). In those early days
refractive surgeons were not aware of the importance of pupil size, corneal thicknesses, curvature of the cornea, dry eye syndrome etc. And, in most cases, they did not have the technology to evaluate those parameters. PRK obtained FDA approval for treating myopia in late 1995. It is still performed today in 10-20% of refractive surgery patients.

**Laser assisted in situ Keratomileusis (LASIK)**

LASIK is currently the predominant type of refractive surgery. Concurrent with the development of PRK, various techniques not involving the corneal surface were being developed. In the early 1990s, Lucco Buratto of Italy described a technique combing the two technologies that is using the blade of the microkeratome to make a corneal flap, with the micron accuracy of the excimer laser to remove tissue, instead of removing a button of corneal stromal tissue with a blade. Ioannis Pallikaris coined the name LASIK, which means removing tissue within the cornea. An advantage of LASIK is the avoidance of the corneal haze and pain associated with PRK. It leaves the corneal epithelium intact, avoiding the majority of nerve endings. Flap is created with the microkeratome or femtosecond laser & a hinge is maintained. The flap is lifted and the programmed excimer laser is focused directly on the eye. The flap is then repositioned and it is held in place by the natural osmotic gradient and endothelial pump inherent in the cornea (without sutures). Normogram and algorithms are developed for the computer – driven treatment, based on the individual surgeon’s technique and takes into account humidity, temperature, oxygen concentration, and other variables. LASIK was approved by the FDA is 1999, although it had been performed earlier in U.S by surgeons as an off-label procedure.

It has been 10 years since ophthalmology was captivated by the ability not only to acquire wave front measurements of the human eye but also to transfer these into a form of excimer laser treatment. This development allowed us to enhance the wave front of an eye by reducing higher order aberrations, either as a primary or secondary treatment.

In some countries wave front guided treatments achieve a high level of market penetration preferred by surgeons and patients alike.

**Wavefront Lasik**

**Defining higher order aberrations**

The subjective refraction method is the primary means for determining the proper patient corrective lens prescription, and has for the past 15 years or so, formed the basis for calculating ablation profiles to be applied to the cornea. The errors in the eye’s optical system, however, are not always limited to defocus and astigmatic errors. For example, it is possible for the focal power to change at different locations across the pupil. These effects cannot be described purely in terms of defocus or astigmatism, because they relate to changes in the defocus and astigmatism as a function of position. Therefore, they are called Higher order aberrations, while defocus and astigmatic errors are defined as Lower order aberrations. Examples of Higher order aberrations are changes in the focal power as a function of pupil diameter (predominantly spherical aberration), increased power in the upper half of the pupil, decreased power in the lower half (vertical coma), or increased or decreased power left to right (horizontal coma). These effects can be small and have relatively little effect, or they can dominate visual quality, causing starburst, glare, image ghosting or even monocular diplopia. With modern aberrometers, it is now possible to measure these higher order aberrations routinely in a doctor’s office. Further more, physicians can base corneal refractive surgery on this information to try to correct the aberrations causing the loss in quality of vision.

**Aberrometry**

Literally, aberration means deviation from its destined path. Optical aberration is the deviation of the wave front from its path. Aberrometry is the technique of measuring optical aberrations. Aberrometer measures the distortions of a light wave that is altered by the optics of eye. The unit of measurement is microns. Limits of ocular performance are determined by quality of retinal image by neural architecture and function of retina.

**Parameters that affect treatment**

Not all deviations in the Zernike polynomials are troublesome for human eye sight. The accuracy of wavefront correction is affected by several parameters including the level of accommodation in the crystalline lens, the degree of intraoperative cyclotorsion & pupil centroid shift. The latter is due to the difference between the dilated pupil when wave front measurements are taken and the smaller size of the pupil during treatment. An additional consideration is the change of normal wave front aberrations that occurs with aging.

In a healthy individual, high positive spherical aberrations of the cornea is partly compensated by negative spherical aberration induced by clear crystalline lens. A positive spherical aberration of more than 0.2 is considered clinically significant. Corneal surface contributes to the bulk of ocular higher order aberrations due to the high refractive index gradient between the air and tears.

**Clinical applications**

Wave front technology has added new understanding of the eye’s refractive characteristics. It offers theoretical guidance to reduce spherical aberrations by achieving the most effective prolate aspheric profile of the cornea.

Wave front LASIK improves the spherical aberration profile of the cornea. It also provides better visual function under
mesopic and scotopic conditions, where as conventional excimer myopic ablations produce significant mesopic and scotopic spherical aberrations because they negatively affect corneal asphericity.

**EPILASIK**

It was initiated in 2003 by Pallikaris whereby a blunt epikeratome is used to create a clear cut cleavage between basement membrane & Bowmans membrane lifting a 45-60 microns intact epithelial sheet. There is histological evidence of intact hemidesmosomes with no disruption of basement membrane integrity which controls the fibrotic activation of keratocytes & faster epithelial wound healing.

**LASIK**

Lasek has maintained its momentum with alcohol at 18-20 % inducing separation of the epithelium between the basement & Bowman’s membrane. The integrity of basement membrane is however naturally disrupted.

*Advantages of surface ablation*
- Conservation of corneal tissue by creating a thin flap
- Feasibility to plan larger optic zone.
- Thinner & steeper corneas with expectant microkeratome complications are ideally performed with surface treatments.
- Wavefront ablations perform better.
- Tear status recovery & contrast sensitivity improves faster than in Lasik

**Corneal Topography**

A pre-requisite to performing safe and precise laser refraction surgery is the ability to accurately measure the shape, thickness and contour of the cornea both pre and post operatively.

Corneal Topography has been used to measure the anterior surface of the cornea to detect and diagnose pathological conditions and plan refractive surgery.

There are two types of topographic imaging systems which is commonly available. Placido ring based system which measures curvature and slit lamp imaging system which measures height. The orbscan combines both the placido ring and slit lamp imaging technology for imaging the anterior and posterior surfaces of the cornea.

**Understanding Topography maps in Orbscan**

The normal cornea is prolate, meaning that meridional curvature decreases from center to periphery. Prolateness of the normal cornea causes it to rise centrally above the reference sphere. Green is “sea level” (match with a sphere that best matches the cornea). Warmer colors are above “sea level”. Cooler colors are below “sea level”. Orbscan gives a typical quad map consists of an anterior elevation map, a posterior elevation map, a curvature map and a pachymetry map.

Keratoconus can be diagnosed early with the help of Orbscan. Scanning slit technology demonstrate poor accuracy when attempting to image the posterior surface of the cornea, especially in cases of thin cornea or those that are post-operative refractive surgery.

<table>
<thead>
<tr>
<th>Red flags (For diagnosis of early cases of Keratoconus)</th>
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<tbody>
<tr>
<td>Anterior BFS/Posterior BFS</td>
</tr>
<tr>
<td>c&lt;1.22</td>
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<tr>
<td>1.22 – 1.27</td>
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<tr>
<td>Above 1.27</td>
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<tr>
<td>Power of posterior BFS</td>
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<tr>
<td>Above 5.2D</td>
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<td>On the posterior flat:</td>
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<tr>
<td>Highest point up above 50 µ</td>
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<tr>
<td>Difference between highest and closest lowest point:</td>
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<tr>
<td>Above 100 µ</td>
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<tr>
<td>Corneal thickness index (CTI)</td>
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<tr>
<td>Above 16</td>
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<tr>
<td>Butterfly or broken boseic pattern on the axial keratometric map</td>
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<tr>
<td>Quad Map – 3 step rule:</td>
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<tr>
<td>1 abnormal map</td>
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<td>2 abnormal maps</td>
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<tr>
<td>3 abnormal maps</td>
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<td>Caution</td>
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<td>Communication</td>
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The pentacam images the anterior surface of the eye by a rotating scheimpflug camera measurement which gives pictures in three dimensions. The measurement process last less than 2 seconds and minute eye movements are captured and corrected simultaneously.

**Microkeratomes**

Microkeratomes have come a long way since they first appeared in the early 1980's. This still is an evolving technology and has significant improvements in both, the safety and predictability of procedures. The newer automated microkeratomes have definitely helped to reduce the LASIK learning curve.

The microkeratome utilized to make the corneal flap was developed and refined by Jose Barraquer. Today, surgeons have many choices nasal or superior hinge, disposables or reusables, automatic or manual, mechanical or non mechanical microkeratomes. Among the newer mechanical microkeratomes, several offer automated advancement without using gears. Modifications in the blade angle approach, the oscillating frequency of the steel blade and the material of the blade (sapphire and diamond blade) have been attempted to improve flap cutting and reduce chatter and irregular astigmatism.

**Non mechanical Microkeratomes**

Majority of microkeratomes in use today are dependent on blade. Blades are vulnerable to damage and thus microkeratome safety will increase considerably if the blade is eliminated. This has led to the entry of two new entities:

1) Water jet based microkeratomes
2) Femtosecond laser ablated flaps.

The water jet based microkeratome is a non mechanical device which is capable of making clean reproducible flaps with a smooth interface. The cut is created by a high speed stream of saline propelled under ultra high pressure of about 15,000 Psi. The water jet device cuts are cleaner and smoother because they make inter-lamellar cuts.

**Femtosecond lasers**

A femtosecond laser represents a break through in ultra fast laser science. The laser uses an infrared beam of light to precisely separate tissue through a process called photo disruption by generating pulse as short as one quadrionth of a second. The laser beam is focused on a preprogrammed depth and position with in the cornea with each pulse forming a microscopic bubble. As the intralase laser moves painlessly back and forth, the bubbles connect to form a flap with no trauma to adjacent tissue, the entire process taking around 20 seconds. The surgeon then lifts the flap to allow treatment by excimer laser. Laser specifications which can be modified to meet individual patients needs include flap diameter, depth, hinge location and width and side-cut architecture. The intralase laser also creates a distinctive beveled edge flap which allows for precise repositioning and alignment after LASIK is completed.

**Solid State Refractive Laser**

Excimer laser technology using 193 nm wavelength for refractive procedures has been here for long time, but all changes / advancements happening are either in its firing pattern, beamsize, scanners or the software driving the basic excimer laser machine, but there has been no change in the technology of the heart of laser machine for a long time. Solid state lasers in ophthalmic surgery have meant increase energy efficiency as well as reduced size & cost. Presently, a new generation of ultraviolet generating solid state laser is becoming available for refractive surgery.

In 2004, Customvis came into the market with its patented technology of solid state refractive laser by the name Pulzar Z1, & set the pattern for a futuristic technology of refractive surgery. The 213nm laser of solid state laser origin delivers innumerable benefits from its earlier 193nm excimer laser.

**Advantages**

- There is no need to charge or refill gases.
- Less damage to optics.
- Less maintenance cost.
- Absolute silent working, no scary loud noise during ablation.
- Small & compact unit.

**Supracor**

It’s a new excimer laser treatment for Presbyopia. Technolas Perfect Vision has developed this entirely new corneal approach for treating presbyopia. This treatment has received CE mark approval & is now commercially available. Supracore is an aberration optimized presbyopic algorithm which is designed to be applied to Myopic, Hyperopic & Emmetropic eyes as well as post-Lasik eyes. It is not a monovision procedure. In this cornea is remodeled for far, near & intermediate visual acuity.
Conclusion

Over the past decade, refractive surgery has improved the quality of life in over 28 million patients with more than 95% patient satisfaction rate making it one of the most popular elective surgery procedures among all specialities of medicine. It is considered safe and has been approved by the military for Navy pilots and NASA astronaut candidates. Extensive research and technological advances in this field has enabled us to tide over the imperfections of this procedure and has made the procedure safer, providing much better visual results.

Laser refractive surgery has come to stay and will have much more advances in the days and years to come.

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