Customized Ablation

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such as the patient's pupil size, in dim and bright light, corneal diameter and thickness are important considerations prior to surgery. LASIK flaps are customized depending on ablation design, thickness, diameter and whether one is treating hyperopia, amyopia or astigmatism. Patients with thin corneas with high refractive errors require special consideration. These eyes may require thinner flaps (160 as apposed to 180 microns), reduction in ablation optical zone size based on the patient's scotopic pupil size, age and functional needs. Intraoperative pachymetry after creation of the microkeratome flap will be accurate in defining the amount of residual bed available for ablation. In corneas that are too thin to safely leave atleast 250 microns bed after LASIK, the use of phakic intraocular lens, or a combination of refractive surgery and intraocular lens (bioptics) could be considered. Ablation diameter includes considerations such as whether it is a hyperopic eye requiring large diameter ablations (8.5mm to 10mm) compared to myopic eyes (8.5 to 9.5mm). Individuals with astigmatism higher than 1.5D require larger flaps to have round effective optical zones with minimal aberrations. Ablation optical zones need to encompass the entire pupil under all physiological pupil diameters to reduce aberrations. Customization can be based on corneal topography or wavefront measurements.

Corneal topography guided ablation has been attempted on patients with regular and irregular astigmatism, decentered ablations, and central islands. The irregular astigmatism group is more challenging and may benefit most from corneal topography guided ablation as the systems become more refined

It is important to stress that corneal topography guide ablations will be more helpful in individuals with topographic abnormalities but have yet to demonstrate their, usefulness in patients with relatively normal corneas with regular astigmatism. Most experienced corneal surgeons use corneal topography to confirm that the astigmatism is regular and that there is consistency between the refraction astigmatism and that noted on corneal topography, but their astigmatic treatment is based on the refraction and not the corneal topography. The refraction accounts for the entire optics of the eye, not just the cornea. Algorithms that

What is customization?

Webster's directory defines customize as: "To build, fit, or alter according to individual specifications or needs". Corneal customization is based on our ability to detect significant optical abnormalities or wavefront errors and correct them. Customized ablation attempts to optimize the eye's optical system using a variety of spherical, cylindrical, aspheric, and asymmetrical treatments based on an individual eye's optics and anatomy, as well as patient needs and preferences. It can be used to improve optical quality in normal eyes as well as eyes with a typical aberrations caused by corneal scarring, penetrating keratoplasty, central islands, decentered ablations, and lenticular abnormalities.

<u>Ways to customize:-</u>

Creating an optimal retinal image requires consideration of several interactive factors. These include:-

- Functional
- Anatomical
- Optical

Functional factors require an understanding of the patient's individual needs and circumstances. Anatomical factors require the consideration of individual structural variations of each eye. Optical factors require an understanding of the unique refraction and aberration profile of the eye. All 3 factors must be considered when contemplating customized corneal ablation.

Functional customization includes considerations such as age, presbyopia, patient's occupational and recreational needs, refraction, and psychological tolerance. Experience has taught that treating younger patients with myopia more aggressively and hyperopia less aggressively than recommended is better tolerated since younger patients have a large range of accommodation on the other hand under correction for the older myope can provide functional near vision for many near tasks. Monovision consideration may be of benefit to presbyopic patients. Anatomic factors

1mm would not adequately treat the most common of higher order aberrations, namely spherical aberration and coma.

2. Spot Scanning Rate:- The frequency of spot placement is important with regard to hydration changes that occur over time, treatments that take too long can adversely affect tissue hydration. The scanning spot must not be more rapid than a rate that can be adequately followed by the tracking system. Finally a scanning spot must be nonsequential in its placement (one spot not directly placed next to the following spot), to avoid thermal build up and improper plume evacuation during treatment. Thus scanning has a number of advantages over bread beam lasers, which are associated with a high incidence of steep central island formation despite the implementation of anticentral island software. The central islands could occur due to a central shielding of subsequent pulses from trapped particles (laser plume) with in the center of the broad beam, as well as central fluid accumulation and inhomogeneities within the beam itself.

The scanning spot ablation with perfect overlap when using eye tracking demonstrates no inhomogeneities or hot spots producing smooth surfaces after ablation which result in better healing and refractive outcome, predictive of greater precision in wavefront customization. The impact of excimer laser photo ablation on the cornea produces a stress wave that propagates through the eye, with small spot ablation < 1.5mm. This energy dissipates beyond the corneal endothelium. For larger spots ≥ 3mm a pressure focus is found 7 to 8 mm behind the corneal endothelium at the level of posterior lens or anterior vitreous, this acoustic stress may lead to vitreoretinal or lens abnormalities, once again we see the benefit of scanning spot delivery.

3. Very Fast Eye Tracking:- During refractive laser surgery procedure, a significant amount of slow and fast eye and head movements occur that need to be compensated by an accurate eye tracking system to stabilise the laser at the planned ablation position. The sampling rate of the required eye tracking system is primarily determined by the repetition rate of the laser and should provide synchronous measurements with minimum processing delay. The processing delay creates a laser positioning error on the cornea, and this amount is determined by the speed of the current utilize both refraction and corneal topography are worthy of further exploration.

Wave front – guided corneal ablation is designed to correct the traditional sphere and cylindrical error of the eye and reduce the eye's higher order optical aberrations. Ablative corrections that reduce the optical aberrations of the eye will increase retinal image resolution (eg. Acuity) and contrast when perfected, such corrections could provide patients with better than normal vision and an era in which the expected outcome is evolving toward 'supervision'.

Measurement of the ocular aberrations can be accomplished in several ways, including using an objective aberroscope, a Shack-Hartmann wave front sensor, a Tscherning wave front sensor, a spatially resolved refractometer and many others are available while all the systems utilize ray tracing in one form or another, each system has a unique way of measuring the displacement of a ray of light from its ideal position.

Technology requirements for customized corneal ablation.

1. Scanning spot delivery.
2. Spot scanning rate
3. Very fast eye tracking
4. Wave front measurements device
5. Corneal topography à for topolink technique.

1. Scanning Spot Delivery:- Spot scanning or flying spot excimer lasers provide the technological platform to perform ablations of any shape.

Spot Size & Shape:- Most excimer laser systems today have beam diameters that can decrease to as small as 1mm, the shape of this 1mm beam could be either gaussian or top-hat pattern. A top hat beam created by a concentric iris aperture produces sharp ablation edges that overlap in the laser vision correction profile. A gaussian beam allows for very uniform overlap in the creation of ablation profile. A truly customized profile can best be created by a gaussian beam with ideal spot overlap. When implementing a gaussian pattern, the size of the spot must correspond to the resolution of aberrations being treated, an optical ablation zone diameter of 6mm would require a spot size of ≤ 1mm to correct fourth order aberrations. Therefore, scanning spot lasers ≥

for classifying the shapes of aberration maps is to conceive each map as the weighted sum of fundamental shapes or bases functions. Zernike polynomials are a set of basis functions used to describe the wavefront error of the eye. Wavefront error is important because it degrades the optical image, extent of degradation based on pupil size, larger the pupil, greater the wavefront error. Consequently, a post – LASIK patient may see 20/15 with a small pupil, but may have vision worse than 20/25 when the pupil opens up due to higher order aberration such as spherical aberration, which occurs when the ablation optical zone size is smaller than the pupil size, and the junction of the treated (ablated) and unablated cornea falls within the physiologically dilated pupil. Thus it is important to dilate the pupil the pupil for a wavefront measurement and the reason why large optical zones and blend zones (larger than the naturally pupil) are essential for custom ablation.

Steps involved in customized ablation:-

Laser / Wavefront interface:-

a. Capture and Comparison à the first step to properly linking up the wavefront device and measurement with the actual laser treatment is to ensure that the most accurate and reproducible wavefront has been captured and implemented.

b. Conversion to Ablation profile à next step in the process is converting the wavefront measurement into an ablation profile of tissue that needs to be removed from the cornea to correct the refractive error and higher order aberrations. In every instance of wavefornt customized ablation, a blend zone is necessary is necessary to produce a smooth transition between the correction of high order aberrations at the edge of the optical zone and the residual unablated cornea.

c. Transfer, Tracking & Alignmentà Linking up the wavefront with the laser is the actual transfer of the wavefront ablation information to the computer assisted input of the laser. The excimer laser tacker can then be engaged to align the laser pulse positioning with the movement of the eye. The computer matched custom ablation pattern is then precisely placed, addressing the higher and lower order aberrations.

5. Topolink LASIK:- A corneal topographer must be able to measure the elevation of the corneal movement and the delay time of the eye tracking and laser positioning systems.

As lasers move to smaller spot sizes the sensitivity to error in the positioning of the laser increases. An error in position of 0.1mm, for example, means for a 2mm broad beam spot profile approximately 10% of the energy of a single shot was applied to the wrong area. Whereas, for a gaussian small spot with standard deviation of 0.4mm, the same error means approximately 20% in mislead energy. Decentered ablation zone reduces nighttime vision and contrast sensitivity, increasing the higher order aberrations.

<u>Methods of maintaining Alignment: -</u>

Passive fixation à is the simplest method where the patient fixated on an alignment light. The surgeon minimizes decentration by suspending and recentering when large movements cause noticeable decentration.

Suction rings à that are fixed on to the cornea and held in place by the clinician, these rings may be decentered, lose suction during the procedure, distort the cornea, and interfere with airflow around the cornea.

Eye Trackingà for this, a sensing device such as a camera or photodiode (or a combination) acquires an image of the patient's eye. A processing subsystem calculates the position of eye from that image and a control system moves the laser beam to compensate for any change in eye position. The disadvantage of eye tracking includes the necessity of a specific illumination system eg: Infrared diodes or lasers. Drawbacks of this method include sensitivity to changes in pupil size, corneal surface, and illumination characteristics during the course of treatment.

4. Wavefront Measurement Device:- The Hartmann-Shack wavefront sensor utilises low energy laser light reflecting off the retinal fovea passing through the optical structures of the eye, creating an outgoing wavefront. The wavefront passes through a lenslet array; the imaged points are captured on a CCD camera. In a perfect optical system, the imaged points form a regular lattice array, in an imperfect optical system; the displacement of the points from the ideal accurately defines the degree of ocular aberration.

Wavefront error is the error between the actual wavefront and the ideal wavefront. A systemic method

iii. Presence of scatter is a minor source of image blur in young normal eye.

Retinal Limitations:- There is a fundamental retinal limitation to visual performance: the ability of photoreceptors to sample the retinal image, to differentiate a letter E from a period, the components of the letter E must be distributed over an adequate number of receptors to allow the components of the letter to be detected, thus the coarseness of the foveolar photoreceptors mosaic limits letter acuity independent of the quality of optics to some where between 20/8 and 20/10.

Neural factors: Just a s the optics blur the retinal image, the post receptoral visual system blurs the neural image. The nervous system however, can take advantage of improvements in retinal image contrast for spatial frequencies upto the limits set by the photoreceptor mosaic. Therefore, in an optically aberrated eye capable of neural limited acuity (20/10 to 20/8), improving the optics cannot improve acuity but will improve contrast for larger pupils.

à The other factor, which influences the outcome of customized ablation, is the corneal biomechanics. Corneas of differing thickness and elasticity will likely have a different biomechanical impact on ablation; variability of corneal hydration may limit the accuracy of tissue removal even with a perfectly accurate laser. The wavefront measurement profile, which is highly sensitive to the structure and orientation of the cornea, will likely change after making a corneal flap. Analysis of wavefront profiles after making a flap alone will need to be analyzed and factored into the ablation nomogram. Another very large variable is the healing of corneal stroma and epithelium following customized ablation. The correction of subtle aberrations can in part, be undone by filling in epithelium or remodeling stroma thus ablation algorithms will need to consider the wound healing aspect of wavefront guided laser vision correction.

The cornea and the crystalline lens undergo aging changes that may degrade the aberrations correction overtime. Only long term clinical experience will tell us how much real-life benefit we will derive from a custom cornea.

surface for it to be useful for planning customized ablation. Systems that only measure curvature may be useful for subjective evaluation of the corneal surface, but they are not adequate tools for customized ablation because lasers ablate in microns not diopters. Elevation based systems like the orbscan II provide a better basis for calculation of the required ablation. Orbscan gives corneal height data in microns.

Wavefront sensing devices measure the entire refractive state of the eye and cannot tell if measured aberrations are caused by the cornea or by a combination of effects of the cornea and crystalline lens. Corneal topographers give direct information on the shape of the cornea, which is unavailable from a wavefront sensor; they should be routinely used as a second opinion when planning a customized ablation. There are situations in which a wavefront sensor will not work well because wavefront-sensing devices must be able to send and receive light form the retinal surface without significant interference from the ocular tissue. In cases where corneal aberrations is predominant and contains irregularisations such as scar, ectasia, dystrophy and surgical complications like steep central islands corneal topography may be able to map ocular aberrations with higher resolution than current wavefront sensors.

Limitations of Customized ablation:- The main stumbling blocks to success are from the variability of the eye itself.

There are optical, retinal and neural factors that limit the finest detail we can see.

The optical factors include 3 sources of image blur in the human eye: diffraction, aberrations and scatter.

i. Diffraction at the eye's pupil is an important source of image blur when the pupil is small, becoming less important with increasing pupil size. Blurring by diffraction is unavoidable, quite unlike aberrations, which can be corrected.

ii. In addition to suffering from monochromatic aberrations, the eye suffers form Chromatic aberrations which cannot be corrected with laser surgery and the presence of which reduces the visual benefit when only monochromatic aberrations are corrected.

atleast not induce new aberrations for all physiologic pupil sizes to improve overall quality of vision.

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Conclusions: Conventional Refractive surgery is not ideal, but if outcomes hit the target and the eye's aberrations are reduced vision is improved. However if more aberrations are induced, vision is likely to be worse. Conventional surgery induces higher order aberrations like spherical aberrations and coma.

Our immediate goal should be wavefront-guided corrections that eliminate the spherocylindrical refractive error in individual patients and reduce or