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Instrument Basics, Part II: Anterior Segment Imaging

Featured Article

by Neil J. Friedman, M.D.

Neil J. Friedman, M.D.
Cataract Section Editor

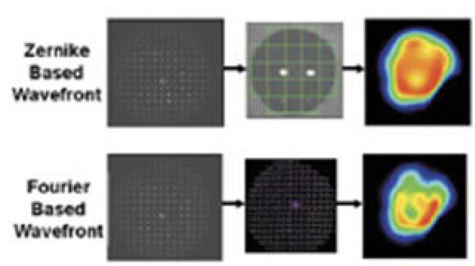
New ophthalmic devices now enable us to image, measure, and map the structures of the anterior segment. Initially, the ultrasound biomicroscope (UBM) allowed us to obtain high-resolution images of portions of the anterior segment that could not be directly visualized. The UBM is a 50 MHz B-scan ultrasound instrument used primarily for research purposes and at large academic centers to evaluate the angle and iris for foreign bodies and tumors, or the anterior segment through a cloudy cornea. Since its development, other modalities have emerged that give us even more detailed information about these structures.

Optical coherence tomography (OCT; Visante by Carl Zeiss Meditec) generates a two-dimensional image from a reflected light beam. The principle is similar to that of B-scan ultrasonography but uses light instead of sound, is non-contact, and provides higher resolution pictures. OCT is wavelength dependent: 1310 nm is optimal for anterior segment imaging (Visante) whereas 820 nm is best for retinal imaging (Stratus, Cirrus). The reason for this is 1310 nm has better water absorption, which decreases retinal exposure. Therefore, more power can be used safely; there is faster scanning (minimizes motion artifact), reduced scattering, and improved penetration into turbid tissue such as sclera, iris, angle, and opaque corneas. The Visante can image and measure all anterior segment tissues: cornea (thickness, LASIK flaps, incisions, wounds, dystrophies, scars), iris (tumors, trauma), angle (angle-closure glaucoma assessment, trabeculectomy patency, drainage device positioning), and lens (cataract location, implant position, accommodative IOL movement).

The competing technology is based on the Scheimpflug principle (Pentacam by Oculus, Galilei by Zeimer). These devices use one or more special cameras to achieve greater depth of focus and thus sharp images of the anterior segment. In a normal camera, the 3 planes of the object, lens, and image are all parallel; however, in the Scheimpflug camera, these planes are rotated so that they intersect at a single point or plane to enable greater depth of field. The instruments allow cataract densitometry, tomography, anterior chamber analysis, as well as corneal maps (pachymetry, topography and elevation of both the anterior and posterior surfaces).

Finally, wavefront aberrometry allows us to measure the higher order aberrations (HOAs) of the eye. Until recently, we were only able to measure sphere and cylinder and correct these low order aberrations with spherocylindrical lenses. HOAs were previously classified as "irregular astigmatism", but now we have devices that measure and map these HOAs.

Before discussing the principles and applications of wavefront analysis, let's first review some basic terminology. Image blur is due to a variety of processes. Light is scattered by the cornea and lens and a small pupil causes diffraction. Optical aberrations are divided into chromatic and monochromatic, which include the low order and higher order aberrations previously mentioned. A wavefront is a physical representation of the optical quality of a monochromatic light beam. A plane or flat wave is perfect. Deformation of this ideal wavefront is caused by imperfections in the optical system (cornea and lens) resulting in a disrupted shape. Hartmann-Shack refers to the most common aberrometry technology. This type of aberrometer measures the wavefront in one shot. This is faster, gives more data points, and has better repeatability than the alternative technology ray tracing, which takes consecutive measurements. Root mean square (RMS) is a measure of the optical aberrations by combining Zernike coefficients.



A wavefront aberrometer shines light into the eye and captures the reflected light as it travels back through the eye from the retina. The 240 Hartmann-Shack data points in a 7 mm pupil are then analyzed to produce an image of the wavefront. How the data is analyzed influences the image. The two most common algorithms are Zernicke polynomials, which uses mathematical functions to describe complex shapes, and Fourier analysis, which uses sine waves to reconstruct the wavefront. The Zernike method only uses a subsample of all the data points (usually to generate a 6th order image). This works well for more common lower-order shapes but loses precision in highly aberrated eyes. In contrast, Fourier analysis fully maps the Hartmann-Shack data to derive the precise shape (equivalent to 20th order Zernike) and can therefore resolve complex patterns. Wavefront analysis is applied clinically in an effort to improve vision. The goals of customized corneal ablation are to reduce LASIK-induced aberration, correct HOAs, and reduce glare and halos. Aspheric IOL technology compensates for corneal aberration and improves contrast sensitivity. Eventually, wavefront glasses and contact lenses may give us sharper vision.