

Fourier Domain Optical Coherence Tomography integrated into a slit lamp; a novel technique combining anterior and posterior segment OCT

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Abstract

Purpose Fourier Domain Optical Coherence Tomography (FD-OCT) provides high resolution cross-sectional images of the retina and the anterior segment. It has become an important tool in ophthalmology in the examination, diagnosis, and treatment of important and common diseases. Present OCT imaging systems are stand-alone devices. The aim of this paper is to show the quality of images made with a prototype of a Fourier Domain (FD-) OCT imaging system (SLSCAN-1) integrated into a slit lamp.

Methods Different representative pathologies of the posterior and anterior segment were observed with the slit lamp and simultaneously scanned with a prototype of the slit lamp-integrated FD-OCT system. The clinical interpretation of posterior segment images made with the prototype were compared to those obtained with a stand-alone FD-system (3D-OCT-1000 Mark II, Topcon).

Results Images made with the slit lamp-integrated FD-OCT were of sufficient quality to allow for a correct interpretation of the observed pathological conditions. Conclusions based on the images of the posterior segment of the prototype were identical to the conclusions based on the images of a stand-alone FD-system (3D-OCT-1000 Mark II, Topcon). In addition to the images of the posterior segment, images could be made of the anterior segment. The OCT system did not interfere with the normal functionality of the slit lamp.

Conclusion The slit lamp-integrated FD-OCT system provided high quality images of both the anterior and the posterior segment. Scans made with the slit lamp-integrated FD-OCT system could be of use in clinical practice. *Eye* (2010) 24, 980–984; doi:10.1038/eye.2009.269; published online 13 November 2009

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Introduction

Since the introduction of the optical coherence tomography (OCT) in the early 1990s, it has become an important tool in the examination of the posterior pole of the eye.^{1–3} Many studies concerned with important diseases including diabetic retinopathy, age-related macular degeneration, vitreo-retinal pathology, and glaucoma have unequivocally shown the valuable contribution of OCT to the diagnosis and treatment of patients with these common diseases.^{4–10} Similarly, OCT of the anterior part of the eye has become increasingly important, enabling *in vivo* evaluation of the dimensions of the anterior chamber. Also in patients with corneal pathology, like corneal dystrophies and degenerations, keratoconus, inflammations, and in corneas following surgery, OCT of the anterior segment has proven to be useful in providing valuable and measurable information additive to observations with the slit lamp bio-microscope alone.^{11–14}

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OCT is a non-invasive, non-contact imaging technique and is a completely safe technique. The scans are made with use of low energy infra-red light. The only requirement of the eye to enable OCT scans of the posterior pole is clarity of ocular media (the cornea, lens, and vitreous) and a pupil of sufficient size to image the posterior pole of the eye. Fourier Domain-OCT (FD-OCT) systems allow for an exceptional resolution and a very fast acquisition time. They provide detailed images of the layered structure of the retina, the peri-papillary retinal nerve fibre layer, or the cornea, iris, and anterior chamber. The cross-sectional images obtained with the FD-OCT systems have considerably improved the quality of the diagnostic process.¹⁻³

Present imaging systems are dedicated stand-alone devices and this limits their availability for routine eye investigation. This limitation may be overcome by implementing OCT technology in a small unit compatible with existing slit lamps, a device widely available in the ophthalmic practice. This idea has led to the realisation of an add-on FD-OCT imaging device (prototype; SLSCAN-1), developed through a collaboration of the department of Biomedical Engineering and Photonics in the AMC and Topcon Europe Medical Research.

With the incorporation of an FD-OCT system into the slit lamp we expect an increased efficiency of the routine clinical examination of a patient. The ophthalmologist can make an OCT scan at exactly the position of an observed lesion in the eye. For the patient, seated behind just one device, there will be an increase in comfort.

The aim of this paper is to describe the first impressions of OCT scans made with a prototype of this slit lamp-integrated FD-OCT system, enabling images of both the posterior and the anterior segment.

Materials and methods

Spectral optical coherence tomography

The slit lamp with integrated OCT used in this study consists of a slit lamp (Topcon SL-D7) with a slit lamp-adapted OCT named SLSCAN-1 (prototype), and a camera (Topcon camera DC1, resolution = 3.24 Mp). The complete OCT setup is placed between the oculars and objective lenses of the slit lamp.

The SLSCAN-1 is a Fourier Domain Optical Coherence Tomograph (FD-OCT) with a broadband superluminescent diode (SLD) light source ($\Delta\lambda$ 30 nm, central wavelength 830 nm). The scan resolution is 8–9 μm in tissue, with a scan speed of 5000 a-scans per second. Each b-scan is composed of 512 a-scans, scan-length is up to 12 mm, and the scan depth is 2 mm in tissue. Positioning of the b-scan is accomplished with

the help of an aiming line visible through one of the oculars.

To make a b-scan, the OCT scanner is switched on by pressing the joystick button. Continuously b-scans are made and are immediately shown on a PC screen. The screen is positioned in a way to allow inspection of the b-scan with a short side-way glance while keeping the observed area of the retina in position. A complete b-scan is made by a click on the joystick. A colour fundus photograph of the observed area is made at the same time as the scan and shows the exact position of the scan with a green line (Topcon camera DC1, resolution = 3.24 Mp).

Scans of the posterior segment are made through a handheld lens, whereas simultaneously the (lesion in the) retina is observed with the slit lamp. Slight movements of the patient, hand-held lens and/or slit lamp during examination results in a fluctuation of the length of the sample arm. A fast Z-tracking system in the reference arm compensates for this dynamic character of the examination, and keeps the position of the retina in the live window at the required position. Any handheld lens can be used with the SLSCAN-1. The type and magnification of the chosen lens will change the lateral dimensions of the scanned line, but will not interfere with the overall quality of the image. In this study, we used a 78D lens (Volk). To scan the anterior segment the fast Z-tracking has to be switched off. The focus of the slit lamp and the OCT are fixed and coincide with one another.

Subjects

Fifty consecutive patients seen in the outpatient clinic of the ophthalmic department of the Academic Medical Center, Amsterdam the Netherlands, between December 2007 and December 2008, were asked to participate in an ongoing study to evaluate the slit lamp-integrated OCT. The study followed the tenets of the declaration of Helsinki. Patients were informed about the nature of the prototype used in the study and gave their written informed consent.

To explore the first impressions of slit lamp with integrated OCT and OCT scans made with this prototype, patients were included with representative corneal or retinal pathologies. Patients with posterior pole pathology with unclear ocular media (the cornea, lens, and vitreous) or a pupil of insufficient size were excluded.

Following standard ophthalmic examination all patients were re-examined with the slit lamp with integrated OCT. All patients with posterior segment pathology had received mydriatic eyedrops in the affected eye(s) (tropicamide and phenylephrine). For

comparison, scans of the posterior segment were made with the 3D-OCT-1000 Mark II (Topcon).

Results

Using the slit lamp (Topcon SL-D7) with integrated OCT was almost identical to normal routine slit lamp examination of the anterior and posterior segment. No limitations were observed in the optics of the slit lamp with integrated OCT that interfered with visualisation of the anterior or posterior segment. The slight increase in the anterior–posterior dimension of the slit lamp caused by the add-on FD-OCT, placed between the oculars and objective lenses, did not hamper operating the device.

Examples of scans made with the slit lamp with integrated OCT are shown in Figure 1. Scans of the posterior segment (Figure 1a–d) were compared with scans made with the 3D-OCT-1000 Mark II. Scans shown are made at almost identical locations to allow for a comparison between both systems.

Patient 1 (Figure 1a) experienced loss of visual acuity because of vitreomacular traction. Images showed vitreous adhesions and intraretinal cysts because of local traction at the fovea. Figure 1b, and 1c show images of patients with age-related macular degeneration (AMD),

following treatment with ranibizumab. Patient 2 (Figure 1b) did not have active leakage, in contrast to patient 3 (Figure 1c) where recurrent or persisting leakage was seen on the OCT images. Patient 4 (Figure 1d) was known with chronic central serous retinopathy, complicated by an occult neovascularisation. The OCT images showed a neurosensory detachment accompanied by an area of pigment epithelial detachment, and irregularities at the level of the pigment epithelium in the fovea.

The scans of the anterior segment showed a good image quality. Figure 1e shows the Artisan phakic intraocular lens of patient 5, and Figure 1f, the images of patient 6 with an iris cyst (Figure 1f).

Discussion

The first results of images prove that this prototype is able to produce OCT images of sufficient quality, to correctly identify common retinal pathologies. Scans can also be made of the anterior segment which is a unique combination of the slit lamp with integrated OCT.

The prototype incorporates both the higher resolution, and the faster scanning speed of a Fourier Domain OCT. The fast scanning speed of 5000 scans per second, with

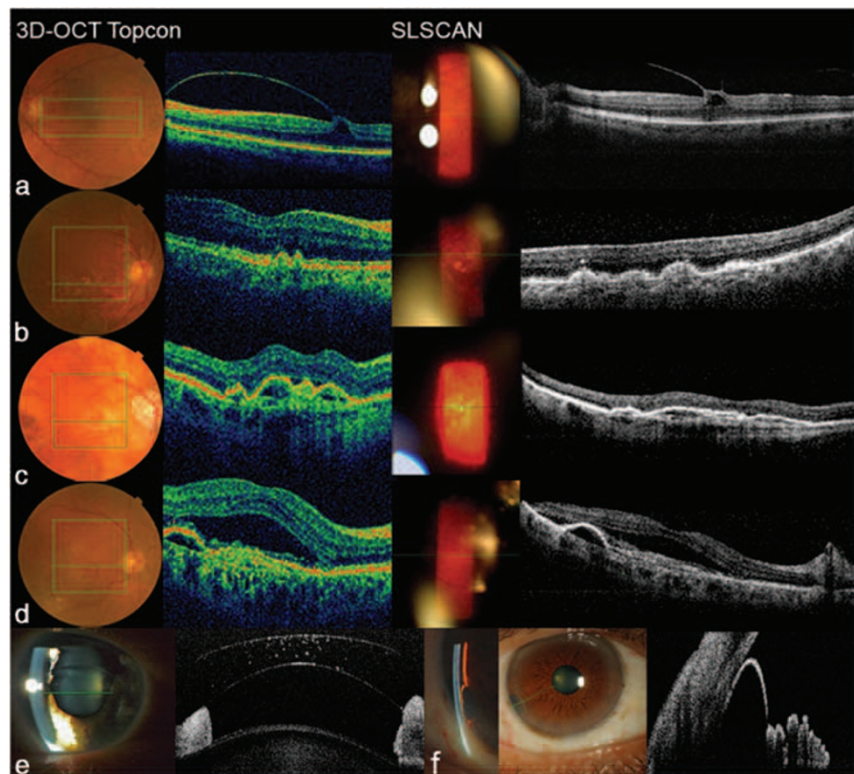


Figure 1 OCT scans of posterior segment, on the left obtained with 3D-OCT-1000 Mark II (Topcon) and on the right sight obtained with the SLSCAN-1. Scans shown are made at almost identical locations. (a) vitreomacular traction, (b–c) age-related macular degeneration, (d) central serous retinopathy. OCT scans of anterior segment, obtained with the SLSCAN-1. (e) Artisan phakic intraocular lens, (f) iris cyst. The green line in the pictures corresponds with scan position of SLSCAN-1.

512 a-scans per b-scan, allows a full b-scan to be made in approximately 0.1 s. In addition, the automatic fast z-alignment built into the device corrects for small movements in the sample arm, that is, the patient handheld lens and/or slit lamp. These features make the OCT system fast enough to make a full and high quality scan, even in an eye observed through a handheld lens introducing involuntary movements because of both the handheld lens and the observed retina. The high resolution of 8–9 μm in tissue is sufficient to show all relevant layers of the retina in detail, as shown in Figure 1a–d. To compare the quality of the scans made with both systems, the scans shown in Figure 1 were made at almost identical locations.

Patients with exudative AMD treated with anti-VEGF intraocular injections, will be regularly examined with OCT scans during follow-up for the presence or absence of signs of active leakage.^{7,15} This study included patients with exudative AMD. The conclusions in these patients based on the slit lamp-integrated OCT were identical to the conclusions based on a stand-alone FD-system (the 3D-OCT-1000, Mark II, Topcon). In some patients a single scan through a suspicious area with leakage proved the presence of signs of active leakage, and a decision to retreat could be considered. In cases with less obvious leakage, a number of scans (5 to 6), 1 mm apart, were made with the SLSCAN-1 covering the whole macular area to screen for local signs of leakage. In addition, with some practical experience, screening for signs of leakage can be done by moving the scan over the macula, while observing the live image of the OCT scan, and the corresponding live colour image of the retina, made by the camera, on the screen.

The scans of the anterior segment with the prototype are not completely comparable with the scans made with commercially available systems. On the one hand, there is a difference in tissue penetration caused by the central wavelength of the SLD light sources. The prototype has a central wavelength of 830 nm *vs* 1310 nm in the commercially available systems. A longer wavelength allows for a slightly better penetration of the highly scattering structures in the anterior segment.¹⁶ On the other hand, the prototype is an FD-OCT in contrast to the commercially available systems, which are time domain (TD).^{12,17} The FD-OCT has a faster scanning speed and an increased resolution, but a reduced scan depth (2 mm in the SLSCAN-1 *vs* >5 mm in TD-OCT). The images of the anterior segment made with the prototype seemed to be of acceptable quality (Figure 1e and f).

The OCT is becoming increasingly important in ophthalmology for both diagnosis and follow-up of patients. The slit lamp with integrated OCT enables to make OCT images during the normal standard examination with the slit lamp, without interfering with

the functionality of the slit lamp. This increases the efficiency of the routine clinical examination of a patient, will increase the comfort of the patient seated behind just one device, and will save time.

In many clinics OCT examinations are performed by technicians, not directly familiar with the pathology at hand. This could lead to inadequate scans missing the relevant pathology. With the slit lamp with integrated OCT the ophthalmologist himself will make the OCT scans, directing the scan to the area of interest, observed with slit lamp biomicroscopy, avoiding this problem.

In conclusion, this study shows that the prototype of an FD-OCT system integrated into a slit lamp can make excellent images of both the anterior and posterior segment. The add-on FD-OCT prototype did not interfere with the standard examinations performed with the slit lamp. Efficiency of patient examinations is greatly improved, because OCT images can be made directly during routine examination with the slit lamp.

Summary

What was known before

- Optical Coherence Tomography (OCT) is a rapidly evolving imaging technique and seems to be already indispensable in ophthalmology. OCT has become an important investigation tool for diagnosis and follow-up of retinal diseases and pathology of the anterior segment. Present OCT systems are dedicated stand-alone devices and this limits their availability for routine eye investigation.

What this study adds

- This limitation may be overcome by implementing OCT technology in a small unit compatible with existing slit lamps, a device widely available in the ophthalmic practice. The integration of a Fourier Domain OCT in the slit lamp enables several possibilities in imaging, including images of both the posterior and the anterior segment.
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Conflict of interest

The authors declare no conflict of interest.

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