ADVANCES IN OPTICAL COHERENCE TOMOGRAPHY

Dr. Richa Ranjan, Dr. Ankita Shrivastav, Dr. Shalini Singh, Dr. Rahul Mayor, Dr. Lagan Paul, Dr. Manisha Agarwal, Optom. Brajesh Kumar

Dr. Shroff's Charity Eye Hospital, Daryaganj, New Delhi, India

Optical coherence tomography (OCT) has proved to be a technological breakthrough in ophthalmology because it provides unprecedented clinically relevant information to assist with the diagnosis and treatment of eye diseases. It is a non-contact, non-invasive imaging modality used to obtain high resolution cross-sectional images of the retina and the anterior segment. It is based on coherence interferometry which involves interference between reflected light from tissues and a reference beam.

PRINCIPLE OF OCT MACHINE

It uses a diode laser light in the near infrared spectrum (810 nm) to produce high resolution cross sectional images of the retina using the principle of coherence interferometry. Here, a partially reflective mirror is used to split a single laser beam into a measuring beam and a reference beam. The measuring beam is directed into the patient's eye which passes through various layers of retina and at each optical interface some of the laser light is reflected back to the OCT photodetector (Figure 1).

The reference beam is reflected off a reference mirror back to the photodetector. The reference mirror is at a known distance from the beam splitter, and its position can be adjusted to make the path traversed by the reference beam equal to that of the distance traversed by the measuring beam to the retinal surface. When this occurs, wave patterns of the reference and measuring beams are in precise synchronization resulting in a constructive interference. This appears as a bright area on the resulting cross sectional image of the retina.

However, some of the light from the measuring beam will be reflected off from the deeper layers of the retina. This light travels a longer distance than the reference beam, resulting in destructive interference when the two beams are brought back to the photodetector. Destructive interference at each point measured by the OCT is translated into a retinal depth and displayed graphically.

OCT images are displayed in false color to enhance differentiation of retinal structures. Bright colors (red to white) represents tissues with high reflectivity, whereas darker colors (blue to black) represents areas of minimal or no reflectivity.

Over the last two decades, the OCT technology has made substantial advances with continuous improvement in instrumentation, ease of use, functionality and data analysis capabilities. It also provides assistance in patient diagnosis, treatment and monitoring the treatment response. We shall be discussing about OCT in this article- from basic to recent advances.

TYPES OF OCT

- Time Domain OCT
- Fourier Domain OCT
  - Spectral Domain OCT
  - Swept Source OCT

TIME DOMAIN OCT

There has been a dramatic progress in the development of OCT technology in the recent times. The first commercially available OCT was a Time-Domain OCT (TD-OCT), which was comparatively slow.

Principle

It consists of a beam splitter with one branch being a reference arm and the other entering the tissue. It also consists of a moving reference mirror. The light from the reference arm and the light reflected back from the tissue undergoes interference, and the interference over time is used to generate an 'A-scan' depth resolved image of the retina at a single point (Figure 2). Moving the tissue and the light source with respect to each other generates multiple A-scans that are combined into a cross-sectional linear image called the B-scan or 'line scan'. TD-OCT is a time consuming process as it scans approximately 400 A-scans/second. The ability of TD-OCT to capture live images and achieve dynamic focusing on the axial plane is a potential advantage of TD-OCT over spectral domain OCT[2].

Resolution

The depth resolution in TD-OCT is 8-10 microns[1].

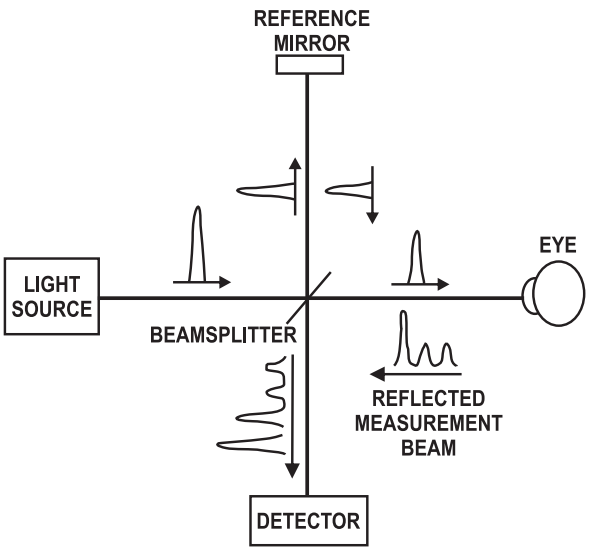

Figure 1: *Principle of OCT.*

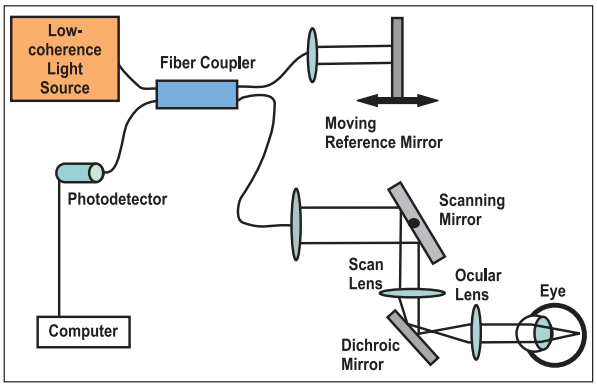

Figure 2: *Optics of Time Domain OCT.*

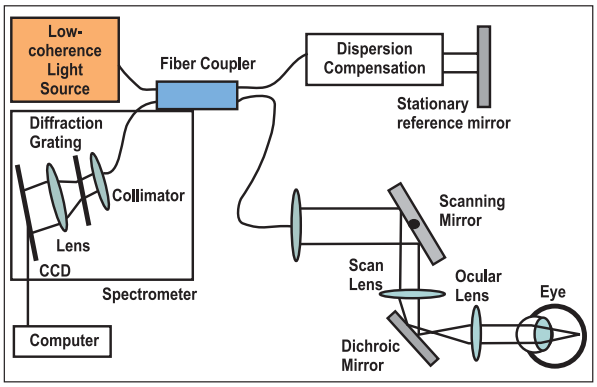

Figure 3: *Optics of Spectral Domain OCT.*

SPECTRAL DOMAIN OCT

Spectral domain OCT (SD-OCT) was the next commercially available methodology which allows for a much faster scanning speed with scanning rates of 20,000–55,000 A-scans/second[1].

Principle

In SD-OCT, there is a stationary reference mirror in contrast to TD-OCT which has a moving reference mirror, thus eliminating the need for mechanical depth scanning. The spectral interference pattern between the reference arm and the sample arm is dispersed by a spectrometer (Figure 3) and collected simultaneously with an array detector or charge-coupled device (CCD) camera, resulting in a faster scanning speed.

Resolution

The depth resolution in SD-OCT is 5-7 micron[1].

Advantage

The point where the sample arm reflection is nearer to the reference arm length, is called the zero-delay point, which is usually placed at the top of the region being scanned, usually the vitreous cavity. It is possible to push the zero-delay point, deeper in the tissue, such as at the level of sclera. This process is called enhanced depth imaging (EDI-OCT), which enables imaging of deeper tissue such as the choroid (Figure 4), an important feature in SD-OCT[3].

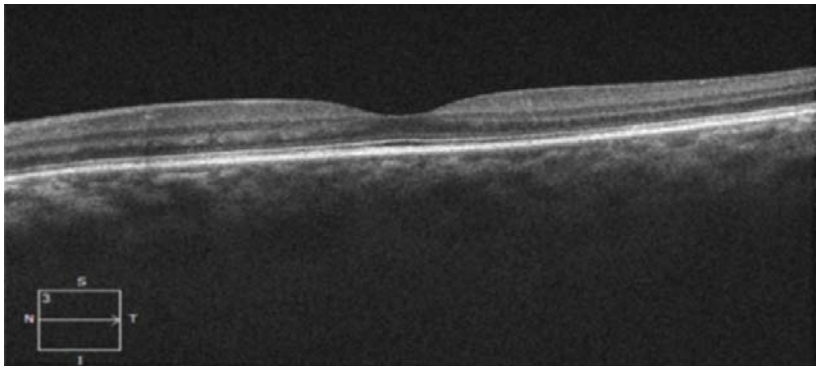

Figure 4: *Enhanced Depth Imaging mode of Spectral Domain OCT showing deeper tissue such as choroid.*

EN FACE OCT

En face OCT is an imaging technique derived from spectral domain OCT.

Principle

En face OCT is based on software reconstruction of OCT images, that combines SD-OCT and transverse confocal analysis, producing transverse sections of retinal and choroidal layers at a specified depth[4]. A-scans obtained using TD-OCT, SD-OCT and swept source OCT (SS-OCT) are used to generate B-scans that are then, reconstructed to C-scans after postprocessing. It produces a "3D brick" or "volume scan" which is then sliced on the coronal plane by the software[5].

Advantages

The advantages of en face OCT over the conventional longitudinal cross-sections are the identification of subtle pathological features in the diseased retina or choroid, and precise localization of the microstructural and morphological changes within the specific sub-retinal layers[4,5]. It images individual retinal layers on the transverse plane and projects OCT images using retinal vessels as landmarks on to other fundus imaging modalities[5]. En face OCT images can be generated using time domain, spectral domain or swept-source OCT methods. En face technology enables diagnosis and monitoring the disease such as Multiple evanescent white dot syndrome (MEWDS), cystoid macular edema (CME), geographical atrophy in Age-related Macular Degeneration, Polypoidal Choriodal Vasculopathy (PCV) etc. In a study by Sayanagi et al, using SS-OCT, 95.3% of polypoidal lesions seen on Indocyanine Green Angiography were identified using en face OCT[6].

SWEPT SOURCE OCT

Swept-source OCT is a recent addition to our armamentarium of retinal and choroidal imaging.

Principle

SS-OCT uses a tunable short-cavity swept laser, with center wavelength of approximately 1050 nm with a single photodiode detector (Figure 5). Longer wavelength enables deeper penetration with accurate imaging of choroidal and retinal layers, lesser artefacts and dampens the effect of cataractous lens[7]. It has a faster scanning speed, allows denser scan patterns and larger scan areas compared with SD-OCT scans for a given acquisition time.

Resolution

SS-OCT uses photodetector instead

Table 1: Differences between TD-OCT, SD-OCT and SS-OCT			
Parameter	**TD-OCT**	**SD-OCT**	**SS-OCT**
Working Principle	Measure the echo time delay & intensity of reflected light	Measure the wavelengths of reflected light	Measure the wavelengths of reflected light
Light Source	Broadband and continuous wave	Broadband and continuous wave	Narrow instantaneous line width, rapidly swept wave
Central Wavelength	830 nm	830 nm	1050 nm
Axial Resolution/ Transverse resolution	~ 10µm/20-25 µm	~ 5 to 7 µm/20-25 µm	~1 to 7 µm/ ~12.5 µm
Scan speed	400 A-scans/s	~50,000 A-scans/s	~100,000 A scans/s

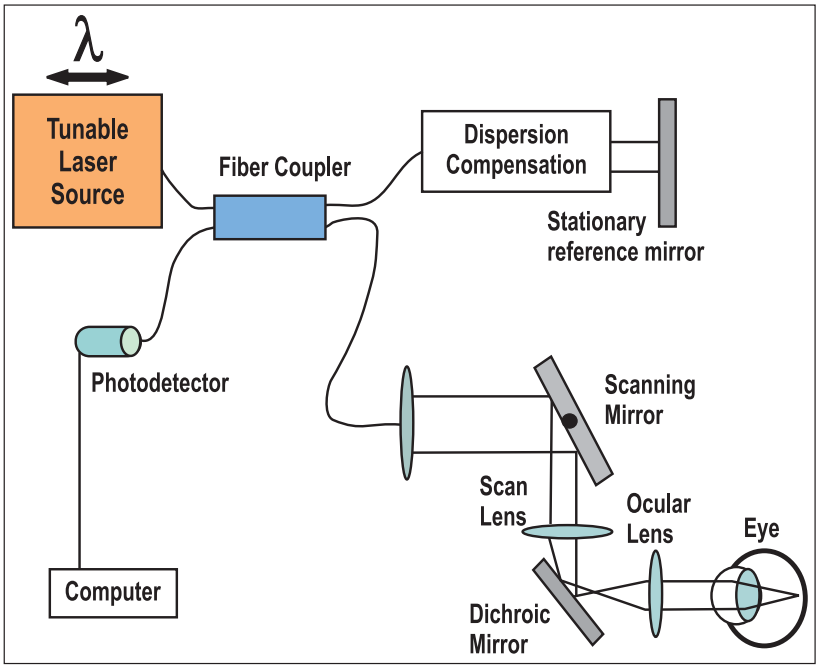

Figure 5: *Optics of Swept Source OCT.*

of CCD cameras thus increasing the resolution of imaging to 1 µm and improved signal-to-noise ratio[8].

Advantages

The SS-OCT scans the retina at twice the speed of SD-OCT (100,000 A-scans/sec compared with 50,000 A-scans/sec), enabling faster acquisition of B-scans images and wider B-scans (12 x 9 mm vs 6–9 mm with conventional SD-OCT). Wide scans are possible due to uniform sensitivity over the entire scan window, thereby, making it possible to visualize the optic nerve, macula and deeper ocular structures on the same scan[7,8]. SS-OCT is less affected by ocular opacity and allows deeper penetration into the choroid due to lesser light scattering by retinal pigment epithelium (RPE). It uses invisible light source, which is less distracting for patients compared to visible light used in SD-OCT. Thus, SS-OCT is better as it is faster, and scans deeper and wider.

OCT ANGIOGRAPHY

Optical coherence tomography angiography (OCTA) is a new technology which provides high-resolution, high-sensitivity and in depth visualization of retinal and eye microstructures without contact. It is based on the en-face OCT technique that reconstructs scans performed multiple times in a vertical plane into a single image shown on a horizontal plane. Schematically, its principle is to highlight only the changes that occur between a time (t1) and a time (t2).

Currently there are three FDA-approved OCTA systems. Two of them use a spectral-domain platform operating at 840 nm wavelength and the third uses swept source OCT technology at 1050 nm wavelength.

Principle of OCTA

OCT-Angiography is based on the principle of diffractive particle movement detection, such as red blood cells, on sequential OCT B-scans performed repeatedly at the same retinal location, therefore showing the presence of blood vessels. OCT-Angiography requires higher imaging speed than most currently available devices are able to provide for a sufficiently dense volume. It offers a non-invasive approach through which the vascular structures of the retina and choroid may be visualized in three dimensions without the need for contrast agent injection (Figure 6).

This method is based on differences between the B-scans to generate a movement-related contrast, especially a contrast related to erythrocyte movement in the vascular system.

To generate the image of the retinal microvascularization, each B-scan of the examination pattern is consecutively repeated several times. The contrast comparisons on consecutive B-scans at the same location reveal some areas with a contrast change over time and some areas with a constant contrast. The temporal change in contrast in a specific location is attributed to the movement of erythrocytes, which therefore indicates the location of the vessels. After correcting for gross eye motion (by using motion tracking or software processing), the only differences remaining between OCT images of the same point in the eye would represent blood flow.

Clinical interpretation of OCT Angiography

OCT-Angiographic maps are a two dimensional representation of the retinal vasculature over a particular area of interest. The analysis interface provides two dimensional maps of the representation of the microvasculature, according to different anatomically interesting segmentation profiles.

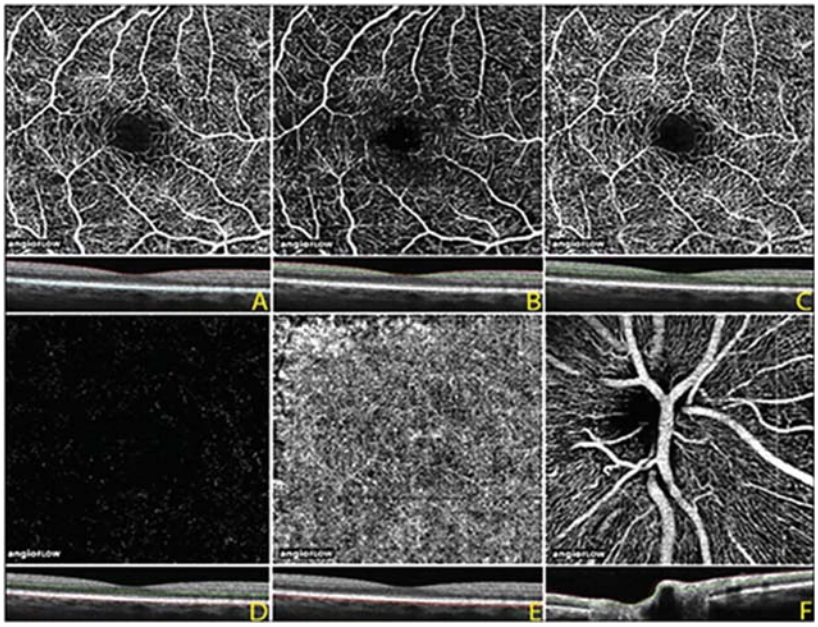

Figure 6: *OCTA image, 3 mm x 3 mm, of a normal eye. Full thickness OCT angiogram and corresponding OCT B scan of the internal limiting membrane to Bruch's membrane* ***(A)****. OCTA of the inner retina* ***(B)****, middle retina* ***(C)****, outer retina* ***(D)****, and choriocapillaris* ***(E)****. OCTA at the optic nerve showing the radial peripapillary vascular network* ***(F)****.*

It is an extraordinary tool for visualizing abnormal choroidal vasculature and it provides information on the plane in which these choroidal neovascularization (CNV) develop: below RPE (Type 1 CNV), above RPE (Type 2 CNV) and intraretinal (Type 3 CNV). It helps in determining the location of CNV, its morphology and response to Anti-Vascular Endothelial Growth Factor (anti-VEGF) therapy. Visualizing a neovascular network does not systematically mean neovascular activity. Indeed, new vessels may be present but inactive either spontaneously (quiescent occult neovascularization) or after suitable treatment. Thus, the analysis of OCT-Angiography should always include a more conventional OCT analysis with B-scans. Comparing both examinations allows an assessment of the anatomical location of new vessels and their activity, evidenced by exudative manifestations.

It finds its utility in vascular disorders of retina such as Retinal Vascular Occlusion, Macular Telangiectasia and Diabetic Retinopathy. It delineates the superficial and deep retinal capillary plexus clearly and also can precisely demarcate the vessels surrounding the foveal avascular zone (FAZ), whereas Fundus Fluorescein Angiography only delineates the superficial vascular plexus with blurry FAZ due to perifoveal leakage. Neovascularisation of disc (NVD) in Diabetic Retinopathy can be detected by viewing the inner retina/optic nerve surface at the most superficial level.

The limitations of OCTA imaging include several artifacts related to eye movements during acquisition or projection artifacts observed during post-acquisition image processing. Other artifacts are related to the intrinsic properties of the eye or eye disease. It is essential to know about these artifacts so as to avoid interpretation errors. It is a good clinical tool for the practitioner but its usefulness with regards to therapeutic monitoring is unclear.

These advances in OCT have revolutionized ophthalmic practice over the last two decades. The newer imaging techniques have increased our ability in diagnosis and management of various retinal pathologies. OCT allows non-invasive, depth-resolved imaging of chorioretinal layers, without the use of intravenous contrast injection. Further innovations are expected to aid in the diagnosis and monitoring of various retinal and choroidal diseases.

Declaration of interest: The authors report no conflicts of interest. The authors have no financial interest to disclose.

REFERENCES

1. Adhi M, Duker JS. Optical coherence tomography – Current and future applications. Curr Opin Ophthalmol. 2013;24:213–21.
2. Pircher M, Gotzinger E, Hitzenberger CK. Dynamic focus in optical coherence tomography for retinal imaging. J Biomed Opt.2006;11:054013.
3. Spaide RF, Koizumi H, Pozzoni MC. Enhanced depth imaging spectral-domain optical coherence tomography. Am J Ophthalmol. 2008;146:496-500.
4. Lau T, Wong IY, Iu L, Chhablani J, Yong T, Hideki K, Lee J, Wong R. En-face optical coherence tomography in the diagnosis and management of age-related macular degeneration and polypoidal choroidal vasculopathy. Indian J Ophthalmol. 2015;63:378–83.
5. Heiferman M, Simonett J, Fawzi A. En Face OCT Imaging in Retinal Disorders. An emerging technique offers innovative insights. Retinal Physician. 2015;12:45-48.
6. Sayanagi K, Gomi F, Akiba M, Sawa M, Hara C, Nishida K. En-face high penetration optical coherence tomography imaging in polypoidal choroidal vasculopathy. Br J Ophthalmol.2015;99:29-35.
7. Mohana K, Bhende D, Muna D. Optical coherence tomography: newer techniques, newer machines. Sci J Med Vis Res Found. 2015;2:75-78.
8. Michalewska Z, Michalewski J, Nawrocki J. Going deeper and going wider. Retinal Physician. 2013;3:42-48.

Correspondence to:
Dr. Lagan Paul
Dr. Shroff's Charity Eye Hospital, Daryaganj, New Delhi, India