IMPROVING AN IMPERFECT VIEW

The role of adaptive optics in monitoring retinal disease.

BY THOMAS R. FRIBERG, MD

With the launch by the Soviet Union of the satellite Sputnik in October 1957, the possibility of foreign satellites orbiting overhead became a reality. The US government recognized that it was important to be able to determine the purpose and nature of such objects. Telescopes could be used to view these objects, but compensation for atmospheric effects and other influences that limited viewing was needed. Under a classified program, researchers at the US Department of Defense developed a methodology called adaptive optics (AO) to improve the performance of their tracking and viewing of satellites.[1]

All optical systems have inherent imperfections that degrade imaging performance. These flaws can be generally separated into two types: those caused by *diffraction* and those caused by *aberrations*. Diffraction occurs when light rays pass through small apertures and spread out, whereas aberrations cause blurring and distortion when light rays pass through imperfect optical components. Simply put, AO is a technology designed to minimize the effects of wavefront distortions in order to improve the performance of optical systems.

To remove or limit these resolution-degrading effects, active optical components are placed within the light path and used to make compensatory adjustments automatically to optimize the optical system. This article explains more about AO technology and how it can be applied to the field of retina.

THE OPHTHALMIC USES OF AO

Devices that use AO to image the human eye have common features. In such devices, light is shone onto the fundus and reflected off of the retina, creating a wavefront analogous to the red reflex. This wavefront of light is then passed through an array of multiple small lenses, or lenslets. The lens array focuses the light wave onto a charge-coupled device sensor, producing multiple focal points on this detector. The pattern that these focal points make on the detector is then analyzed for uniformity by a computer algorithm.

If there are aberrations or diffraction imperfections along the light path, the pattern will be imperfect. If the points are not uniformly distributed, mirrors within the light path are intentionally deformed to improve the wavefront. The new wavefront is then sampled again, and, if it is still imperfect, the deformable mirror is readjusted. This feedback process is repeated in a closed loop fashion until the wavefront is optimized.

When optimization is achieved, the eye can then be imaged through the modified light path. Hence, the optics have been adapted to eliminate most of the optical imperfections in the eye being imaged, allowing much higher resolution of microscopic structures. Retinal photoreceptors and the retinal pigment epithelium (RPE) can be imaged in this way.[2] By using different wavelengths and specialized techniques such as offset apertures, most of the other cellular elements of the retina can also be imaged in vivo.[3]

AO systems that use scanning lasers for illumination provide the greatest resolution, but these systems are complex and lack uniformity. Such laser-based systems must be carefully monitored so as not to exceed safe retina exposure levels in humans. Also, the field of view for such SLO systems is typically quite small (Figure 1). The deformable mirrors, which can be shaped to achieve wavefront control and correction of optical aberrations, have

AT A GLANCE

- Imperfections are inherent in all optical systems, and these flaws affect imaging performance.
- The purpose of adaptive optics is to minimize the effects of wavefront distortions in order to improve the performance of optical systems.
- Adaptive optics systems using scanning lasers for illumination provide the greatest resolution but have complex optical designs that lack uniformity and require high maintenance. LED-based systems may prove more useful for current retinal applications.

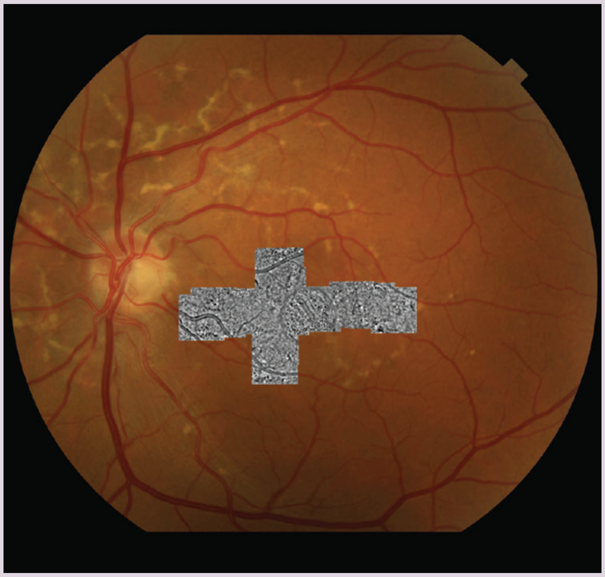

Figure 1. A black-and-white AO image is superimposed on a color fundus image to show the area from which the AO image is taken.

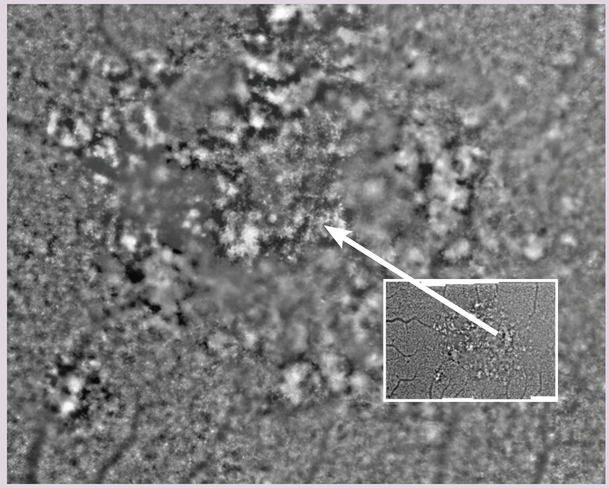

Figure 2. AO image of the left eye of a patient with CSCR taken in April 2017.

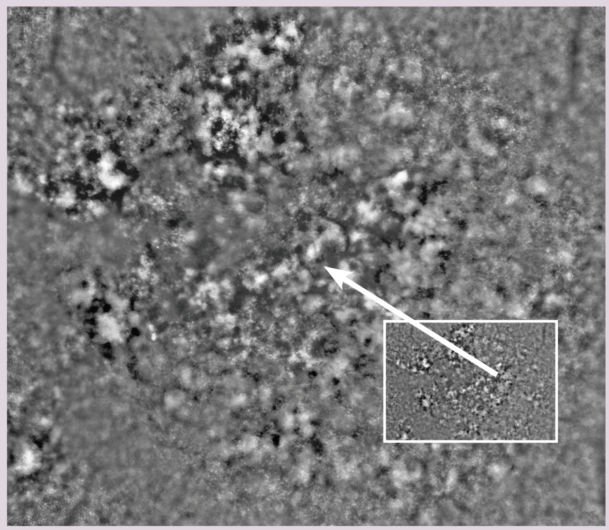

Figure 3. AO image of same eye as Figure 2 taken in August 2017.

historically been the most expensive components of AO systems, but their cost has been markedly reduced over time.

A NEW APPROACH

Recently, a commercially available system, the rtx1 (ImagineEyes) has been introduced. It is an approved medical device in the European Union, Japan, and Australia but is considered an investigational device in the United States and thus requires oversight by an institutional review board for use in any research application.

In contrast to the scanning laser–based devices described above, the rtx1 uses LEDs to produce broader illumination of the retina. With this approach, relatively large areas of the retina (4° x 4°) can be imaged. Such "flood" systems are much more practical for imaging in the clinical setting, when acquisition time is an important limitation. A drawback is that their resolution is not adequate to allow imaging of the cones within the fovea (the cones there are much smaller and more densely packed than extrafoveal cones) or the rods in the periphery.

My colleagues (Ethan Rossi, Assad Durrani, Valerie Snyder, and Kari Vienola) and I imaged patients with a variety of retinal disorders with the rtx1 AO retinal camera to gain experience with the device and to determine whether clinically useful information could be obtained with such a device.

PERSONAL EXPERIENCE

As part of this ongoing pilot project, my colleagues and I studied patients with central serous chorioretinopathy (CSCR), retinal dystrophies, and macular degeneration using this AO device. Over time, we were able to observe changes in the photoreceptors of patients with CSCR after the subretinal fluid had resolved (Figures 2-4). We speculate that these changes occur at the outer segment RPE interface and are related to RPE remodeling and photoreceptor regeneration.

We also used the AO device to image patients with geographic atrophy (GA) over time and noticed obvious changes in the distribution and amount of pigmentation within their GA lesions. These changes occurred rather rapidly, within a few months, and we speculate that they may be secondary to the redistribution of pigment material and melanosomes by phagocytes or other

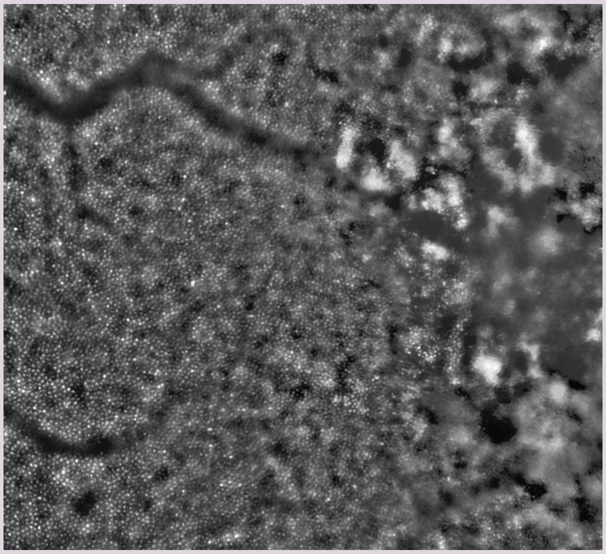

Figure 4. AO image of the eye with CSCR shown in Figure 2, taken in a region nasal to the fovea and magnified to show the mosaic of individual photoreceptors.

pigment-laden cells. Michel Paques, MD, PhD, has recently suggested that more frequent imaging might reveal that these changes occur from day to day.[4]

A PLACE IN THE FUTURE OF RETINAL IMAGING

The ability to microscopically monitor changes in the photoreceptors and RPE layer in vivo might prove useful in assessing both the progression of retinal disease and the effectiveness of new treatments. I anticipate that such monitoring will prove much more sensitive than standard methods such as fundus photography and perhaps even optical coherence tomography. AO systems will likely have a role in clinical retina practice once the results of more rigorous studies with multiple modalities become available. At present, we are in the earliest stages of exploration, and I find this field particularly exciting and unique. ■

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