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## Diagnostic and surgical techniques

# Application of anterior segment optical coherence tomography in glaucoma

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ABSTRACT

Optical coherence tomography (OCT) is a cross-sectional, three-dimensional, high-resolution imaging modality that uses low coherence interferometry to achieve axial resolution in the range of 3–20 μm. Two OCT platforms have been developed: time domain (TD-OCT) and spectral (or Fourier) domain (SD/FD-OCT). Visante anterior segment OCT (Carl Zeiss Meditec) is a TD-OCT widely used for anterior segment imaging. The SD-OCT systems with both posterior and anterior segment imaging capabilities include the RTVue, iVue (Optovue), the Cirrus (Carl Zeiss Meditec), and the Spectralis (Heidelberg Engineering, Inc.). Each of the SD-OCTs has a wavelength in the range of 820–879 nm. Anterior segment OCT is a non-contact method providing high resolution tomographic cross-sectional imaging of anterior segment structures. Anterior segment OCT provides qualitative and quantitative assessment of the anterior segment structures important to the pathogenesis and the anatomical variations of glaucoma, and the approach to and success of treatment. We summarize the clinical applications of anterior segment OCT in glaucoma.



Many situations in clinical ophthalmology require precise understanding of the dimensions and spatial relationships of various structures in the eye. Anterior segment optical coherence tomography is a non-contact method that provides cross-sectional, three-dimensional, high-resolution images using low coherence interferometry to achieve axial resolution in the range of 3–20 μm. Optical coherence tomography (OCT) was invented by David Huang and colleagues in 1991. Anterior segment imaging using OCT was first demonstrated in 1994 by Izatt et al using light with a wavelength of 830 μm. Later, Lubech's group described OCT imaging of laser thermokeratoplasty lesions in 1997, and Maldonado and colleagues reported imaging of LASIK flaps in 1998. Huang and Izatt in 2001 first demonstrated the modern version of anterior segment OCT using 1,310 nm wavelength light and a scan speed of 4000 A-scans/sec, with telecentric transverse scanning and rapid scanning optical delay technology in a reference arm yielding an axial resolution of 17 μm.

Subsequently, the development of spectral domain OCT (SD-OCT) led to the application of this novel technology to image the posterior as well as anterior segment with faster acquisition and better image quality. Anterior segment OCT provides qualitative and quantitative assessment of the anterior segment structures involved in the pathogenesis of

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glaucoma.[7,8,35,90,98,107] High-definition and three-dimensional imaging of anterior segment structures with SD-OCT provides a definition of ocular tissues comparable to histology.[12,61]

## 1. Principle and technique

OCT, based on the principle of low coherence interferometry, is similar to ultrasonography in concept except that it uses infrared light instead of ultrasound to obtain images. In a typical OCT system (Fig. 1), light from a broadband, near-infrared source (super luminescent diodes, fiber amplifiers, femtosecond pulse lasers in the wavelength range of 800–1550 nanometers, etc.) and a visible aiming beam is combined and coupled into one branch of a fiber-optic Michelson interferometer. The light is split into two beams using a 2 × 2 coupler, one fiber leading to a reference mirror and the second focused into the tissue of interest. Light reflecting from the reference mirror is recoupled into the fiber leading to the mirror. Mismatch in index of refraction in the tissue of interest leads to reflection of light that is then recoupled into the fiber leading to the tissue. Light that has been back-reflected from the tissue and light from the reference arm recombine within the 2 × 2 coupler. Changes in the length of reference arm help in sampling at various depths of the tissue of interest. The depth resolution of the optical coherence tomography system is inversely proportional to the bandwidth of the source. An optical detector in the final arm of the Michelson interferometer detects the interference between the reference and tissue signals. The reference-arm mirror is scanned at a constant velocity, allowing depth scans (analogous to ultrasound A-scans) to be made. The beam can be scanned laterally across the tissue by mounting either the tissue or the interferometer optics on a stage to build up two- and three-dimensional images, pixel by pixel.

OCT at 1.3 μm wavelength of light is better suited for anterior segment imaging than the 0.8 μm wavelength. There is increased penetration at this wavelength because of decreased scattering. This enables visualization of more detailed anterior segment morphology. Note that 1.3 μm wavelength is strongly absorbed by water in ocular media, and therefore only 10% of the light incident on the cornea reaches the retina. This improves retinal protection and allows for the use of high power illumination which, in turn, enables high-speed imaging. According to the current standard set by the American Laser Institute and the American National Standard institute (ANSI 2000), the permissible exposure level at 1.3 μm wavelength is 15 mW, which is 20 times higher than the 0.7 mW limit at the 0.8 μm wavelength. The high-speed imaging provided enables imaging of dynamic ocular elements, decreases motion artifacts, reduces time needed for examination, and allows rapid examination of relatively large areas.

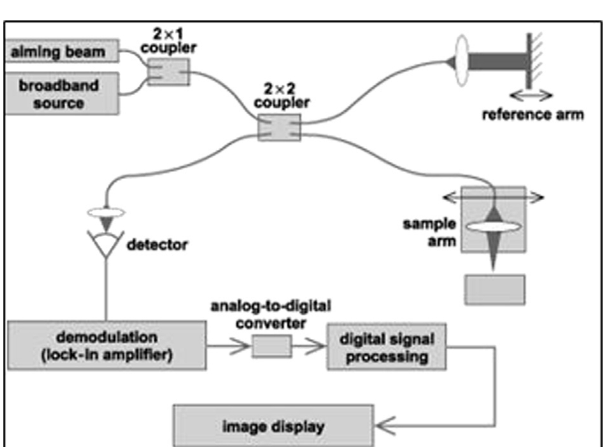

**Fig. 1 – Flow chart depicting the principle of AS-OCT.**

Two OCT platforms have been developed: time domain and spectral (or Fourier) domain. Time domain OCT (TD-OCT) utilizes a moveable reference mirror. The mirror moves for each A-scan to determine the ocular structure's depth, and this limits the speed at which the image is acquired. Fourier domain OCT (FD-OCT), by comparison, has a fixed reference mirror to measure the depth information and uses a Fourier transformation algorithm of the spectral interferogram to produce the A-scan, thus resulting in faster acquisition and better image quality. Time domain anterior segment OCT (AS-OCT) systems include the Visante AS-OCT (Carl Zeiss Meditec, Inc., Dublin, CA) and SL-OCT (Heidelberg Engineering GmbH, Tiergartenstr., Heidelberg, Germany). Visante uses a semiconductor optical amplifier light source capable of emitting 22 mW of low coherence light with a central wavelength of 1.3 μm. The scanning speed of 4,000 axial scans per image and image acquisition rate of 8 frames/sec achieves an axial resolution of 18 μm and a lateral resolution of 60 μm. The telecentric transverse scanning capacity allows for better imaging of anterior chamber and cornea. Slit-lamp adaptation of anterior segment OCT utilizes a charged couple device allowing visualization of the scan area in real time. Both of these instruments have a relatively slow scan rate that limits the sampling density. In addition, the OCT designed for posterior segment imaging has been used as a rapid method of assessing the configuration of the anterior chamber.[40] Fourier-domain OCT utilizes spectral analysis of interferometric signal as a function of wavelength and is principally divided into two types: SD-OCT and swept-source OCT (SS-OCT). SD-OCT utilizes a spectrometer to record the spectral fringe pattern, whereas SS-OCT makes use of a single detector with a rapidly tunable laser as a light source. FD-OCT (RTVue, Optovue, Inc, CA) has also been approved by the U.S. FDA for use in corneal and anterior segment imaging. The RTVue's Fourier (or spectral) domain OCT technology uses low coherence interferometry to detect light echoes, relying on a spectrometer and high-speed CCD camera. The RTVue utilizes light at 840 nm wavelength and measures all echoes of light simultaneously—as compared to sequentially in the case of TD-OCT—improving sensitivity and imaging speed and features a parallel acquisition design that helps to obtain a whole axial scan by simultaneously capturing 2,048 pixels, providing a high-definition image in 0.04 seconds without creating significant motion errors. The scanning speed is 26,000 A-scans per second, 65 times faster than the scanning capability of TD-OCT. The cornea/anterior segment module of RTVue allows for anterior segment and corneal imaging with a resolution of 5 μm. The Cirrus spectral-domain optical