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Technology Requirements for On-Target Wavefront Results

This year marks a major milestone. Four years ago the FDA approved wavefront-guided LASIK to treat myopia. Alcon LADARVision / LADARWave was the first FDA-approved platform. Since then, several others platforms have emerged. Treatment ranges have been expanded. New applications have been explored. Major refinements have been accomplished. But the fundamental requirements of the accurate wavefront-guided laser vision correction have remained the same.

Regardless of the refractive error we plan to treat, regardless of the aberration pattern we attempt to eliminate, regardless of the mathematical formula we chose to describe the imperfections in our vision system, the technology that we select to accomplish the most accurate correction must fulfill 3 fundamental requirements: it must accurately CAPTURE the aberrations, it must accurately MATCH the map of the aberrations with the corneal treatment zone, and it must accurately TREAT not only the larger imperfections, the sphere and cylinder, but also the more complex, higher order ones to insure great vision both day and night.

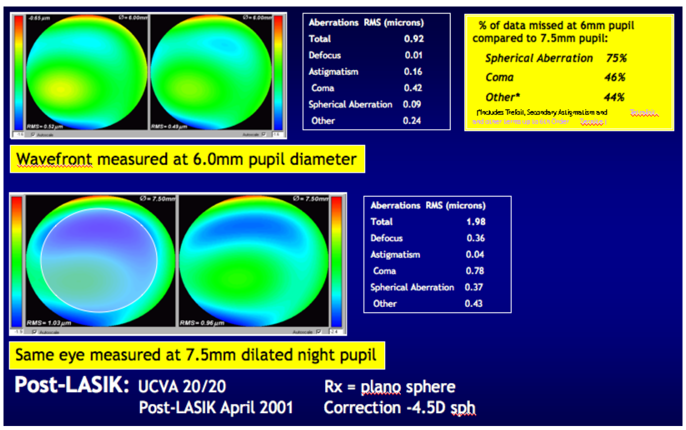

Figure 1: The scotopic pupil of 7.5 mm has 75% more spherical aberration and 46% more coma aberration than the photophic pupil of 6.0 mm in the same patient. If only the 6.0 mm wavefront was measured and treated in this patient, most of the spherical and coma aberrations would have been left untreated and likely to result in glare and haloes at night.

CAPTURE

- **Wide range of aberrations**
- **Wide area of aberrations**

Both Zernicke and Fourier polynomials describe many different shapes of higher order aberrations. Quality of vision has been correlated with higher order aberrations[1]. In order to improve the quality of vision with laser vision correction, we must treat as many aberrations as possible. In order to treat them, we must first detect and map them. Hartmann-Shack wavefront sensors utilizing >100 spots, created by >100 lenslets focusing aberrated light onto a CCD detection array have proven to be the most sensitive detectors of higher order aberrations, capturing up the 8th order[2].

Most aberrations become significant at night, when the pupil dilates (Figure 1). Therefore, they must be detected and then treated over a large pupil area. The data must be the real measured data over the entire optical zone that will be treated. Some system collect the data over a 6.0 mm optical zone, for example, and then estimate the data in the surrounding 0.5 mm annulus, based on the data in the 6.0 mm optical zone (Figure 2). Studies show, however, that estimated aberrations are, on the average, 18% higher than the actual measured aberrations (Figure 3) [3]. Therefore, if we treat the patient based on the estimated map rather than on the measured map, we would overcorrect him, inducing new aberrations.

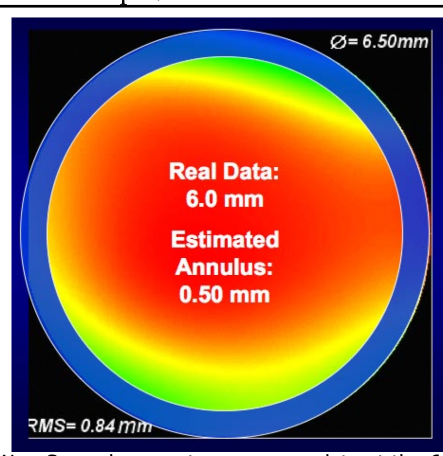

Figure 2: WaveScan aberrometer measures data at the 6.0 mm optical zone, then estimates the data in the surrounding 0.5 mm annulus.

MATCH

- **Centration**
- **Cyclotorsion**

Studies have shown that pupil center shifts inferonasally when the pupil dilates[4,5,6]. Therefore, measuring aberrations over dilated pupil and then treating them over undilated pupil results in decentration of wavefront-guided ablation and induction (rather than reduction) of higher order aberration. The pupil center shifts even if the pupil is just mildly dilated in a very dark room or with a mild mydriatic. Systems that measure the wavefront map over dilated pupil (even slightly dilated) and then treat over undilated pupil will most likely decenter their ablations in the superotemporal direction and induce aberrations rather than treat them. This defeats the purpose of wavefront-guided ablation. To accurately superimpose the center of the wavefront map on the center of the natural pupil, we must rely on fixed, rather than shifting landmarks. With LADARVision / LADARWave system, for example, centration photos are taken prior to pupil dilation. The software calculates and "memorizes" the relationship between the limbus and the center of the natural pupil. The limbal ring is then used as the landmark throughout the wavefront mapping and the treatment. The fixed relationship between the limbal ring and the center of the natural pupil assures accurate centration of the wavefront map over the center of the natural pupil.

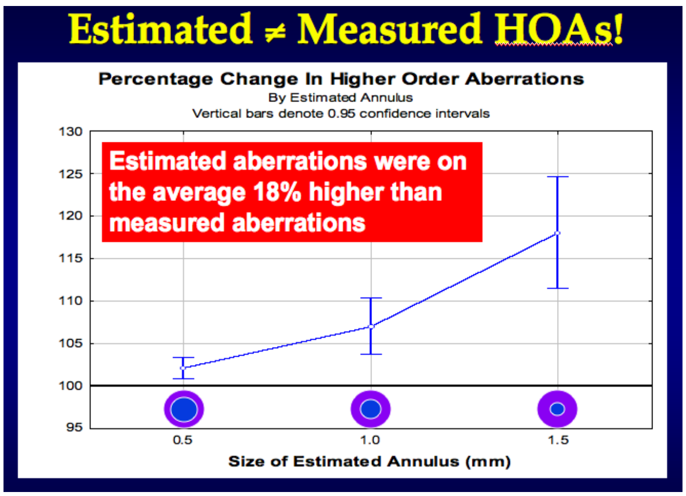

Figure 3: Aberrations must be measured, rather than estimated, to avoid overestimation and overcorrection of aberrations.

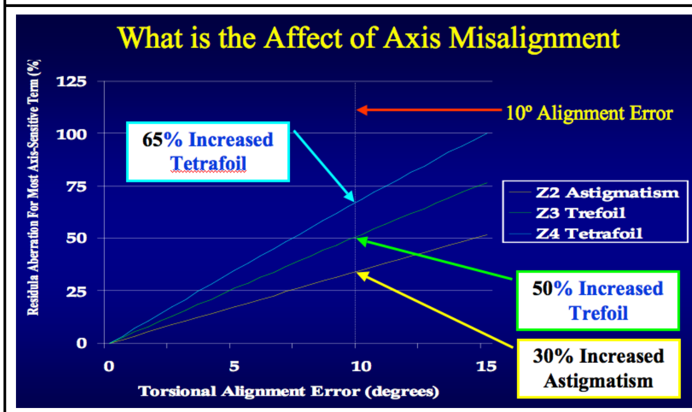

Figure 4: Ten degree misalignment between the map and the treatment surface results in inaccurate correction

Figure 5: Limbal registration with horizontal reference marks assures accurate match between the wavefront map in the supine position and the eye in the reclined position.

Most eyes cyclotort when patient lies down under the laser.[7] Treatment misalignment of even 5 degrees creates a clinically significant residual postoperative RMS error of 0.5 microns for a 6 mm pupil when treating a -3.00D of cylinder.[6] A 10 degree alignment error between the wavefront map and the position of the eye, results in 30% increased astigmatism and 50-65% increase in higher order aberrations (Figure 4). Therefore, if a system lacks the ability to accurately match the wavefront in a sitting position to the eye in a reclining position, the accuracy of the treatment will decline, and significant aberrations will be induced.

There are two methods of addressing rotational misalignment between the supine map and the reclining eye: limbal registration and iris registration. With iris registration, iris landmarks are identified with the patient sitting up at the WaveScan. The software then attempts to match these landmarks to the iris as the patient reclines under the laser. This system is accurate 50-80% of the time. The WaveScan is generated in a dark room and often with the aid of a mild mydriatic. A slightly dilated pupil obscures the position of many iris landmarks that may suddenly become apparent when the pupil is constricted by laser light during the ablation itself. Also, the position of the landmarks in a slightly dilated pupil may shift when the pupil constricts. Additionally, hippus of the undilated pupil results in constant iris motion during the ablation and a moving target effect of the iris landmarks. Clearly, a system with fixed, constant, and obvious landmarks is preferable to insure accurate match between the map and the eye. Limbal registration with horizontal reference marks provides this solution 100% of the time (Figure 5).

TREAT

- **Fast, closed-loop tracker**
- **Small Gaussian beam**

To accurately follow and track saccadic eye movements during patient fixation, 100 Hz closed-loop bandwidth tracker is required.[2] This means that the tracker must sample the position of the eye at least 100x10=1000 times/sec to accurately compensate for the natural saccadic eye movements. Once the position is detected, the mirrors that direct the laser energy must be quickly repositioned to the new eye location so that the beam is always on target, regardless of small eye movements. For example, LADARVision tracks the eye at a frequency of 4000

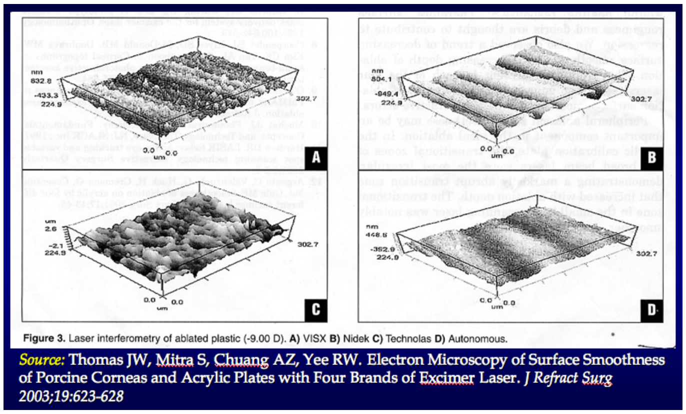

Figure 6: Small scanning Gaussian beam is essential for smooth surface ablation

times/sec and the internal mirrors reposition quickly in less than 10 milliseconds, creating a closed-loop tracker assembly that verifies that the laser treats an unwavering image of the eye during any eye movement – from the natural saccades to the large amplitude nystagmus.

Small scanning beam of Gaussian shape is another essential requirement for wavefront-guided customized ablation.[2] Such uniformly overlapping beam allows for the smooth corneal surface which is essential to creating a smooth "canvas" upon which the custom correction is placed (Figure 6).[8] Furthermore, the smaller the beam, the finer the aberrations we can correct. For example, Huang D et al demonstrated that decreasing the spot size, increases the order of aberrations we can correct.[9] Beam diameter of 2 mm can correct only 2nd order aberrations, i.e. sphere and cylinder only. The beam diameter must be 1 mm or less to correct higher order aberrations.

As the words "wavefront" and "custom" become more and more commonplace, we must constantly analyze the rigors of the technology behind these words to assure that it delivers on its promise.

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The Secret to a Great Wavefront Map: the O.D.

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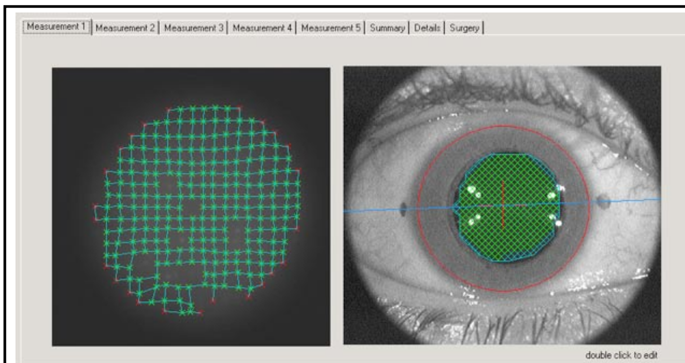

Figure 7: Unusable wavefront map due to corneal dry spots and unstable tear film

We all know by now what wavefront technology is and what it is used for, but what does it take to make a good wavefront map? It seems simple enough; just align the eye and press the button to scan. However, to take wavefront to the next level of accuracy and effectiveness, the process starts in the exam room.

A good refraction is the key to capturing a good wavefront map. The wavefront map is great at measuring higher order aberrations and guiding the laser in treating the eye to reduce the chance of having induced glare and halos, but that's not all we're looking at. What is a good Custom Wavefront treatment without addressing the refractive error, as well? The aberrometer treats refractive error as a lower order aberration. It measures defocus and astigmatism and the laser treats the eye as such without any subjective feedback from the patient. Anyone who has ever used an autorefractor knows that the subjective and objective pre-

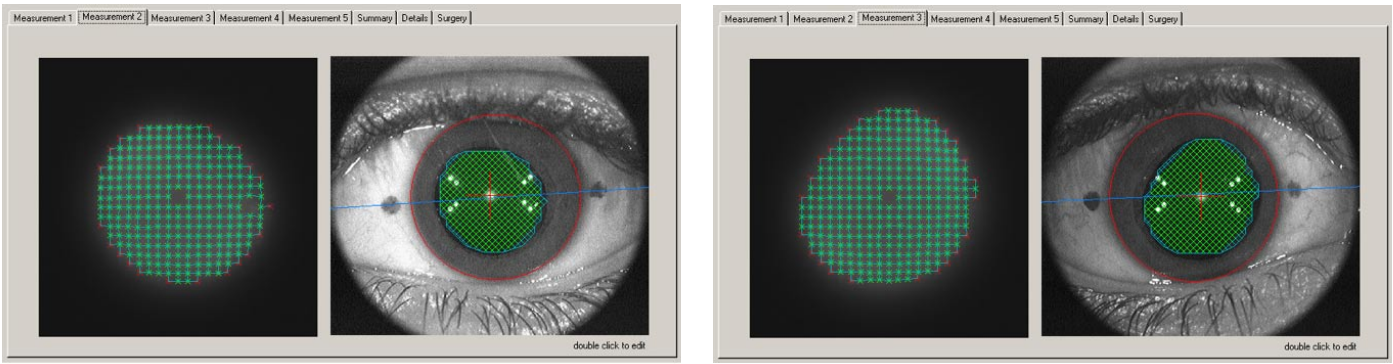

Figure 8: Trichiatic eyelash resulting in the absent data point (left). Epilation restored the integrity of the wavefront map (right)

scriptions can differ. Refractive astigmatism can differ from corneal astigmatism. The patient may be accommodating through the instrument. The patient may or may not notice the difference between -1.00 and -1.25D of cylinder. The aberrometer does not know these things as it processes its map, but the doctor does and should use this knowledge to distinguish between a good map and a bad one. The doctor has to know if they are satisfied with the map they just took or if they should take another one. Because the patient goes directly from the mapping to surgery, the maps that you just took are all you have to choose from.

When I refract a patient at pre-op, I look at the autorefraction and K readings to get a better sense of the physical properties of the patient's eyes. As you know, vision is a combination of how the eye is anatomically and how the brain interprets the visual stimulus. The cylinder measured in the wavefront map can often resemble the astigmatism found in the K readings so I make sure I push the cylinder during the refraction to see if the patient would accept such a correction. If there is too large of a discrepancy between refractive and corneal cylinder, then the wavefront may under- or over- correct the astigmatism and the patient will end up with blur. You also want to push plus in the sphere, but sphere can be adjusted in the wavefront scan for surgery whereas cylinder cannot.

Tear film plays a big part in wavefront mapping. Dry spots can skew data points in the Hartmann-Shack grid and create irregularity in the map (Figure 7). An irregular tear film can also induce cylinder in the wavefront refraction. Unstable tear film and SPK should be noted in the pre-op and treated with artificial tears prior to the surgery day. An optometrist performing the mapping can detect dryness during the scanning process and use artificial tears to improve the map. I had one instance where I noticed a persistent dry spot in the map and noticed an eyelash turned in towards the cornea. I epilated the lash and the dry spot vanished (Figure 8). Pay close attention to corneal scars and cataracts as they, too, can distort the wavefront map. Sometimes, switching to conventional LASIK is the better option.

Great attention to detail is needed to get great wavefront results. It all starts with a good refraction and ocular health check and ends with a clean wavefront scan where the refractive Rx matches the wavefront Rx. While mapping the eye, I always take the extra time to make sure everything looks good and the patients always appreciate it. ■

Sight Gags *by Scott Lee, O.D.*

2006 calendar of the Upcoming Events for PVI Affiliated Doctors:

09/14/06: PVI Grand Rounds - Conductive Keratoplasty (CK)
10/18/06: Staff Training
11/15/06: PVI Grand Rounds - Retina

Note from the Editor-in-Chief: *Thanks for reading and your continued interest in the latest in high technology eye care. We always appreciate your comments and feedback! drlee@pacificvision.org.*