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Optical coherence tomography angiography: A comprehensive review of current methods and clinical applications

Amir H. Kashani [a,*], Chieh-Li Chen [b], Jin K. Gahm [c], Fang Zheng [d], Grace M. Richter [a], Philip J. Rosenfeld [d], Yonggang Shi [c], Ruikang K. Wang [b]

[a] USC Roski Eye Institute, Department of Ophthalmology, Keck School of Medicine of University of Southern California; Los Angeles, CA 90033, United States
[b] Department of Biomedical Engineering, University of Washington Seattle, Seattle, WA 98195, United States
[c] Laboratory of Neuro Imaging (LONI), USC Stevens Neuroimaging and Informatics Institute, Keck School of Medicine of University of Southern California, Los Angeles, CA 90033, United States
[d] Bascom Palmer Eye Institute, Department of Ophthalmology, University of Miami Miller School of Medicine, Miami, FL 33136, United States

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ABSTRACT

OCT has revolutionized the practice of ophthalmology over the past 10–20 years. Advances in OCT technology have allowed for the creation of novel OCT-based methods. OCT-Angiography (OCTA) is one such method that has rapidly gained clinical acceptance since it was approved by the FDA in late 2016. OCTA images are based on the variable backscattering of light from the vascular and neurosensory tissue in the retina. Since the intensity and phase of backscattered light from retinal tissue varies based on the intrinsic movement of the tissue (e.g. red blood cells are moving, but neurosensory tissue is static), OCTA images are essentially motion-contrast images. This motion-contrast imaging provides reliable, high resolution, and non-invasive images of the retinal vasculature in an efficient manner. In many cases, these images are approaching histology level resolution. This unprecedented resolution coupled with the simple, fast and non-invasive imaging platform have allowed a host of basic and clinical research applications. OCTA demonstrates many important clinical findings including areas of macular telangiectasia, impaired perfusion, microaneurysms, capillary remodeling, some types of intraretinal fluid, and neovascularization among many others. More importantly, OCTA provides depth-resolved information that has never before been available. Correspondingly, OCTA has been used to evaluate a spectrum of retinal vascular diseases including diabetic retinopathy (DR), retinal venous occlusion (RVO), uveitis, retinal arterial occlusion, and age-related macular degeneration among others. In this review, we will discuss the methods used to create OCTA images, the practical applications of OCTA in light of invasive dye-imaging studies (e.g. fluorescein angiography) and review clinical studies demonstrating the utility of OCTA for research and clinical practice.

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* Corresponding author. USC Roski Eye Institute, Keck School of Medicine of USC, 1450 San Pablo St., Suite 4700, Los Angeles, CA 90033, United States.
E-mail address: ahkashan@usc.edu (A.H. Kashani).

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1. Introduction

Optical Coherence Tomography (OCT) is a non-invasive, interferometric imaging modality that enables *in vivo* imaging of the retina in cross-section (Drexler and Fujimoto, 2008). Since its original introduction in 1991 (Huang et al., 1991), OCT has been used to quantitatively evaluate retinal thickness and assess qualitative anatomic changes such as the presence or absence of many pathologic features, including intraretinal and subretinal fluid. The original implementation of OCT used time-domain technology (TD-OCT) that required a moving reference mirror. Therefore, TD-OCT only allowed ~400 A-scans per second and was commonly used to evaluate only 6 evenly spaced radial line scans that intersected at the fovea. The resolution of TD-OCT was also limited to 10–15 μm under the most ideal circumstances. The overall acceptance and clinical utility of TD-OCT was limited until the implementation of broad-band spectral domain technology (SD-OCT), a Fourier domain (FD-OCT) methodology, allowed 20,000–40,000 A-scans per second. This significantly improved the field-of-view and image resolution (~3–5 μm) and decreased motion artifact. Subsequent advances such as swept-source OCT (SS-OCT) incorporate a long wavelength and narrow-bandwidth source that is swept through a broad range of optical frequencies allowing very high spatial resolution and improved tissue penetration. The high cost of SS-OCT technology has limited wide-spread commercial and clinical acceptance of this method to date. Many additional improvements in OCT methods such as phase-sensitive OCT (Schwartz et al., 2014, Wang et al., 2007a; Wang et al., 2006), polarization-sensitive OCT (Pircher et al., 2011), spectroscopic OCT (Kim et al., 2015), and OCT Angiography (OCTA) (Ferrara et al., 2016) have been developed in recent years. These methods hold the promise of combining structural information with information about the function of the retinal tissue, and possibly of assessing tissue metabolism as well. A detailed review of each of the many OCT methods is beyond the scope of this review article, but the brief history of OCT provided above describes the overall context in which OCT angiographic methods have been developed.

The purpose of this article will be to review the recent developments in the use of OCT technology for non-invasive assessment of the retinal vasculature in health and disease with a particular emphasis on OCTA, whose role in the field of ophthalmology is only beginning to be defined. We will begin with a technical discussion of the various methods employed for OCTA, in order to lay the foundation for understanding its strengths and limitations. To understand the best applications of this method, we further compare and contrast it with current standard-of-care methods, including fluorescein angiography (FA) and indocyanine green angiography (ICG). The review concludes with a discussion of published articles in disease-specific categories that illustrate the strengths and limitations of OCTA, as well as highlight some of the novel findings OCTA has enabled.

2. Principles of optical coherence tomography angiography

Since OCTA is a technique that is based on OCT, a brief review of current OCT methodology is necessary as a prelude to the discussion of OCTA methods. OCT obtains depth-resolved tissue reflectivity characteristics by detecting the interference signal formed