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Retinal and Choroidal Imaging Update

Retinal imaging using adaptive optics technology☆

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Abstract

Adaptive optics (AO) is a technology used to improve the performance of optical systems by reducing the effect of wave front distortions. Retinal imaging using AO aims to compensate for higher order aberrations originating from the cornea and the lens by using deformable mirror. The main application of AO retinal imaging has been to assess photoreceptor cell density, spacing, and mosaic regularity in normal and diseased eyes. Apart from photoreceptors, the retinal pigment epithelium, retinal nerve fiber layer, retinal vessel wall and lamina cribrosa can also be visualized with AO technology. Recent interest in AO technology in eye research has resulted in growing number of reports and publications utilizing this technology in both animals and humans. With the availability of first commercially available instruments we are making transformation of AO technology from a research tool to diagnostic instrument. The current challenges include imaging eyes with less than perfect optical media, formation of normative databases for acquired images such as cone mosaics, and the cost of the technology. The opportunities for AO will include more detailed diagnosis with description of some new findings in retinal diseases and glaucoma as well as expansion of AO into clinical trials which has already started.

Keywords: Retinal imaging, Adaptive optics technology

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Introduction

Imaging of the human retina has undergone revolutionary changes thanks to which we are able to view miniscule retinal structures and its abnormalities. Current retinal imaging modalities are mostly non-invasive and provide high resolution of the tissue with good topographic orientation. Conventional color fundus imaging, scanning laser ophthalmoscopy (SLO) and optical coherence tomography (OCT) have become routine in clinical practice. Newer technologies are constantly under investigation and often underway.

Retinal cameras for current clinical imaging are generally designed without correcting aberrations beyond defocus. In order to bring the lateral resolution of ophthalmoscopes to the microscopic scale, it is necessary to compensate not only for defocus, but also astigmatism and higher order aberrations. Similarly, current OCT technology provides excellent axial resolution of images but less precise lateral resolution. Adaptive optics (AO) is a technology used to improve the performance of optical systems by reducing the effect of wavefront distortions (aberrations) (Table 1). It was first used in astronomical telescopes and laser communication systems to remove the effects of atmospheric distortion, later in microscopy and optical fabrication to reduce optical aberrations. Adaptive optics works by measuring the distortions in a wavefront and compensating for them with a device that corrects those errors such as a deformable mirror or a liquid crystal array.[1–3]

Retinal imaging using AO aims to compensate for higher order aberrations (deviation of light from the ideal shape) originating from the cornea and the lens. This is done by using deformable mirror which serves as wavefront corrector. The first use of retinal AO allowed visualization of single cone photoreceptors. Currently, both cone and rod individual photoreceptors can be imaged using this technology (Fig. 1).[4,5] AO systems have been coupled to scanning laser

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Table 1. Differences between optical coherence tomography and adaptive optics technology.

	Optical coherence tomography	Adaptive optics
Principle	Low coherence interferometry	Correction of wave front distortions
Detectors/correctors	Reference mirror/spectrally separated detectors	Deformable mirrors
Attachment devices	Charge-coupled device (CCD) camera	Scanning laser ophthalmoscope/retinal camera
Type of resolution	Axial	Lateral
Image type	B-scan	En-face image

ophthalmoscope (SLO),[6] flood-illuminated camera,[7] and optical coherence tomography.[8]

Clinical applications

The main application of AO retinal imaging has been to assess photoreceptor cell density, spacing, and mosaic regularity in normal eyes and various ocular diseases. Analysis of the spatial distribution of the cone photoreceptors provides new information on the physical aspects of visual sampling of the human eye. Apart from photoreceptors, the retinal pigment epithelium (RPE) cells can be seen using reflectance-based AO imaging.[9] The retinal nerve fiber layer, retinal vessel wall and lamina cribrosa can also be visualized with AO technology (Fig. 2).[10–12] Patient factors, such as unstable fixation, small pupil size, and media opacities, can present challenges with image stabilization and light scatter, resulting in image blur. Considerable image processing effort is required to collect and produce the highest resolution images, including registration, montaging, and quantitative analysis.[3] Despite all these challenges, retinal AO has been successfully used in several disease entities in ophthalmology.

Diabetic retinopathy

Diabetic retinopathy (DR) is a microangiopathy resulting in blood rheological abnormalities as a consequence of chronic hyperglycemia.[11,12] Rather than purely a vascular disease it is now considered a neurovascular disorder. It has been observed that excess plasma glucose may not account for all cellular and functional changes in the progression of DR. In addition to high glucose, the dysregulated levels of excitotoxic metabolites, nutrients, hormones and several other factors, have been found to play a role in neurodegeneration in DR.[13] The neurodegeneration in DR consists of apoptosis affecting the photoreceptors, bipolar and ganglion cells.[14]

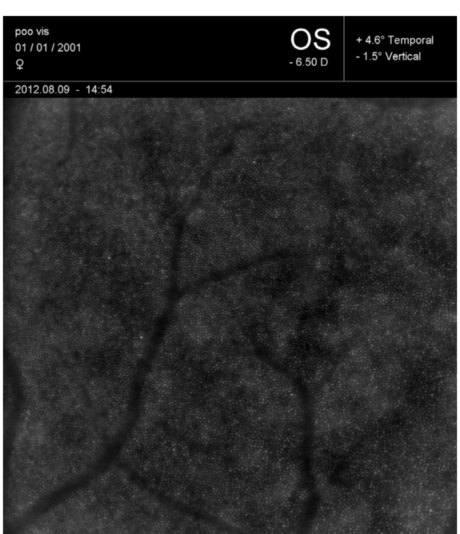

Figure 1. An image of photoreceptor mosaic in a young healthy myopic eye using adaptive optics retinal camera (ImagineEyes, Orsay, France) demonstrating a homogeneous mosaic of retinal cones and rods (Image by Dr. Igor Kozak).

Figure 2. An image of the same eye as in Fig. 1 using the same instrument but focusing on the inner retina showing retinal nerve fibers and details of retinal blood vessels (Image by Dr. Igor Kozak).

Retinal microvascular and perfusion changes in patients with diabetes have been observed even in the eyes with no or minimal clinical retinopathy.[15,16] These changes have been demonstrated by SLO-based AO imaging without the use of contrast enhancing agents in both cross-sectional[17] and longitudinal assessment.[18] Non-invasive assessment of the capillary network has been performed using AO-OCT and AO retinal camera.[19,20] Recently, a subtle decrease of parafoveal cone density was found in diabetic patients in comparison with age-matched control subjects. The cone density decline was moderately associated with a disturbance in the glucose metabolism.[21] AO has been used to visualize photoreceptors after macular laser photocoagulation with pattern laser. In small observation, no evidence of reduced photoreceptor density around the laser lesions, no apparent size reduction of the lesions relative to the initial application diameters, and, thus no direct evidence of photoreceptor migration or healing were found.[22]

Age-related macular degeneration

Age-related macular degeneration (AMD) is a multifactorial disease that can cause severe vision loss due to either