New perspectives in retinal imaging - angio OCT

Musat Ovidiu, Colta Diana, Cernat Corina, Boariu Ana Maria, Alexandru Lucian, Georgescu Raluca, Patoni Ioana
*Ophthalmology Department, "Dr Carol Davila" Central Military Emergency University Hospital, Bucharest, Romania

Correspondence to: Diana Colta, MD,
Ophthalmology Department, "Dr. Carol Davila" Central Military Emergency
Hospital, Bucharest, Romania,
134 Plevnei Street, District 1, Bucharest, Romania,
Phone/ fax: +4021 3137189, E-mail: colta.diana@gmail.com

Abstract

In the last few years, structural and functional optical coherence tomography (OCT) technology has seen new and revolutionary developments. The most important of all is OCT angiography (Angio-OCT). Angio-OCT already plays an important role in clinical ophthalmology as a new, non invasive and dyeless diagnostic tool, which serves as an adjunct to, or even a replacement for fluorescein and indocyanine green (ICG) angiographies. Angio-OCT brings multiple technical and clinical improvements in the study of retinal diseases, glaucoma, and optic nerve disorders. It enables rapid, high-resolution, detailed images of large retinal vessels and capillary networks in seconds by using a strategy called "motion contrast", as opposed to revealing detailed images of large retinal vessels and capillary networks in seconds by using a strategy called "motion contrast" as opposed to the minutes required in conventional fluorescein angiography. These images are uniquely three-dimensional and allow an isolated study of individual capillary beds at different depths of the retina.

Keywords: optical coherence tomograph angiography, angio-OCT, dyeless, choroidal neovascularization

Definition

OCT angiography (Angio-OCT) is an application of optical coherence tomography (OCT), which documents differences in reflectivity within tissues (retina).

Angio OCT analyzes not only the intensity of the reflected signal but also the time changes in the reflection caused by the moving particles (erythrocytes) flowing through the vessels. These changes in the OCT signal, measured by repeatedly capturing OCT images (B-scans) at each point on the retina, allow the creation of an image contrast between the perfused vessels and the surrounding tissues, which does not display any time changes in the OCT signal due to the lack of movement [1].

Principles

Split-spectrum amplitude-decorrelation angiography, or SSADA, is an algorithm used to distinguish between static and non-static tissue. This algorithm identifies the blood flow by calculating the decorrelation of signal amplitude

from consecutive B-scans performed at the same retinal acquisition plane [2].

SSADA is capable of detecting the flow at both the optic nerve head and the macula, quantifying the data as both flow index and vessel density.

The allowable field of view (FOV) in the retina SSADA scans ranges from 2 × 2 mm to 12 x 12 mm. A 3 × 3 mm FOV is the recommended default size for the visualization of the retinal capillaries. The 6 × 6 or 8 × 8 mm scans are the recommended scans for the performance of large area scans of the retina. The 12 x 12 mm scan is only available on research prototypes [3,4].
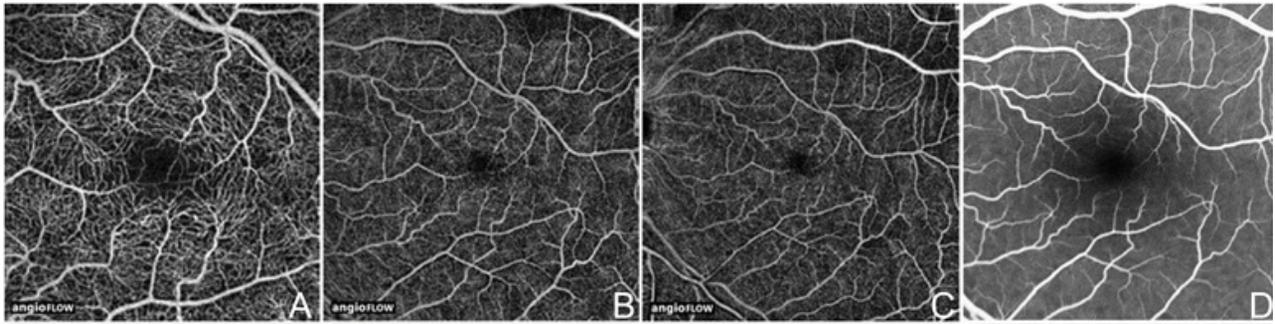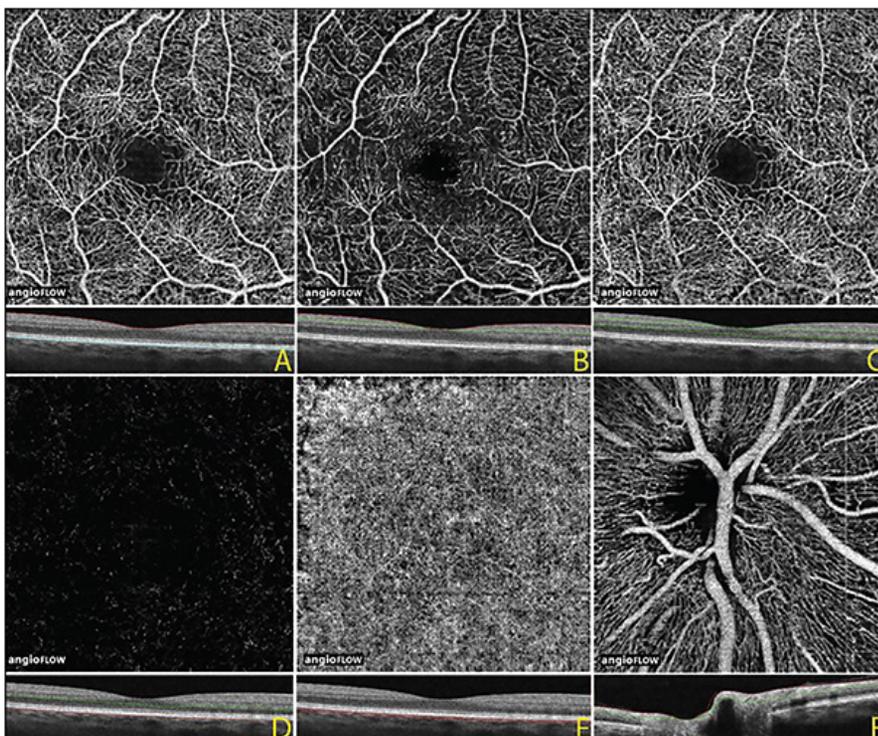

Fig. 1 OCT Angiogram (Angiovue) (A) Full-thickness (internal limiting membrane to Bruch's membrane) 3 x 3 mm. (B) Full-thickness 6 x 6 mm. (C) Full-thickness 8 x 8 mm. (D) Fluorescein angiography 8 x 8 mm. Less capillary detail than A-C

Interpretation of Angio OCT

Most commonly, the OCTA image is displayed as an en face map of the vasculature, which offers the advantage of allowing the visualization of the vasculature over the entire region of the scan in one image and also corresponds to what ophthalmologists are used to seeing on retinal exams and on fluorescein angiography.

The en face vascular image can include all the vessels seen throughout the retina (Fig. 2A) or can be used to isolate the vessels in the inner retinal layers, the middle retina, and the outer retina.

Fig. 2 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)

These approaches are illustrated in Fig. 2B-D, in which segmentation displays the inner retinal plexus in the superficial retina, the deep retinal plexus in the middle retina, and the outer retina, which is devoid of any retinal vasculature except for pathology, such as choroidal neovascularization. Sometimes, the different retinal vascular layers can be color-coded, allowing the display of the 3D information to be presented in a two-dimensional display format.

Further, superficial segmentation also allows the visualization of the radial peripapillary network of vessels in the peripapillary area (Fig. 2F).

A deeper segmentation allows the visualization of the choriocapillaris. However, at this level, there may also be a loss of resolution because of the reduced penetration of the SD-OCT signal beyond the retinal pigment epithelium (Fig. 2E).

Moreover, a longer wavelength swept source OCT may allow a better penetration past the RPE, therefore allowing a better visualization of the choriocapillaris and of the structures beneath the RPE [5].

Clinical Applications

OCT angiography produces 3D data that must be segmented into different slabs before it can be evaluated by clinicians. First, computer segmentation of OCT images provides a reference plane or surface. Appropriate tissue slabs are then defined based on these reference planes. The useful reference planes include the inner limiting membrane (ILM), outer boundary of the inner plexiform layer (IPL), outer boundary of the outer plexiform layer (OPL), and Bruch's membrane (BM). In scans of healthy eyes, automated algorithms perform well in identifying these reference planes. However, in cases where the retina is deformed, manual correction or adjustments of slab boundaries may be required [5].

Cross-sectional OCT angiograms combine color-coded flow information superimposed on the gray-scale structural information. Therefore, both the blood flow and the retinal structural information are presented together. This is useful for the clinical evaluation on the depth of abnormalities such as retinal or choroidal neovascularization.

Since OCT angiography generates a data cube, segmentation and en face presentation of vascular perfusion at various layers of the retina can summarize the flow information at relevant anatomic layers or slabs. These images can be more easily interpreted by clinicians and aid in their ability to recognize abnormalities in the vascular patterns.

SSADA is capable of flow detection at both the optic nerve head and the macula and quantifies the data as both flow index and vessel density. The flow index is the average decorrelation value and contains information on capillary flow velocity. Decorrelation values increase with the flow velocity until a saturation point is reached in larger blood vessels. This means that the flow index contains information on vessel flow in addition to the vessel density. The vessel density is defined as the percentage area occupied by flow pixels. These parameters have been used to study pathology in AMD, glaucoma and diabetic retinopathy [2,4].

Diabetic Retinopathy
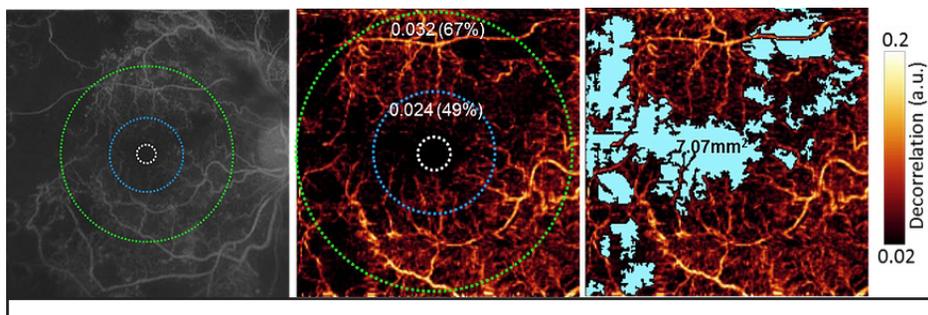
Fig. 3 Quantification of the inner retinal blood flow in nonproliferative diabetic retinopathy with macular edema. Fluorescein angiography (Left) shows defined foveal avascular zone (FAZ) as the area inside white dashed line, parafoveal region between white and blue dashed lines, and perifoveal zone between blue and green dashed lines. Enlargement of the FAZ is shown extending into parafoveal region (Middle). Scattered areas of macular nonperfusion are colored blue and presented on the 6x6 mm OCT angiogram (Right)

Glaucoma
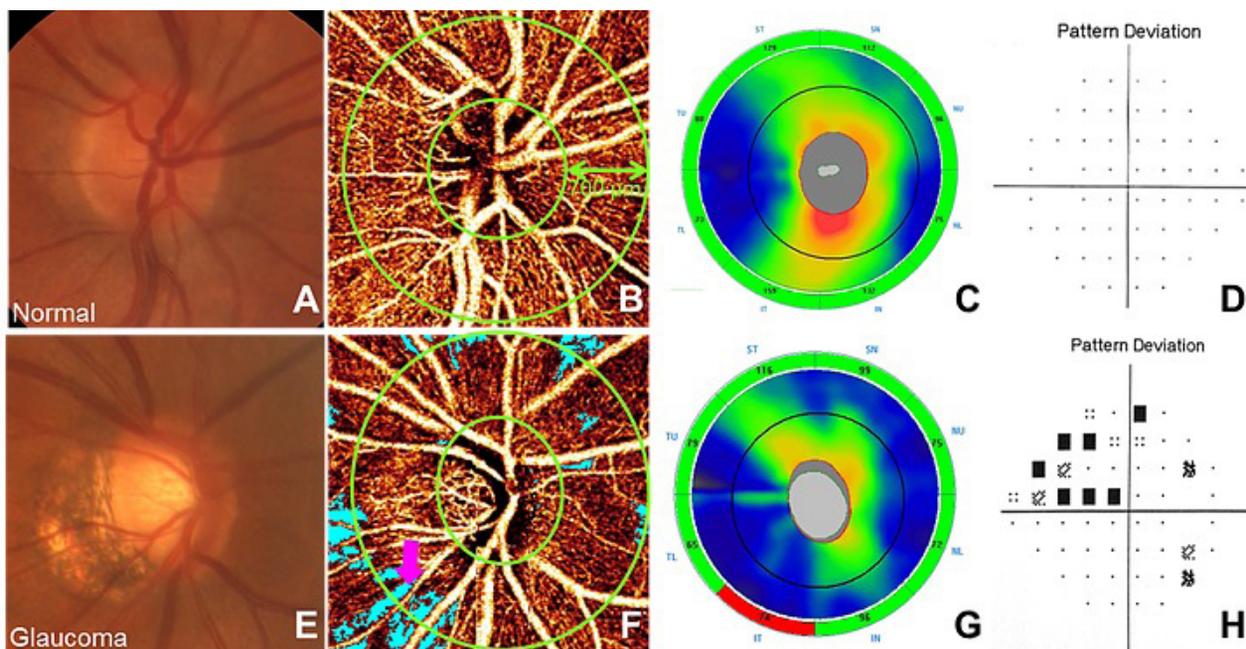
Fig. 4 Top row shows an example of a healthy eye and bottom row a glaucomatous eye. In comparison to the healthy eye (B), en face OCT angiogram of glaucomatous eye (F) shows a reduced density of the peripapillary microvasculature network. Patches of nonperfusion in glaucoma correlated well with the locations of retinal nerve fiber layer thickness maps deficits (G) and visual field loss (H)

Neovascular Age-Related Macular Degeneration
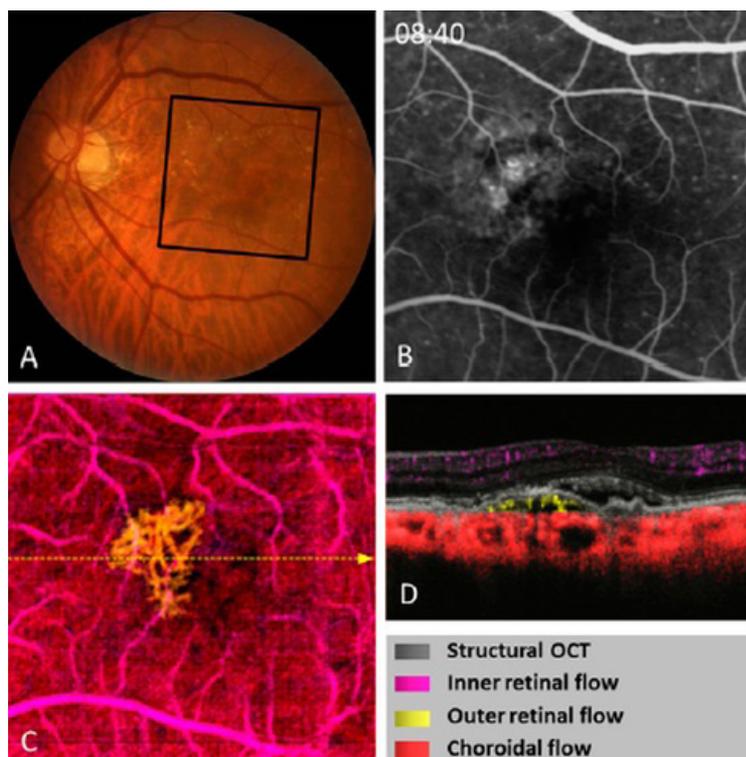
Fig. 5 The type I CNV is identified by OCT angiography (C), but it is not well defined by fundus photography (A) or fluorescein angiography (B). The black square outlines the areas shown on the angiograms. The CNV area is shown on the en face color-coded OCT angiogram (C). The dashed yellow line shows the location of the OCT cross section (D). The analysis of the yellow highlighted CNV flow reveals that CNV is predominantly under the retinal pigment epithelium

Conclusion

Optical coherence tomography angiography is a promising new imaging modality that provides 3D depth resolved information on the retinal vasculature by using noninvasive imaging techniques. It has shown great promise in the imaging of chorioretinal pathology, both in the clinical use and in potentially enhancing our understanding of the pathogenesis and evolution of the retinal disease.

In the future, further enhancements, such as increased scanning speeds, better software processing, and the introduction of longer wavelength swept source technology, may enhance the abilities of OCTA.

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