High resolution retinal images for better diagnosis

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Long wavelength light permits in vivo imaging of the human eye at a cellular scale.

Eye diseases can often be detected at an early stage if cellular-scale images of the retina are available. However, it is not easy to obtain high-resolution images of photoreceptors—light-detecting cells—because of inherent flaws in the eye’s own optics, so-called aberrations. The size of a photoreceptor is around a few microns, and consequently, the required resolution is less than 5 µm. Present standard retinal imaging systems cannot provide such a high resolution.

‘Adaptive optics’ (AO) is based on a feedback loop comprising aberration measurement and dynamic wavefront correction to cancel the aberration of the eye. It has recently been introduced for a variety of high-resolution retinal imaging applications that have revealed microstructures of the retina. AO instruments have also shown a probe-wavelength-dependent contrast in the retinal microstructure. Until now, the retinal microstructure has been investigated with visible and near infrared light, up to 840 nm, which is still sensible by the human eye despite not being in the visible (380–750 nm) spectrum. We are working on high-resolution long-wavelength imaging to reveal more properties of the retina.

The 1 µm wavelength we are using has several advantages. Not only are the eye’s photoreceptors unaffected by this wavelength of light, but water, the principal component of the fluid in the eye, has a local minimum in its absorption of light at 1.05 µm. In addition, longer wavelengths are less scattered by the retina, and they enable deeper penetration into the eye. Further, water has a relatively constant refraction index around 1 µm, which minimizes wavelength-dependent blurring of images.

We have developed an AO scanning laser ophthalmoscope (AO-SLO) with a 1.04 µm probe beam. The AO subsystem is a confocal microscope used to correct the retinal images obtained by the SLO subsystem for the eye aberration. An amplified spontaneous emission light source with a center wavelength of 1.04 µm was used as a probe beam and introduced into an SLO based on reflection optics, as shown in Figure 1. The reflection setup reduces obstructive surface reflection from objects and wavelength-dependent aberrations. We use off-axis spherical mirrors to help reduce the size of the SLO so that the entire setup fits onto a 70 cm × 90 cm compact optical bench. Although the tilted use of these mirrors generates a strong astigmatism (an asymmetric aberration), this is canceled by using a second pair which is tilted orthogonally to the others.

The AO subsystem uses a Hartmann-Shack wavefront sensor (HSWS) to measure the aberration and a deformable mirror (DM) to correct it. The HSWS consists of a standard silicon-based CCD camera and a 32 × 32 lenslet array. At 1.04 µm, the sensitivity of this CCD is low, so we used an 840 nm superluminescent diode to measure the aberration. The AO software determines and applies the optimal shape of the DM to compensate. It

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Figure 2. 300µm × 300µm patch of in vivo human retina at 3 degree eccentricity measured without AO (a) and with AO (b). Retinal patches at 5 degree eccentricity with focus at the photoreceptor layer (c) and at superficial vessels (d).

Figure 3. A mosaic of retinal patches. The photoreceptors are clearly visualized up to an eccentricity of 10 degrees.

Using AO dramatically improves the resolution of the SLO, as shown in Figure 2(a) and (b). Individual photoreceptors are clearly visible as well as the improvement in resolution due to the AO correction. In addition, it is possible to focus on different layers of the eye’s tissues by applying an additional defocus to the DM. This permits the investigation of not only the retina but also the choroid, a deeper part of the eye that cannot be viewed at shorter wavelengths. The focus is on the photoreceptor in Figure 2(c) and on superficial vessels in Figure 2(d). Fine, small vessels and individual blood cells in large vessels can easily be seen. Figure 3 shows a wide field image obtained as a mosaic of several retinal images and clearly shows the presence of photoreceptors at an eccentricity of 5–10 degrees.

To summarize, 1µm is a new and attractive band for retinal investigations. Another technique, named optical coherence tomography (OCT), has already begun to employ 1µm light in clinical studies to reveal eye diseases deep at the rear of the eye.\(^8\) We hope that the combination of 1µm AO and OCT may provide high-resolution images of the retina and the layer behind it, the choroid. Another attractive feature of using 1µm light is its invisibility, and we hope to introduce a 1µm aberrometer\(^9\) to replace the current 840nm one, which will enable high-resolution retinal imaging without any optical stimulation to the subject. This is expected to reveal more detailed physiology of the eye.

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References