The VISX Perspective on Fixed vs. Variable Spot Scanning Ablation

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VARIABLE SPOT SCANNING FOR CORRECTING ABERRATIONS

The VISX technique for performing wavefront ablations uses variable spot scanning (VSS) on the STAR S3 Excimer Laser System. This technique is analogous to painting a room with large brushes for speed and small brushes for detail. With this technique, a laser beam of varying size is scanned over the corneal surface during the laser ablation process. The laser beam does not have a top hat energy profile distribution. Rather, the laser beam is composed of seven overlapping beams that smooth the ablation near the edge of the beam. The laser beam size varies from about 0.65 mm to 6.5 mm as the laser beam scans over the surface. During the scanning of the laser beam, the center of the beam moves over the corneal surface. The displaced position and size of the laser beam for each pulse of the treatment is calculated prior to the ablation. To calculate the position and diameter of each pulse in the treatment, a target ablation shape is defined. The target ablation shape may include irregular ablation shapes to address coma, spherical aberration, and trefoil. Therefore, the target ablation shape is not limited to simple shapes such as spherical, cylindrical, and toric surfaces.

ABLATING HIGHER ORDER ABERRATIONS

The VISX approach to performing wavefront ablations is to define the entire wavefront error in optical path difference relative to a plane wave. This entire wavefront error includes both defocus and astigmatism, and the higher order terms such as coma and spherical aberration to sixth order (Fig 1). The left panel of Figure 1 shows the entire wavefront error of a patient on a scale of 19 µm. The right panel of Figure 1 shows the higher order aberrations of the same patient on a scale of 4 µm. This patient has unusually large amounts of higher order aberration induced by a decentered ablation. However, the overall wavefront is a smooth surface (left panel of Fig 1). The ablated target shape on the cornea is calculated from the measured elevation of the entire wavefront error. With our approach, the entire wavefront, including higher and lower order aberrations, is simultaneously corrected during the ablation. Therefore, characterizing the ablation for individual Zernike polynomials is inappropriate for our approach. The variable spot scanning ablation algorithm is able to solve for the complex ablation shape required to correct the aberrations (Fig 1) to better than 0.25 µm.

VARIABLE SPOT SCANNING—A SIGNIFICANT ADVANTAGE IN SPEED OF ABLATION

To provide treatments with comparable times, small spot lasers ablate tissue at laser pulse rates that are 10 to 20 times faster than a variable spot scanning laser, such as the VISX STAR S3 Excimer Laser System. At high laser pulse rates, the plume of ejected corneal material builds up above the ablating corneal surface. The plume does not remain in one isolated area. As shown in Figure 2, a small spot scanning laser with a 1-mm beam pulsing at 250 Hz will produce a cloud of debris that hovers over the ablating surface. This cloud of debris will partially occlude a laser beam that passes through it. This partial occlusion of the penetrating laser beam will change the energy profile of the laser beam on the ablating corneal surface. This change in the irradiating beam energy profile causes errors in the ablation. These ablation errors appear both as a roughening of the ablated surface and as errors in the ablation profile relative to the target ablation profile. With variable spot scanning operating at lower laser pulse rates, the plume is aspirated between subsequent laser pulses. Many small fixed spot lasers do not provide an aspirator to remove the plume of ejected material.

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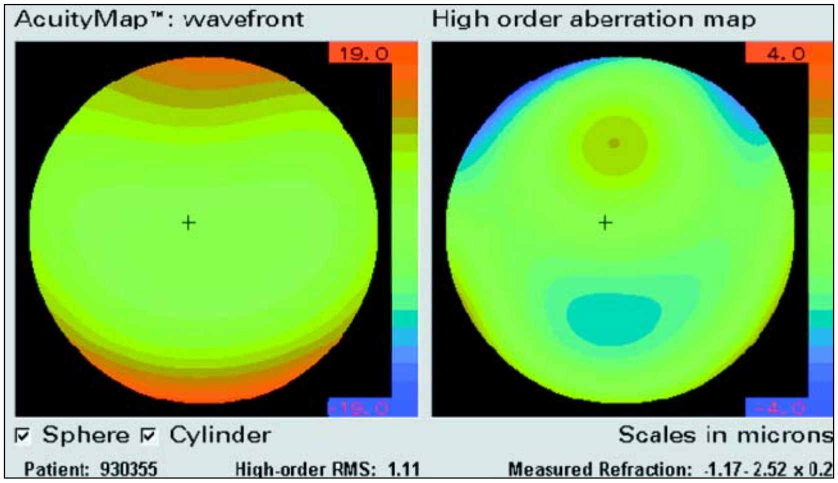

Figure 1. Wavefront map of an eye with unusually large levels of high order aberration.

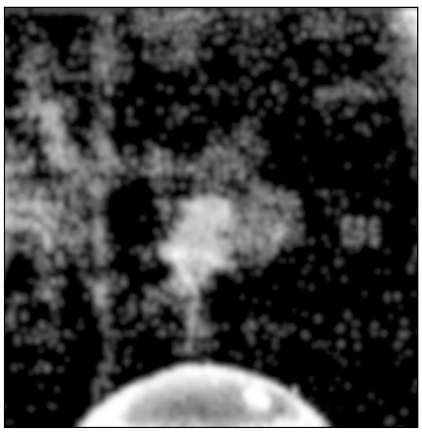

Figure 2. Image of a debris cloud forming over a cornea ablated with a 250 Hz, 1-mm scanning laser beam.

BEAM HOMOGENEITY AND CENTRAL ISLANDS ARE NOT A PROBLEM FOR VARIABLE SPOT SCANNING

With the variable spot scanning technique, the laser beam scans over the surface during the ablation. The profile of the laser beam is carefully checked and qualified by measuring ablated plastic before surgery. An additional test is made with a plastic PreVue lens that is ablated with a patient's planned treatment. With this lens, the patient must read better than 20/20 on an eye chart. Ablating a PreVue lens with the laser checks both the laser and the measured wavefront. If significant errors in the laser beam profile or measured wavefront exist, the patient will not attain a high level of visual acuity through the PreVue lens, and will not be treated.

ACCURACY AND SPEED OF THE VISX STAR S3 EYE TRACKER COMMENSURATE WITH A 0.65-MM BEAM

Eye motion has been extensively studied during LASIK with the VISX STAR S3 Excimer Laser System. An internal study analyzed the motion of 45 eyes during LASIK at a local clinic. These data showed that eye motion with the VISX STAR S3 laser tended to be slow, with relatively little saccadic eye motion. The Fourier transform is an appropriate technique for analyzing the rapidity of eye motion. By plotting the power spectrum of the eye motion from a Fourier transform, the amount of eye motion that occurs at different frequencies can be determined. The distribution of eye motion in the study showed over 95% of the energy in the power spectrum to be 10 Hz or less. Therefore, an eye tracker in the VISX STAR S3 laser with a total response time of 100 ms is highly appropriate for tracking during laser vision correction.

Both the accuracy and speed of the VISX STAR S3 eye tracking system have been measured. The accuracy of the eye tracker has been measured by comparing the motion of the limbus, an independent anatomical feature, to the motion of the pupil. The error was about 25 µm—substantially less than the 0.65 mm minimum beam size. The time delay from when the eye moves until the VISX STAR S3 laser beam is in position has been measured at less than 100 ms.

PRIMARY ADVANTAGES OF VARIABLE SPOT SCANNING

The primary advantage of variable spot scanning is that it is an integrated approach for simultaneously correcting both lower and higher order aberrations without compromising treatment times or ablated surface quality. This technique has enough detail for correcting aberrations found in both healthy eyes and pathological eyes. Variable spot scanning ablates smooth surfaces on PreVue lenses that can be used to validate treatment before surgery.