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Combinations of techniques in imaging the retina with high resolution

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A B S T R A C T

Developments in optical coherence tomography (OCT) have expanded its clinical applications for high-resolution imaging of the retina, as a standalone diagnostic and in combination with other optical imaging modalities. This review presents currently explored combinations of OCT technology with a variety of complementary imaging modalities along with augmentational technologies such as adaptive optics (AO) and tracking. Some emphasis is on the combination of OCT technology with scanning laser ophthalmoscopy (SLO) as well as on using OCT to produce an SLO-like image. Different OCT modalities such as time domain and spectral domain are discussed in terms of their performance and suitability for imaging the retina. Each modality admits several implementations, such as flying spot or using an area or line illumination. Flying spot has taken two principle forms, *en-face* and longitudinal OCT. The review presents the advantages and disadvantages of different possible combinations of OCT and SLO with AO, evaluating criteria in choosing the best OCT method to fit a specific combination of techniques. Some of these combinations of techniques evolved from bench systems into the clinic, their merit can be judged on images showing different pathologies of the retina. Other potential combinations of techniques are still in their infancy, in which case the discussion will be limited to their technical principles. The potential of any combined implementation to provide clinical relevant data is described by three parameters, which take into account the number of voxels acquired in unit time, the minimum time required to produce or infer an *en-face* OCT image (or an SLO-like image) and the number of different types of information provided. The current clinically used technologies as well as those under research are comparatively evaluated based on these three parameters. As the technology has matured over the years, their evolution is discussed as well with their potential for further improvements.

Contents

Abbreviations: 3D, three-dimensional; AMD, age-related macular degeneration; AO, adaptive optics; APD, avalanche photodiode; cSLO, confocal scanning laser ophthalmoscopy; dB, decibel; D-OCA, Doppler-optical coherence angiography; ERG, electroretinography; FA, fluorescein angiography; FD, Fourier domain; FF, full field; FFT, fast Fourier transformation; *I*, imaging content units, or number of channels simultaneously working in a combined configuration; ICG, indocyanine-green; IS, inner segments; LF, line field; L-SLO, line-scanning laser ophthalmoscopy; mfERG, multifocal electroretinography; Mv/s, megavoxels per second; NA, numerical aperture; n.a., non-applicable; OCA, optical coherence angiography; OCT/SLO, combined OCT and scanning laser ophthalmoscopy; OCT, optical coherence tomography; ODT, optical Doppler tomography; OPD, optical path difference; OS, outer segment; PED, pigment epithelium detachment; RNFL, retinal nerve fiber layer; RPE, retinal pigment epithelium; S-OCA, scattering-optical coherence angiography; SD, spectral domain; SLD, superluminescent diode; SLO, scanning laser ophthalmoscopy; SS, swept source; TD, time domain; μm, micron; ms, millisecond; *X*, *Y*, *Z*, rectangular axes, with *X*- and *Y*-oriented lateral to the retina and *Z* along the depth.

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1. Introduction

Today, ocular imaging technology has reached high heights of sophistication, building on the tremendous progress in the last 5 years. However, none of the current imaging methods available fulfill all the ideal requirements of the ophthalmologist faced with the need for rapid and accurate diagnosis. This has led to exploration of combinations of imaging and assistive techniques by groups attempting to solve these deficiencies. The goals driving the combination of different imaging technologies are diverse, including the need for precise targeting and real-time focusing of the *en-face* optical coherence tomography (OCT) (which lead to the addition of a scanning laser ophthalmoscopy (SLO) channel to the OCT channel), the need for correlation of retinal blood flow with changes in morphology (such as in the combination of OCT with fluorescence imaging) or the need for enhancing the imaging performance (such as the addition of adaptive optics (AO) and tracking to SLO or OCT or combined OCT/SLO).

Expansion of a familiar perspective found in one type of instrument may stimulate interest in combining it with an additional modality, which shares the same viewpoint. For example, *en-face* imaging (C-scan) has the advantage that ophthalmologists are more familiar with the interpretation of