Introduction

OCT angiography is a new imaging technology that provides volumetric analysis of retina, choroid, and optic nerve. It helps to delineate early hemodynamic alteration in the vasculature of retina and choroid. Being non-invasive, OCT A is employed over standard angiographic techniques of fundus fluorescein angiography (FFA) and indocyanine green angiography (ICGA) which study changes in retinal superficial layers and choroid respectively. It gives a high specificity and sensitivity in diagnosis and follow-up of vascular diseases such as diabetic retinopathy, vascular occlusion, and macular degeneration. This article seeks to detail the principle and techniques of OCTA.

Abstract

OCTA is one of the breakthroughs in the advancing field of ophthalmic imaging. It is a useful clinical tool to evaluate structural vascular anatomy of retina, choroid and optic nerve head.

A non-invasive in-vivo imaging modality combining both quantitative and qualitative assessment of vasculature seen on standard angiography, OCTA is an emerging technology for evaluation and follow-up of conditions like diabetic retinopathy, retinal vascular occlusive diseases, uveitis, inherited diseases, age-related macular degeneration and optic nerve disorders.

Ocular Blood Supply

The vascular network of human retina is divided into different capillary plexuses. Each capillary plexus has characteristic morphometric features and are linked by interconnecting vessels.

From the anterior most layer i.e. internal limiting membrane (ILM) to posterior most axial locations, four distinct plexuses are:

1. Radial peripapillary/Nerve fibre capillary plexus (NFLCP)
2. Superficial capillary plexus (SCP)
3. Intermediate capillary plexus (ICP) and the deep capillary plexus (DCP)
4. Choroid (Figure 1)

Keywords: OCT Angiography, Retinal Vasculature, Multimodal Imaging

Figure 1: Diagram showing the retinal circulation. The ICP and DCP receive the supply from the SVC arterioles and drain into the SVC venules. Anastomosis occurs between plexus from different level from both the arterial and venular side. Source- Drawings by Dave Schumick from Anand-Apte and Hollyfield (2009) Encyclopedia of the Eye
Principle

OCT- A is based on low coherence interferometry principle. Sequential B-scans are taken over time positioned at the same retinal location and subjected to analysis for changes in amplitude or phase of image captured by device. The reflected beams are detected as high flow slow flow or no flow zone. Movement is suspected in case of any change detected in intensity, amplitude, phase or both. The movement is due to the flow of erythrocytes in the vessels. The obtained signal can then be amplified X number of times (incorporated software eg SSADA—split spectrum amplitude-decorrelation angiography) and digitally processed to provide an en face view of the vasculature at different predetermined slabs\(^1\,^2\) (Figure 2).

3. Outer retinal slab- This slab extends from 70µm below IPL to 30µm below RPE reference line. This region has no retinal vasculature and is thus, seen as an empty space in a normal eye. Any abnormality is useful to identify type 2 choroidal neovascular membrane (subretinal) (Figure 5).

4. Choriocapillaris- Extends 30µm below RPE reference to 60µm below RPE reference. It incorporates choriocapillaris and allows detection of early type 1 CNVM (sub-RPE).

Foveal avascular zone (FAZ): is a complete avascular zone with variable dimensions in normal healthy individuals. The

![Figure 2: A schematic flowchart of OCTA working [3]. Repeated B scans labelled N1, N2, N3 are repeatedly captured from the location line L1 in the diagram. The difference between successive B scans N1- N2 and N2-N3 is derived (Line L2). Line L3 is from the combined data. The procedure is repeated at different location to form a volumetric cube data. Source- A practical guide to optical coherence tomography angiography interpretation by Greig, E., Duker, J., & Waheed, N.](image1)

![Figure 3: Inner retinal slab: a) OCTA image similar to that of FFA. b) Superficial retinal plexus. Source- A practical guide to optical coherence tomography angiography interpretation by Greig, E., Duker, J., & Waheed, N.](image2)

![Figure 4: Middle Retinal slab. a) OCTA image showing the deeper dense retinal plexus b) anatomical depiction of the deep retinal plexus. Source- A practical guide to optical coherence tomography angiography interpretation by Greig, E., Duker, J., & Waheed, N.](image3)
SVP, present in ganglion cell layer (GCL), terminates slightly away from foveal centre than deep vascular layer.

**Interpretation**

**Sequence of steps to be followed in reading and interpreting scan (Figure 6) are:**
- Image the correct area → See the en-face OCTA images → Check segmentation lines → Look at the B scan with flow overlay → evaluate enface intensity images (Figure 7)

**En face OCT images** - The superficial slab captures SCP and part of radial peripapillary capillary plexus. The SCP along with the DCP delineates the FAZ. In diabetic retinopathy, FAZ alter microaneurysms and early vascular changes will be visualised in the inner retinal slab.

Outer retina and choriocapillaris (ORCC) slab may be combined as one: useful in cases of wet AMD.

**Segmentation lines**

The predetermined slabs are recognised automatically and demarcating segmentation lines are set. After selection of image to be read, segmentation line needs to be checked for correct identification of retinal boundaries. In a normal healthy individual, it is accurately detected. However, it may be misread in pathological conditions with haemorrhage or fluid.

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**Figure 5:** Outer retinal slab: (a) No vascularity seen in OCTA, (b) anatomical zone seen in outer retinal slab-IPL to RPE Source- A practical guide to optical coherence tomography angiography interpretation. by Greig, E., Duker, J., & Waheed, N.

**Figure 6:** showing the OCTA scan report: (a) enface retinal image, (b) cross-sectional image with segmentation into slabs- superficial(red-green), deep(green-blue), avascular(blue-yellow), (c, d, e) angiogram images of the superficial, deep and avascular slab, (f) OCTA image of the whole retinal layers encoded in false colours. Source: Hormel TT, Jia Y, et al. Plexus-specific retinal vascular anatomy and pathologies as seen by projection-resolved optical coherence tomographic angiography
Enface intensity images
The structural and angiography projection for a given retinal slab should be examined. Various pathological findings such as edema, fluid and haemorrhages may cause lower signal strength and thus a false low intensity. These may be misinterpreted as low flow and are thus called shadow artifacts. If the structural en face image shows good signal intensity and angiogram shows reduced flow in the same area, this can be interpreted as a true reduction in flow.

Various pitfalls in OCT interpretations due to artifacts created by technique or software are as follows:

1. Signal strength- Signal is information derived from tissue being imaged. Noise is spurious, unwanted information generated through image acquisition and processing. Low signal and high noise may give a poor image quality.

2. Motion artifacts- Any kind of movements such as head or eyes creates a ‘bulk motion’. The OCTA detects any movement as flow of RBC’s, thereby misinterpreting bulk motion as changes in the blood flow.

3. Projection artifact- OCT beam travelling through retina layers, strike SCP and is reflected back and captured. The rest of beams travel deeper and are reflected by RPE. Sometimes, light beam reflected by RPE is influenced by flow and erroneously depicts SCP in the deeper layers. This misinterpretation of flow is the most important artifact in OCTA.

4. Segmentation artifacts- Each slab is generated by an upper and lower boundary that slices horizontally through 3D cube. The algorithms automatically detects retinal boundaries based on reflectivity and texture. Pathologies such as fluid in DME, drusens in AMD may alter boundary detection and lead to altered slab formation resulting in segmentation errors.

5. Shadow artifact- Any structural aberration obstructs the visualization of deeper/outer layers due to reflectance of the beam. Obstruction is caused by hemorrhage, drusens, etc.

Abnormalities Seen in OCTA
1. Abnormal flow- neovascularization
2. Abnormal/anomalous vasculature- aneurysms and dilated vessels, or
3. No flow/dropout areas, as seen in nonperfusion

Clinical Application of OCTA
1. Diabetic retinopathy: FFA is indicated for vascular changes in DR. OCTA detects early changes in DR with vascular losses. Commonly noted changes are: FAZ enlargement with DR progression,(Figure 8) microaneurysms (seen as small capillary dilatations) and Capillary dropouts.

High-resolution 3D structural reconstruction aids in studying detailed pathophysiology of DR progression.

2. Age-related macular degeneration:
OCTA is useful for diagnosis of wet AMD. Three types of wet AMD: Type 1 - below RPE, type 2 - between RPE and retina, and type 3 - arises from superficial retinal vasculature and growing downwards toward the neurosensory retina and eventually choriocapillaris.
OCTA identifies, localizes subclinical CNVM and helps to monitor regression post antiVEGF injection.3

3. Retinal vascular occlusions: to assess the non-perfused areas and development of collaterals.

4. Retinal pathologies like macular telangiectasias, retinal inflammatory disease, retinal tumors and retinal hereditary dystrophies.

**Summary Points**
- OCTA images flow in retinal and choroidal vasculature.
- It has a steep learning curve.
- It is important to evaluate the correct slab such as superficial and deep plexus in vascular diseases, ORCC in CNVM.
- Artifacts may lead to misinterpretation.

**Reference**
1. Chow D, Oliveira P. OCT Angiography. 1st ed. Beijing: Thieme; 2017.
2. Hormel TT, Jia Y, Jian Y, Hwang TS, Bailey ST, Pennesi ME, Wilson DJ, Morrison JC, Huang D. Plexus-specific retinal vascular anatomy and pathologies as seen by projection-resolved optical coherence tomographic angiography. Prog Retin Eye Res. 2021 Jan;80:100878.
3. Greig, E., Duker, J., & Waheed, N. (2020). A practical guide to optical coherence tomography angiography interpretation. International Journal Of Retina And Vitreous, 6(1).
4. Spaide RF, Fujimoto JG, Waheed NK, Sadda SR, Staurenghi G. Optical coherence tomography angiography. Prog Retin Eye Res. 2018;64:1-55.
5. Rocholz R, Corvi F, Weichsel J, et al. OCT Angiography (OCTA) in Retinal Diagnostics. 2019 Aug 14. In: Bille JF, editor. High Resolution Imaging in Microscopy and Ophthalmology: New Frontiers in Biomedical Optics [Internet]. Cham (CH): Springer; 2019. Chapter 6.