Editorial

Evolution, recent progress and future development of optical coherence tomography

Evolución, recientes avances y futuro desarrollo de la tomografía de coherencia óptica

M. España-Contreras a,*, I. Fernández-Baca-Casares b, E. Santos-Bueso c

a Unidad de Neurooftalmología, angiografía y tomografía de coherencia óptica, Hospital Regional Universitario Carlos Haya, Málaga, Spain
b Servicio de Oftalmología. Hospital Regional Universitario Carlos Haya, Málaga, Spain
c Unidad de Neurooftalmología, Hospital Clínico Universitario San Carlos, Madrid, Spain

The first description of Optic Coherence Tomography (OCT) was published in Science in November 1991. From the beginning, OCT revolutionized ophthalmological diagnostics and nowadays has become an essential tool for clinical decision-making and follow-up, both in retinal diseases and glaucoma. In addition, the use of anterior pole OCT is becoming widespread.

The first tomographs to be used in clinical practice were based on time domain technology (TD-OCT), with the standard device being Stratus OCT® (Carl Zeiss Meditec). This technology, with 10 μm axial and 20 μm transversal resolution images, surprised us by showing what we had never seen before in vivo. In this way, we were better able to understand the vitreous-retina interface disease, to the point that new entities were defined such as myopic foveoschisis, to name but one example of the many contributions OCT has made to ophthalmology.

With the fast pace of technological developments, a new generation of Fourier or spectral domain tomographs (SD-OCT) appeared, characterized by very high capture rates of 25,000–75,000 A scans per second against 400 of TD-OCT. SD-OCT enabled high-definition assessment of large retinal zones (4–7 μm axial resolution and 10–20 μm transversal resolution), as well as in 3-D mode. This higher resolution allowed us to identify the retinal structures with greater precision as well as to identify some new areas such as the “interdigitation zone”.

In addition, SD-OCT gave us access to a new analysis methodology, i.e., the in-face or frontal images that displayed the retina and optic nerve in layers.

From the beginning, researchers have worked to improve OCT technology, basically seeking higher capture rates, enabling scans with greater density of data, as well as pursuing images with higher resolution and lower amount of artifacts caused by movements. In this regard, some technical and software improvements have been continuous, with some variations between manufacturers. Eye tracking and eye correction movement or offsetting software improve image quality and reproducibility of captures.

Additional contributions of the OCT technology include analysis protocols such as measuring ganglion cell layers and deviation maps for following up optic nerve diseases; software for automatic location of the fovea and change control

* Corresponding author.
E-mail address: esbueso@hotmail.com (M. España-Contreras).
© 2015 Sociedad Española de Oftalmología. Published by Elsevier España, S.L.U. All rights reserved.
that enable comparisons between explorations at different points in time (which are very useful for assessing the progression of the disease), and new in-face imaging segmentation programs or pigment epithelium analysis (available in some tomographs).

A further challenge was to achieve greater penetration capacity in tissue in order to obtain quantifiable images of the choroids. This was made possible with Enhanced Depth Imaging-OCT (EDI-OCT), a technique described by Spaide et al. which has provided valuable information on the role of the choroids and its patterns of change in various diseases.\(^5\)

Pursuing the above objectives, an additional development of the Fourier domain has recently been included in clinical practice, i.e. the Swept-Source-OCT (SS-OCT) technology which provides much higher rates (exceeding 400,000 A scans in some prototypes),\(^5\) and higher penetration capacity in ocular tissue, utilizing a larger 1.050 nm wavelength against the 840 nm of SD-OCT, which minimizes the dispersion produced by pigment epithelium and enables visualization of structures such as the choroids or the lamina cribosa, without diminishing the resolution of innermost layers. In addition, higher scan rates enable the reduction of image distortions caused by ocular movements.\(^5\)

At present, numerous research lines are seeking new developments in the OCT which are not yet included in daily clinical practice, including Polarization Sensitive-OCT (PS-OCT) that includes a technology based on changes of polarized light according to the light-tissue interaction. This technology can distinguish ocular structures based on properties altered by polarization. It could be useful for early detection of glaucoma, as there are studies suggesting that polarization changes in the nerve fiber layer precede thickness reduction, or alternatively to estimate in a noninvasive manner filtering surgery bleb fibrosis using anterior segment PS-OCT, among other examples of clinical application.\(^5\)

Another interesting development in OCT is the inclusion of Adaptive Optics-OCT (AO-OCT), that improves transversal resolution from 1 to 5 μm,\(^7\) correcting optical aberrations that occur when the beam of light traverses different optical media, thus enabling the acquisition of high-quality images presenting fine details such as retinal microvasculature, photoreceptors, lamina cribosa and microstructures within the nerve fiber layer and the ganglion cells layer denro, almost at the cellular level.\(^5\)

In addition, recent developments provide functional information as well. In this regard, two new techniques such as angiographic Doppler-OCT, angiograph (OCTA) are highly useful for studying blood flow.\(^5\) OCTA, which seems superior to Doppler-OCTA, utilizes an SS-OCT system and an algorithm to process movement contrast, improving flow signal detection (such as the Split-Spectrum Amplitude Decorrelation Angiography [SSADA]). In this way it obtains in-face images with functional information about microvasculature, generating noninvasive high resolution images qualitatively similar to conventional fluorescein angiography,\(^9\) showing vascular patterns consistent with histological studies.\(^10\) In addition, it provides in-face images of sections along any plane, separating the circulation of the disk, the retina and the choroids as well as enabling flow quantification (which could have prognostic implications).\(^11\) For all the above reasons, even though it is not able to detect a leak or stain (although it does identify fluid and tissue thickening), it is superior to conventional contrast angiography as it is faster, more sensitive and with greater penetration without considering the advantage that it avoids the possible adverse effects of contrasts.\(^12\)

A further emerging innovation in the field of OCT is Photoacoustics Ophthalmoscopy (PAOM), a new, noninvasive 3D microscopic imaging technology that is able to measure the optical absorption of the retina, which is key to measure the volume of blood and oxygenation of hemoglobin in retinal vessels as well as pigment distribution in the retinal pigment epithelium,\(^4\) data which is impossible to obtain with currently available methods which can only detect the reflection of retinal tissue or re-emitted light of endogenous chromophor or of an extrinsic contrast agent. Basically, this new technology detects the ultrasound waves generated by the absorption of a laser light pulse in the retina. When the photons are absorbed by highly absorbent tissue such as blood vessels, the optic energy absorbed is transformed into heat which produces a transient temperature rise which in turn causes a thermal expansion that generates ultrasound waves that are detected by a transducer to generate an Image.\(^13\)

Yet another innovation, the Vertical Cavity Surface Emitting Laser (VCSEL) technology, which uses a new light source, is able to achieve ultrafast scanning rates of 580,000 A scans per second\(^2\) as well as tissue penetration exceeding 38 mm, thus producing an image of the entire ocular globe with a single scan.\(^3\)

However, the inclusion into daily practice of many of these technologies could be slower than the development of prototypes. Even so, considering the vertiginous pace of technological breakthroughs nowadays, it is quite possible that by the time this article is published other interesting developments have taken place in OCT.

REFERENCES


