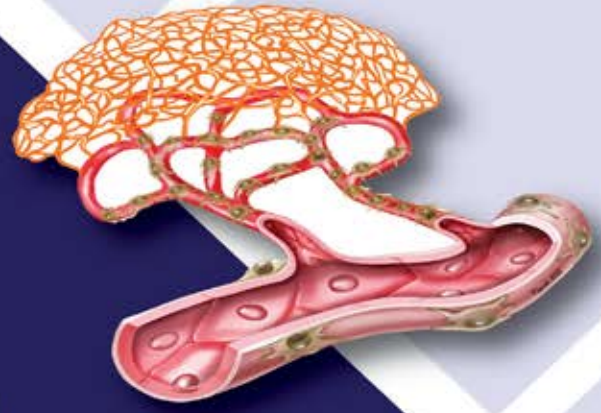
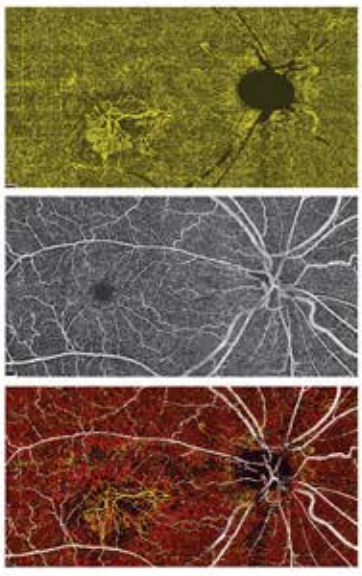
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Clinical OCT Angiography Atlas







Marco Rispoli
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David Huang
Yali Jia
Maria Cristina Savastano

Foreword
James Fujimoto

2nd Edition

JAYPEE

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Chapter 3 OCT angiography: Terminology

David Huang, Tristan Hormel, Yali Jia

INTRODUCTION

Clinical use of optical coherence tomography angiography (OCTA) expanded rapidly since its introduction in 2014. The vocabulary describing OCTA features and measurements has similarly expanded. This chapter defines and updates the most important terms likely to be encountered in OCTA applications.

AVASCULAR AREA

Avascular areas within the eye do not include vessels. Healthy retina normally contains an avascular area known as the foveal avascular zone. Pathological capillary dropout leads to the formation of additional avascular areas.

MOTION ARTIFACTS

Motion artifacts are produced by motion contrast not attributable to blood flow. Common sources of these artifacts are microsaccades (which cause bright stripes in OCTA images), ocular pulsation, and drift. Postprocessing algorithms can remove motion artifacts by sampling noise statistics from the OCTA data volume and applying a suitable correction.[1-7] Motion artifacts can also be reduced by tracking systems that follow the eye's movement and trigger a rescan of affected B-frames.[8-10]

EN FACE AND CROSS-SECTIONAL IMAGES

Since OCTA data is three-dimensional, it must be projected onto two dimensions in order to be easily viewed on a computer screen.

En face projections create direct-facing images of retinal vasculature analogous to the familiar fundus photography image. En face OCTA images are used for clinical inspection and the basis for additional processing and quantification. Creating an en face OCTA image requires first identifying an anatomic slab and then projecting the flow signal either by averaging ("mean projection") or taking the maximum value ("maximum value projection").[11]

Cross-sectional images are useful for identifying the depth of vascular pathology within the retina. They can be displayed as individual B-frames, but often visualization of features can be enhanced by averaging multiple frames.[12]

FLOW SIGNAL

Optical coherence tomography angiography detects flow by measuring the variation in the OCT reflectance signal between consecutive cross-sectional scans (B-scans) due to the motion of blood cells. Since the OCT signal is complex, flow can be measured by variation in either its amplitude, phase, or both. The flow signal can be computed as variance, difference, ratio, or decorrelation between the repeated OCT B-scans. The flow signal is nonlinearly related to flow velocity; it has both a sensitivity (the lowest detectable flow signal) and a saturation limit. The flow signal also depend on the reflectance signal strength and the caliber of the blood vessels.[13]

NONPERFUSION AND LOW-PERFUSION AREAS

Nonperfusion areas are regions of the eye that normally contain vessels but are avascular due to pathologic capillary dropout. Nonperfusion area can detected as abnormally large gaps between blood vessels.[14] The nonperfusion area is a sensitive metric for detecting diseases in which distinct areas of capillary dropout is interspersed with areas with normal vessel density. In other diseases, vessel density can be reduced without forming large gaps. These diseases are better detected by identifying low-perfusion areas—areas where the vessel density is significantly lower than that in the corresponding location in the perfusion map averaged from a reference population of healthy eyes.[15]

OPTICAL COHERENCE TOMOGRAPHIC ANGIOGRAPHY

Optical coherence tomography angiography is a functional extension of OCT that detects blood vessels by motion contrast. This enables the visualization of capillaries and other small vessels not visible on structural OCT. OCTA scans contain both reflectance and flow signal and can be used to provide both structural and angiographic images in three dimensions.

PROJECTION ARTIFACTS

Moving blood cells scatter the OCT beam and cause variation in OCT signal in distal tissue. This variation produces artifactual flow signal that appears as duplication of superficial vasculature in deeper slabs in en face images, and as "tails" descending from vessels in cross-sectional images.[16] Projection artifacts falsely increase vessel density measured in deeper slabs and can cause erroneous detection neovascularization in the normally avascular outer retina.

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PROJECTION-RESOLVED OPTICAL COHERENCE TOMOGRAPHY ANGIOGRAPHY

An OCTA postprocessing technique that analyzes both flow and reflectance signals to distinguish between in situ vascular flow and projected flow. Projected flow signal is removed while keeping vascular flow signal intact.[17,18] Projection-resolved OCTA (PR-OCTA) operates volumetrically, and so can remove projection artifacts both from en face images and cross-sectional scans.

REFLECTIVITY

Reflectivity is a material property that measures a tissue's propensity to reflect incident light. The reflectivity of a material generally varies with the wavelength, incidence angle, and polarization of the illuminating light source. Retinal layers vary in reflectivity, which causes some layers to appear relatively dark and others to appear relatively bright. Fluid spaces in the retina have very low reflectivity. The nuclear layers have relatively low reflectivity. The retinal pigment epithelium has high reflectivity due to high content of melanosomes. The nerve fiber layer and Henle's fiber layer have directional reflectivity that is brightest with perpendicular light incidence relative to the fibers.

REFLECTANCE SIGNAL

The reflectance signal is measured in structural OCT, where coherence gating is used to resolve the depth from which light is backscattered. The reflectance amplitudes are represented in color scale or gray scale in structural OCT images. Reflectance depends on intrinsic tissue reflectance as well as extrinsic factors such as shadowing and polarization shift from more superficial tissue structures, and beam defocus and incidence angle.

SCAN

There are several types of scans in OCT. A line scan, or *A-scan* (also called *A-line*), is a measurement of reflectance versus depth at a single lateral position. A cross-sectional scan, or *B-scan* (also called B-frame) is composed of A-lines formed by lateral scanning of the OCT beam. A volumetric scan is a collection of B-scans, the sample of a contiguous tissue volume. The full volume scan is usually what is meant by an "OCT scan" or an "OCTA scan." A *C-scan* is an image formed by resampling the volumetric scan in an en face plane perpendicular to the A-scan direction.

SHADOW ARTIFACTS

Shadow artifacts are produced by reflectance signal attenuation due to scattering, absorption, or polarization shift by tissue in the OCT beam path.[16] This in turn leads to loss of flow signal. In OCTA images, shadowing can appear similar to capillary drop out. So measurements of vessel density must take both flow and reflectance signal into account to more accurately detect blood vessels and exclude regions where vessels cannot be reliably detected due to severe shadowing.[19] Common causes of shadow artifacts are vignetting (iris), vitreous floaters, and hyperreflective material within the retina.

SIGNAL STRENGTH

Signal strength is an important quality metric of an OCT image. Low signal strength can be caused by defocusing, poor tear film, vignetting, cataract, and vitreous opacities. Signal strength can affect the measurement of vessel density on OCT images and requires compensation.

SLAB SEGMENTATION

The segmentation of tissue slabs is a necessary image processing step for creating en face OCTA images of retinal plexuses or complexes. The boundaries between retinal anatomic layers are identified by reflectivity transitions in structural OCT. This then form the basis for identifying the boundaries of the retinal plexuses and complexes (**Table 1**).[20-23]

SPLIT-SPECTRUM AMPLITUDE-DECORRELATION ANGIOGRAPHY

Split-spectrum amplitude-decorrelation angiography (SSADA) is an OCTA algorithm that enhances the signal-to-noise ratio (SNR) for flow detection through spectral-splitting, in which the reflectance signal is measured separately in different spectral subbands and then averaged to produce the flow signal.[24] This averaging procedure reduces axial resolution, but SSADA measurements retain sufficient axial resolution to measure retinal vascular plexuses in isolation. Spectral splitting increases the flow detection SNR by (1) enhancing speckle contrast within the spectrally split subbands, since narrower spectrum increases the depth range of speckle grain, (2) summing of speckle contrast from spectral subbands, since each carries unique speckle pattern, and (3) damping axial bulk motion noise due to decreased axial resolution. SSADA can increase the SNR of flow detection by a factor of four and enables the construction of high-quality OCT images based on only two B-scans at each tissue location, the minimum possible.

Table 1 Relationship between retinal vascular plexuses and complexes to anatomic layers.

Anatomic layer	Plexus	Complex
Nerve fiber layer (NFL)	Nerve fiber layer plexus (NFLP)	Superficial vascular complex (SVC)
Combined ganglion cell and inner plexiform layer (GCIPL)	Ganglion cell layer plexus (GCLP) Anterior three quarters of GCIPL	
Inner nuclear layer (INL)	Intermediate capillary plexus (ICP) Posterior quarter GCIPL and anterior half of INL	Deep vascular complex (DVC)
Outer nuclear layer (OPL)	Deep capillary plexus (DCP) Posterior half of INL and entire OPL	

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STRUCTURAL OPTICAL COHERENCE TOMOGRAPHY

In structural OCT, a beam of light is used to scan tissue and the backscattered light detected interferometrically to obtain depth information. Lateral scanning of the beam is used to provide three-dimensional volumetric imaging of tissue microstructure.[25] OCT is most widely used in ophthalmology to resolve the layered structure of the retina and cornea with micrometer resolution, but it is also used to image many other tissues, such as skin,[26] or nonbiological materials, for example paintings.[27]

VASCULAR PLEXUSES AND COMPLEXES

The retina contains four vascular plexuses that form two complexes.[28] From most anterior to most posterior these are the *nerve fiber layer plexus, the ganglion cell layer plexus, the intermediate capillary plexus, and the deep capillary plexus*. The nerve fiber layer plexus and ganglion cell layer plexus are both named for the anatomic layers in which they are found. The nerve fiber layer plexus also called the *radial peripapillary capillary plexus* near the optic disk. Together the nerve fiber layer and ganglion cell layer plexuses form the *superficial vascular complex*, while the intermediate and deep capillary plexuses form the *deep vascular complex*. **Table 1** shows the relationship between retinal plexuses and anatomic layers.

VESSEL METRICS

Optical coherence tomography angiography is used to measure vessel metrics. The most common are *vessel densities*, which can be measured as area density (the number of flow pixels divided by the total number of pixels in an en face image of a vascular plexus or complex), line density (similar measurement made after vessels have been skeletonized, leading to a length/area ratio), or volume density (vascular voxels as a fraction of total number of voxels within a tissue volume).[29] Vessel density measurements is used to quantify tissue perfusion and detect pathological loss of vessels.[30-32] Other vessel metrics use to detect pathology include measurement of the *vessel area of neovascularization,[33] area of dilated capillaries,[34] fractal dimension,[35,36] and tortuosity.[37]*

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Clinical OCT Angiography Atlas

This *Clinical OCT Angiography Atlas* shows the state-of-the-art principles of clinical OCTA imaging. The key word is "clinical", helping users to interpret OCTA images and guiding clinicians to understand the features of angiographic images. The first edition was a great success and is now sold out. Worldwide enthusiasm will still increase for OCT angiographic imaging, and we anticipate a progressive development of its clinical applications.

This second edition Atlas has been deeply transformed and developed. All chapters have been completely rewritten; some are entirely new and ground-breaking. We report the great advances OCT Angiography has obtained in the clinical field since the first edition in 2015. OCTA allowed us to identify new pathologies, recognize new syndromes, and organize disorders in new classifications. Known diseases are now better understood and new diseases are described. In this book, the operating principles, clinical applications, and future promises of OCTA are clearly explained by world-renowned original developers of the technology.

Part I, Section 1 of the Atlas, exposes the basic principles of OCT angiography, the methods and technology, the interpretation of OCTA imaging, the vascular anatomy of retina, and the clinical applications from an angiographic perspective.

In Part II, we provide a general update on the state of clinical OCT angiography research in a variety of retinal, choroid, and anterior chamber disorders.

In Part III, we describe the future clinical applications and implications of next generation of devices.

This Atlas should serve as a basic guide to ophthalmologists and technicians, as they use OCT angiography in their everyday clinical activities.

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