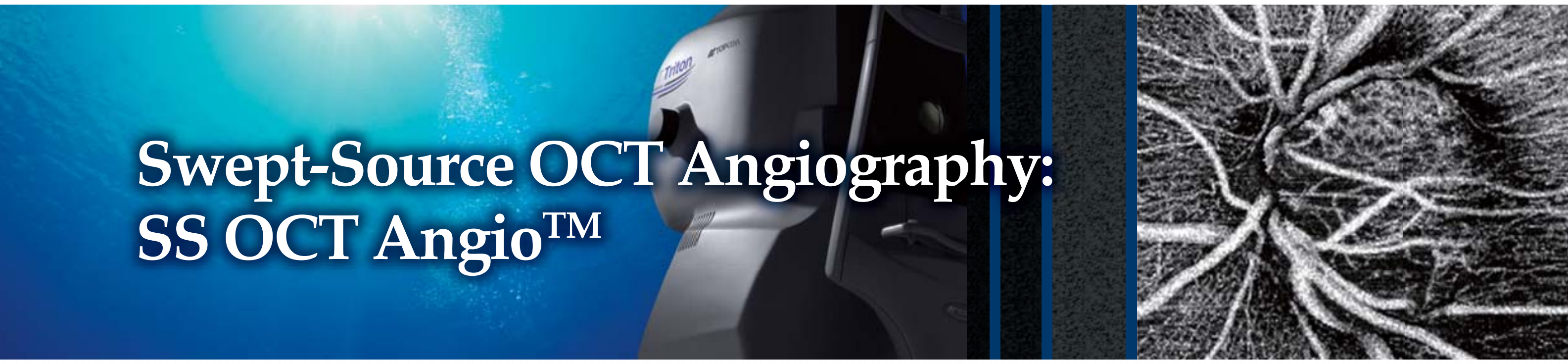
Swept-Source OCT Angiography: SS OCT Angio™



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Introduction

Optical coherence tomography angiography (OCTA) is a fast, easy, non-invasive, three-dimensional imaging method to visualize intravascular flow at the microcirculation level [1-3]. OCTA is performed within a few seconds without injecting any dye and without causing any discomfort. Topcon (Topcon Corporation, Tokyo, Japan) has developed an innovative OCTA algorithm that aims to provide improved detection sensitivity of low blood flow and reduced motion artifacts without compromising axial resolution. Topcon's OCTA implementation further benefits from being paired with swept source OCT (SS-OCT) technology, given the high 100kHz A-line rate, one micron wavelength light source, and deep signal penetration through the retina and choroid. IMAGEnet®6, a web-based ophthalmic data management system, incorporates visualization of angiographic data sets, providing for both standard and customizable en-face and cross-sectional views of OCTA data in conjunction with corresponding structural data.

OCTA methods are generally based on quantification of motion contrast. In a practical implementation, ocular B-scan data may be scanned two or more times in the same location, and a calculation is performed across corresponding pixels in each frame or combination of frames in order to quantify the degree of motion contrast. This measure is then presumed to correspond to angiographic flow, as blood flow is the primary cause of signal change under normal imaging conditions after bulk motion has been accounted for. Some angiographic methods compute the differences between image frames, whereas others may compute the variance over an arbitrary number of frames.

There are many variations to perform such calculations using OCT intensity information. A commonly used OCTA method which calculates speckle variance was first demonstrated by A. Mariampillai et al.[1].

Y. Jia et al. later proposed a method known as split-spectrum amplitude decorrelation angiography (SSADA) which simultaneously splits the spectrum into smaller bands while utilizing a simple decorrelation measure as the basis for motion contrast [2]. Moreover, Y. Huang et al. recently proposed a differentiation-based method modified from the so called optical microangiography (OMAG) algorithm where calculations are based on the absolute difference between linear intensities [3].

In this paper, we introduce Topcon's novel, patent (under examination) motion contrast measure using a ratio method, named OCTARA (<u>OCT</u> <u>A</u>ngiography <u>R</u>atio <u>A</u>nalysis), where the full-spectrum is kept intact and therefore the axial resolution is preserved. It is shown that Topcon's innovative method provides advantages over differentiation-based approaches while possessing improved sensitivity over methods based on amplitude decorrelation.

Methods

Using DRI OCT, we performed SS-OCT imaging at 100,000 A-scans per second in both healthy and diseased eyes. Volumetric OCT scans were acquired over a 3 mm x 3 mm field of view in about four seconds of total OCT scan time. Each B-scan position was repeatedly scanned 4 times.

For OCTA processing with OCTARA, B-scan repetition at each scan location were registered. OCTA images were generated by computing a ratio-based result, *r*, between corresponding image pixels:

$$r(x,y) = 1 - \frac{1}{N}\sum_{i,j}^{N} \frac{\min\left(I_i(x,y), I_j(x,y)\right)}{\max\left(I_i(x,y), I_j(x,y)\right)}$$

where $I(x,y)$ is the OCT signal intensity, N is the number of scanned B-scan combinations at the given location, and i and j represent the two frames within any given combination of frames. As will be shown later, this formula represents a relative measurement of OCT signal amplitude change that optimizes angiographic visualization over both the retina and choroid and also enhances the minimum detectable signal relative to amplitude decorrelation. It should be noted that the directionality of the ratio is arbitrary (i.e., numerator versus denominator) and that the subtraction from unity is an optional operation that serves to conveniently orient the direction of the display range similarly to other calculation methods such as differentiation and decorrelation. Furthermore, our method preserves the integrity of the entire spectrum and therefore does not suffer from compromised axial resolution, an inherent disadvantage of split-spectrum OCTA techniques. Motion artifacts were suppressed by selectively averaging over multiple B-scan combinations in the present OCTA study. High quality OCT structural images were generated by averaging registered B-scans. Segmentation of retinal layer boundaries was performed on OCT structural images.

Standard OCT structural imaging provides intensity images for the evaluation of retinal structure and anatomy. Functional OCTA imaging detects motion by measuring intensity fluctuations in repeatedly scanned OCT images, and enables visualization of blood flow and microvasculature physiology. Since OCTA is processed from OCT intensity images, the functional data is intrinsically registered with the structural data (Fig. 1).

En-face projections of volumetric scans allow visualization of structural and vascular details within segmented retinal layer boundaries.

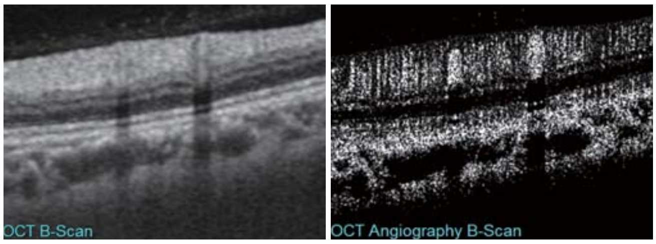

Fig. 1. Example of a structural OCT B-scan (left) and corresponding cross-sectional OCT angiogram (right) in a normal subject.

Results

Comprehensive structural and functional imaging of the human retina was performed by standard OCT and OCTA. SS-OCT utilizes longer wavelength infrared light than conventional spectral domain OCT (SD-OCT) and therefore has improved penetration into tissue, can image through optical opacities, and is invisible to the subject. SS-OCT also does not suffer significant signal roll-off when compared to SD-OCT, which requires enhanced depth imaging (EDI) techniques to visualize the choroid.

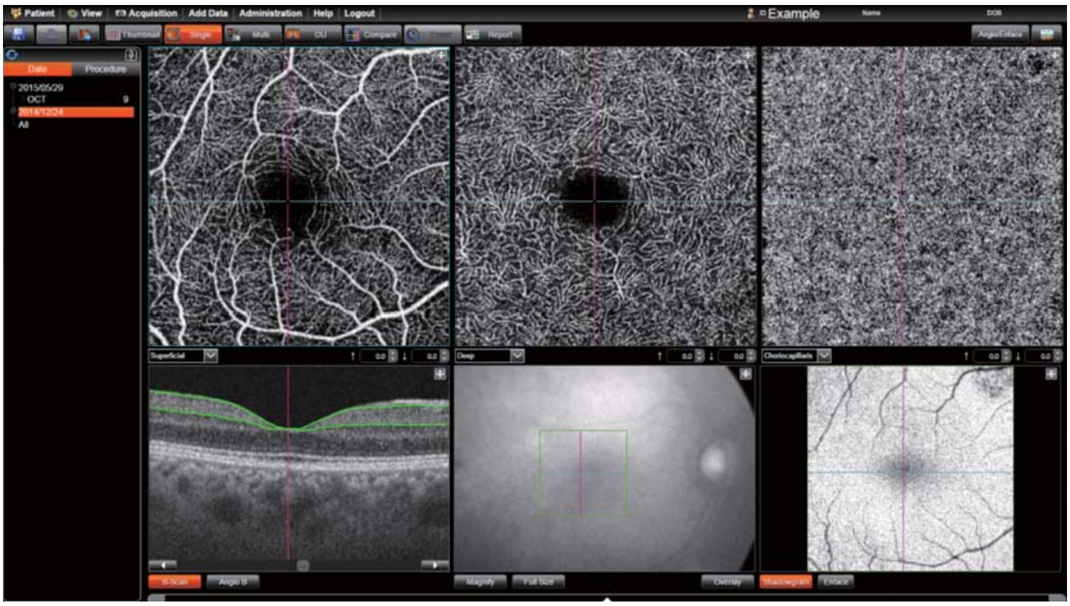

Fig. 2. En-face OCTA of the macula using Topcon IMAGEnet6 software showing superficial (top left) and deep (top center) capillary plexus as well as choriocapillaris (top right) using default settings. Corresponding OCT cross section (bottom left), IR fundus image (bottom center), and enface OCT (bottom right) are also shown.

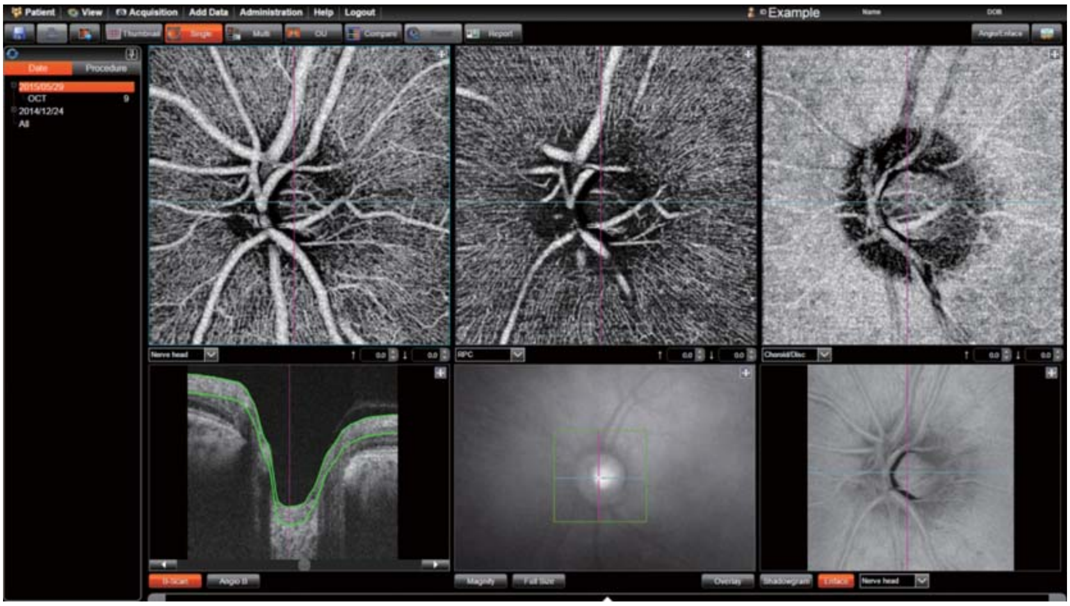

Fig. 3. En-face OCTA of the optic nerve head using Topcon IMAGEnet6 software showing superficial vascular layers (top left), superficial vascular layers emphasizing the radial peripapillary network (top center), and deep vascular layers (top right) using default settings. Corresponding OCT cross section (bottom left), IR fundus image (bottom center), and enface OCT (bottom right) are also shown.

Normal eye

In the foveal region, retinal vasculature and the foveal avascular zone were clearly visualized. The inner vascular plexus in the ganglion cell layer and an outer layer of capillaries in the inner nuclear layer were readily distinguishable. The densely packed choriocapillaris network was also detected (Fig. 2). In the optic nerve head region, the radial peripapillary capillary network and microcirculation in the disk were visualized (Fig. 3).

Diseased eye

There are clear signs of disease in a patient with branch retinal vein occlusion (BRVO) in the superficial vasculature. An irregular structure is also observed in the choriocapillaris (Fig. 4).

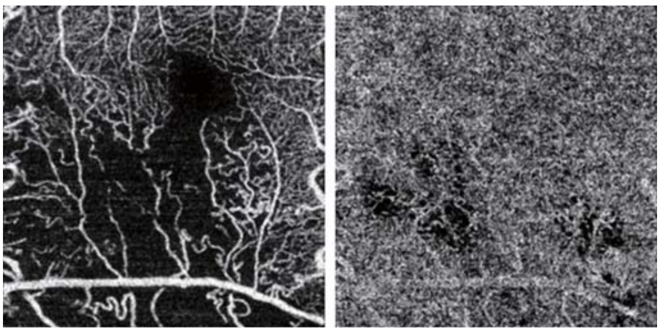

Fig. 4. En-face OCTA images of the macula for a patient with branch retinal vein occlusion (BRVO) showing the superficial capillary plexus (left) and choriocapillaris (right).

Furthermore, in diseased eyes with geographic atrophy (GA) and choroidal neovascularization (CNV), choroidal perfusion information in large choroidal vessels and choriocapillaris was detected (Fig. 5). It is believed that the larger choroidal vessels are well visualized in these cases in association with atrophy of the RPE and/or choriocapillaris.

Topcon's innovative OCTA processing method, OCTARA, based on a ratio calculation, demonstrates improved detection sensitivity of microvasculature. In Fig. 6, an example from a diseased eye with CNV shows choroidal vascular structure uniformly visualized with better detection sensitivity of low flow compared to intensity differentiation-based OMAG [3]. In Fig. 7, notice that the vascular network was better visualized compared to the SSADA algorithm [2]. In this latter example it should be noted that the differences in relative angiographic signal intensity are due both to the separate factors of full-spectrum versus split-spectrum and of ratio versus amplitude decorrelation. The effects of these two sets of factors are additive in nature.

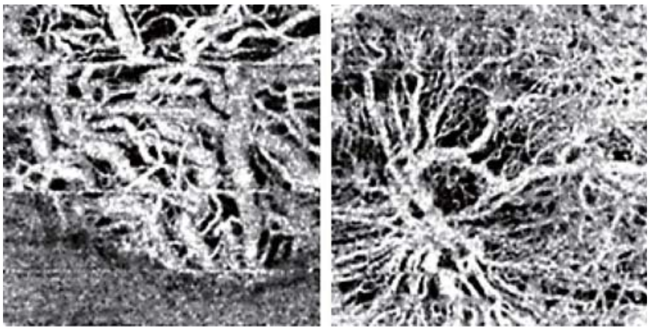

Fig. 5. Example DRI OCT angiography images of GA (left) and CNV (right) cases displaying angiographic signal integrations below the automatically segmented Bruch's Membrane boundary. Data courtesy of Dr. Laura Kuehlewein and Dr. SriniVas R. Sadda, Doheny Eye Institute.

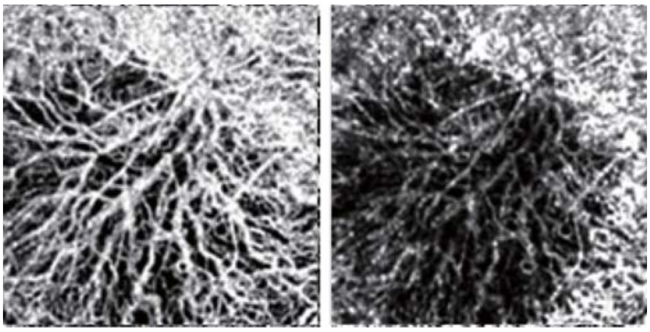

Fig. 6. Topcon OCTA (OCTARA) algorithm based on ratio (left) comparison with intensity differentiation-based optical microangiography (OMAG) algorithm (right). Large areas of the choroidal neovascular membrane are more clearly and uniformly visualized with the ratio-based methodology than with the differentiation-based calculation. Data courtesy of Dr. Laura Kuehlewein and Dr. SriniVas R. Sadda, Doheny Eye Institute.

Conclusions

Standard OCT structural imaging reveals micron-scale morphological changes in the retina while OCTA detects functional impairment in retinal and choroidal vasculature at the capillary level. Topcon's OCTARA method notably is not based on amplitude decorrelation, but rather an innovative scheme using the intensity ratio, thereby enabling significantly improved detection sensitivity of microvasculature signal. In addition, Topcon's OCTARA method does not require splitting the spectrum and therefore preserves axial resolution. Meanwhile, active motion correction has been developed and will be an added feature to further reduce motion artifacts in OCTA. All in all, Topcon's high sensitivity, high axial resolution OCTA was demonstrated in this paper. Together with industry-leading high speed and 1μm-wavelength high tissue penetration SS-OCT, Topcon's OCTARA method can facilitate better visualization and detailed evaluation of individual capillary layers as well as choroidal vasculature.

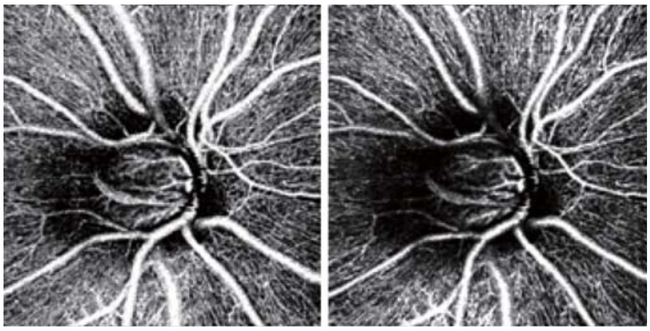

Fig. 7. Topcon OCTA (OCTARA) algorithm (left) comparison with split-spectrum amplitude-decorrelation angiography (SSADA) algorithm (right). Topcon's OCTA implementation utilizes an intensity-based ratio calculation with full-spectrum processing, thereby allowing the axial resolution of angiographic images to match that of the underlying OCT images for a better visualization of the vascular network. Significant portions of the Topcon OCTA image are displayed with higher relative intensity with better visualization of hard-to-detect capillary flow.

References

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