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Review Article

Clinical applications of spectral domain optical coherence tomography in retinal diseases

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ABSTRACT

Optical coherence tomography (OCT) was introduced about two decades ago and has revolutionized ophthalmic practice in recent years. It is a noninvasive noncontact imaging modality that provides a high-resolution cross-sectional image of the cornea, retina, choroid and optic nerve head, analogous to that of the histological section. Advances in OCT technology in signal detection technique from time-domain (TD) to spectral-domain (SD) detection have given us the potential to study various retinal layers more precisely and in less time. SD-OCT better delineates structural changes and fine lesions in the individual retinal layers. Thus, we have gained substantial information about the pathologic and structural changes in ocular conditions with primary or secondary retinal involvement. This review we discuss the clinical application of currently available SD-OCT in various retinal pathologies. Furthermore, highlights the benefits of SD-OCT over TD. With the introduction of enhanced depth imaging and swept – source OCT visualization of the choroid and choriocapillaris has become possible. Therefore, OCT has become an indispensable ancillary test in the diagnosis and management of diseases involving the retina and/or the choroid. As OCT technology continues to develop further it will provide new insights into the retinal and choroidal structure and the pathogenesis of posterior segment of the eye.

Optical coherence tomography (OCT) has emerged as an important imaging modality in the evaluation and management of retinal disease. The noninvasive nature of the test and the ability to image intra-ocular structures *in vivo* with resolution approaching that of histological sections has made OCT particularly useful in the detection and quantification of macular and optic nerve head pathologies [1–5]. Since its introduction in the late 1990s for clinical application in the imaging of retinal and optic nerve disorders, OCT has shown major improvements in technology with increasing resolution of the images.

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First reported in 1991, OCT is analogous to ultrasonic pulse-echo imaging, but instead of sound waves, it uses near-infrared light to produce cross-sectional or three-dimensional (3D) images of the retina [1–8]. The images are generated through the measurement of magnitude and echo time delay of back scattered light from an optical beam across the retina. Since direct detection of light echoes is not possible due to the high velocity of light, measurements are done correlating sample reflections from a reference mirror using a Michelson interferometer. In this arrangement of the system, referred to as the time-domain (TD) OCT, one arm of the interferometer directs lights and collects the back scattered signal from the object of interest. A second reference arm with a reflecting mirror is mechanically controlled to vary the time delay and measure interference. The combination of reflected light from the sample arm and reference light from the reference arm gives rise to an interference pattern, given that light from both arms has traveled similar optical distance within the coherence length. Areas of the sample that reflect back a lot of light will create greater interference than areas that do not. Any light that is outside the short coherence length will not interfere. This reflectivity profile, called an A-scan contains information about the spatial dimensions and location of structures within the item of interest. A cross-sectional tomographic B-scan is achieved by laterally combining a series of A-scans.

However, conventional TD-OCT has several limitations. Because there is a time delay involved during the axial translation of the reference mirror, the number of A scans acquired is limited, resulting in a B-scan with poor resolution. Another related problem is the lack of registration, poor point to point correlation between an OCT B-scan and the patient's fundus. A final critical limitation related to the slow-speed of TD-OCT is poor sampling density. Large amount of data is interpolated by sampling only a fraction of the mapped area.

Within the past decade, a new generation of OCT technology known as "SD-OCT" or "Fourier domain" OCT has evolved. In SD-OCT, light echoes are detected by measuring the interference signal as a function of wavelength by the use of an interferometer with a stationary reference arm [9]. The measurement of light echoes simultaneously allows high speed scanning with scan rates 50–100 times faster than conventional TD-OCT. This results in improved resolution of the B-scan images (the axial resolution on SD-OCT is 4–7 μ as compared to 10 μ on the Stratus TD-OCT) [6–8]. Spectralis (Heidelberg Engineering, Vista, CA/Germany.), one of the commercially available SD-OCT, also incorporates the Tru-track™ technology, which significantly reduces image corruption due to motion artifacts and provides the opportunity to correlate quantitatively the same areas of retinal pathology at sequential time points [Fig. 1].

Imaging on spectral-domain optical coherence tomography

Retinal cross-sectional imaging on Stratus OCT is dominated by signals from the nerve fiber layer (NFL), the outer segment-inner segment line of the photoreceptors (ellipsoid zone) and the retinal pigment epithelium (RPE). Low-backscattering ganglion cell layer (GCL), external limiting membrane (ELM) are poorly resolved as well as the boundaries between the transparent and highly scattering layers such as the NFL, the inner plexiform layer (IPL), the outer plexiform layer (OPL), the ellipsoid zone (also known as IS-OS line) and the RPE [Fig. 2].

The demonstrated improvement in speed with SD-OCT allows for a shift from two-dimensional sampling to comprehensive 3D screening of ocular pathology with OCT [9]. The ultrahigh resolution images enable excellent visualization of the architectural morphology of the internal retinal layers. Although the axial image resolutions are comparable in the SD and the TD-OCT images, the increase in the transverse pixel density which is possible using SD-OCT significantly improves the visualization of retinal architecture. In addition, intra-retinal interfaces are continuous in the higher transverse pixel density, SD ultrahigh-resolution OCT image [9]. On SD-OCT, the following bands are seen outside the hypo-reflective band of the outer nuclear layer (ONL) by SD-OCT at the fovea in healthy eyes: (1) A thin, hyper-reflective band presumably corresponding to the ELM; (2) a slightly thicker hyper-reflective band presumably corresponding to the interface of the inner and outer segments of the photoreceptor layer (PRL); (3) a thin, only occasionally visible, hyper-reflective band presumably corresponding to the outer segment-RPE interdigitation; and (4) a broad hyper-reflective band thought to correspond to the RPE/Bruch's membrane complex [Fig. 3].

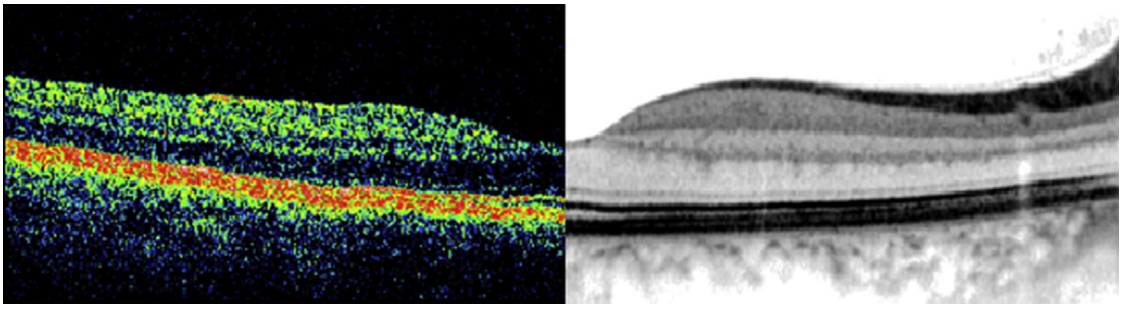

Fig. 1 – Retinal cross-sectional image from the same subject on time-domain Stratus optical coherence tomography (left) and spectral-domain Spectralis optical coherence tomography (right).