Aberrometry and Customized Lasik

With rapid strides made in wave-front sensing technology and customized ablation, a paradigm shift has occurred in our perception of ‘vision’. We now realize that vision is not merely the ability to read the high contrast Snellen’s chart, but a composite dynamic specialized function, which varies according to the surroundings, lighting and contrast.

**What is aberrometry?**  Aberrometry is another means to measure optical aberrations or refractive errors. It measures the shape of a wavefront of light that has passed through the eye’s optics. Wavefront technology brings our understanding of the eye’s refractive characteristics to a new level.

Optical aberrations or refractive errors include myopia, hyperopia, astigmatism and higher order aberrations. The sphere and cylinder are termed lower order aberrations and can easily be corrected by glasses. Other optical aberrations, for instance coma, spherical aberration, trefoil etc, which are not corrected by traditional spherocylinder lenses are called higher order aberrations. Correction of such optical aberrations improves the optical transfer function and increases the contrast and spatial detail of retinal image. Wavefront guided customized refractive surgery is aimed at correcting higher order aberrations in addition to lower order aberrations.

The quality of an optical system can be specified in three different ways- point spread function, line spread function and wavefront aberration. The third way of specifying optical quality is by measuring the underlying optical aberrations rather than the secondary effect of these aberrations on the image quality. This is a more fundamental approach to the description of optical imperfections in the eye from which secondary measures can be derived.

**Wavefront**

If we have an eye with perfect optical system focused for distance, light from a point source on the retina will form a perfect parallel beam as it leaves the eye. A wavefront is a virtual surface perpendicular to these rays of light.

**Wavefront error / aberration**

Wavefront error is the error between actual wavefront and ideal wavefront typically defined within the area delimited by pupil. A variety of wavefront-sensing or aberrometry devices are available to measure it, which are employed to guide laser ablation during customized refractive surgery.

The three main technologies used for analyzing wavefronts are Hartmann-Shack aberrometry, Tscherning aberrometry and Laser Ray tracing. In Hartmann-Shack, the most common type of aberrometer a collimated HeNe laser beam is projected on the retina. The light reflected from the retina is imaged onto a lenselet array and sampled with a charged coupled device chip. An aberrated wavefront passing through this lenselet would produce varying shifts of these spots over their subapertures. The shift gradient of these spot positions is analyzed which gives an accurate account of wavefront error. There are two common algorithms for wavefront analysis: Zernicke polynomials (mathematical functions are used to describe complex shapes) and Fourier analysis (sine waves are used to reconstruct the wavefront). The normalized Zernicke polynomial, which represents total wavefront error as a series of terms that describe surface shape components with respect to angular and radially arranged basis functions of different frequencies and orders has been popular as the standard method to depict wavefront error. Common models in market are [1] The Zywave aberrometer [Trivitron healthcare, Bausch & Lomb], the wavefront guided treatment is popular as zyoptix [2] Alcon LADARWave [3] Nidek OPD scan II wavefront aberrometer, [4] Topcon KR-9000 PW Wavefront Analyzer [5] Ziemer Maxwell Optical Wavefront Aberrometer.

**Zernicke polynomials**

1st order – Tip, Tilt

2nd order – Defocus [plus or minus spherical power Z [2,0], Oblique astigmatism[Z2,-2] and ATR/WTR astigmatism [Z2,2]

The first and second order aberrations are called lower order aberrations, which are corrected by glasses. Third order and above are termed higher order aberrations.

3rd order – Vertical coma [Z3,-1], Horizontal coma [Z3,1], Oblique trefoil [Z3,-3], Horizontal trefoil[Z3,3]

4th order – Spherical aberration [Z4,0], Oblique quadrafoil [Z4, -4], Oblique 2nd order astigmatism[Z4,-2], WTR/ATR 2nd order astigmatism [Z4,2], Quadrafoil [Z4,4]

However, the main limitation of the Zernike method is that it only utilizes a subset of the acquired data points (typically the amount necessary to produce a 6th order image). The optical aberrations are reported as the root mean square (RMS) by combining Zernike coefficients. This strategy works well for the more common lower-order shapes but is less accurate in eyes with highly aberrated wavefronts. Fourier analysis, on the other hand, uses all the Hartmann-Shack data points to derive the precise shape of the wavefront.
(equivalent to the 20th order Zernike image) and is likely to be better for evaluating highly aberrated eyes. [Common model –Wavescan wavefront system, VISX, AMO]. Fourier analysis has also the advantage that it is independent of pupil shape. Zernicke method requires a round pupil for wavefront analysis.

In Tscherning aberrometry, a collimated laser beam illuminates a mask with a regular matrix of 168 pinholes to form a bundle of thin parallel rays. These rays form a spot pattern on the retina, which is captured by a CCD camera by indirect ophthalmoscopy. [Common model –Wavelight analyzer, Wavelight Allegretto, Alcon]

In laser ray-tracing technique, a thin infrared laser beam is projected on to the retina and location of the reflection is studied one by one in succession over 64 sampling points. The procedure is fast, done within 0.06 seconds so that eye movements do not interfere with measurement. [Common models – iTrace, Tracey technology, Topcon iTrace Combo Visual Function Analyzer]

In the normal eye higher order aberrations are relatively small, comprising 10 – 15 % of the aberrations of the eye \( K^{15} \). The limits of refractive surgery with the present technology make any attempt to address any aberration more than 4th order redundant. All aberrations are not equal. Defocus decreases acuity more than astigmatism, coma decreases acuity more than trefoil, and quadrafoil causes much less visual deterioration than secondary astigmatism. Higher order aberrations of the eye are generally much smaller than defocus and astigmatism. The wavefront variance generated by higher order aberrations is less than would be generated by 0.25D of defocus \( 8,9 \). Hence the eye needs to be stable and measurements very reliable to assure the success of higher order corrections.

**Importance of wavefront**

Wavefront error is important because it degrades the optical image, the extent of which is dependent on pupil size. Larger the pupil, larger the wavefront error \( K^{15} \). The ratio of optic zone diameter to pupillary diameter [fractional clearance] has a significant effect on higher order aberrations in wave-front guided LASIK \( K^{11} \). A person who has undergone myopic LASIK surgery may be comfortable on a sunny beach [with a small pupil of 2mm] but will find the spherical aberrations troubling him while night driving in a highway. In a conventional LASIK laser ablation has been steadily improving, resulting in better quantification of wavefront aberration and precise excimer laser ablation, visual outcome following customized excimer laser ablation has been steadily improving, resulting in better patient satisfaction and acceptance.

In aspheric treatment mode, prolateness of the cornea is increased in order to reduce spherical aberrations. The curvature of an ellipsoid can be expressed through an asphericity quotient or Q value. The Q value of a sphere is 0, while Q value of a prolate ellipsoid is negative and for an oblate ellipsoid positive. A perfect prolate ellipsoid has a Q value of -0.52. The average Q value of human cornea is -0.26 and is half way between a perfect ellipsoid and a sphere. Myopic refractive surgery makes the cornea oblate, ie flatter in the center and steeper in the periphery. Such a cornea will have a positive Q value and more of spherical aberrations. Spherical aberration accounts for the major bulk of higher order aberrations [HOA] after refractive surgery and hence aspheric treatment alone may suffice in most patients. In aspheric treatment mode, prolateness of the cornea is preserved as much as possible. The excimer laser beam profile is designed in such a way to ablate more tissue in the periphery so that disturbance of Q value is less \( K^{11} \).

**Conclusion**

Aberrometry as a science continues to evolve. With accurate quantification of wavefront aberration and precise excimer laser ablation, visual outcome following customized excimer laser ablation has been steadily improving, resulting in better patient satisfaction and acceptance.

**References**