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Use of a new intra-ocular spectral domain optical coherence tomography in vitreoretinal surgery

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ABSTRACT.

Purpose: **To describe the use of a novel intra-ocular side-scanning probe enabling the acquisition of spectral-domain optical coherence tomography (SD-OCT) images during surgery in a series of patients with complex forms of retinal detachment.**

Methods: **A 23-gauge, side-scanning SD-OCT probe (C7 System; LightLab Imaging, Inc/St Jude Medical, St. Paul, MN, USA) in a 20-gauge catheter, was used to acquire the intra-operative OCT images in seven patients with vitreoretinal diseases. Twenty-five gauge pars plana vitrectomy (PPV) was performed in every patient in a standard fashion. After enlarging the temporal sclerotomy to a 20-gauge port, all the patients were scanned with intra-ocular side-scanning SD-OCT, during different steps of the surgery based on surgeon needs. Scans were recorded real time and directly evaluated on a screen during surgery. Optical coherence tomography (OCT) scans were judged beneficial when they would recognize structures otherwise not seen on biomicroscopy.**

Results: **The intra-ocular SD-OCT has been helpful in acquiring extra information during vitreoretinal surgery such as the detection of the presence of otherwise invisible membranes (epiretinal membrane, subretinal membrane), the location of small tears and the identification of the retinal plane under suboptimal conditions for visualization.**

Conclusion: **The use of an intra-ocular SD-OCT can expand upon visual cues during surgery, helping in the decision-making process and allowing additional deliberate surgical manoeuvres aimed at improving surgical outcomes.**

Key words: image-guided surgery – intraoperative optical coherence tomography – optical coherence tomography – retinal detachment – retinal surgery – vitrectomy vitreoretinal disease

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Introduction

In the last decade, Optical Coherence Tomography (OCT) has changed how we diagnose, treat and follow most vitreoretinal disorders. Pre- and post-operative OCT scans allow physicians to better understand the aetiology, plan surgery and evaluate the results of interventions carried out in vitreoretinal diseases (Sakata et al. 2009; Adhi & Duker 2013). The introduction of spectral-domain OCT (SD-OCT) substantially improved image resolution close to the vitreoretinal interface (Kiernan et al. 2010).

In 2009, a hand-held SD-OCT was first used to image the retina in full-term infants with shaken baby syndrome (Scott et al. 2009), in a young child with albinism (Chong et al. 2009) and in premature infants with advanced retinopathy of prematurity (Chavala et al. 2009). In the same year, Dayani and colleagues (2009) published the first report of the intra-operative use of a hand-held SD-OCT in macular surgery. Beside the hand-held SD-OCT, initial attempts were carried also with microscope-mounted OCT systems (Binder et al. 2011; Ehlers et al. 2011, 2013a,b,c; Ray et al. 2011; Huang et al. 2012; Huang & Hirose 2012; Hahn et al. 2013), to study the feasibility of an integrated

OCT allowing the visualization of real-time intra-operative manoeuvres.

Surgical microscopes with integrated OCT systems have recently been commercialized. Heads-up displays allow the surgeon to rapidly visualize an area of interest, to perform surgical manoeuvres while analysing the instrument–tissue interactions and to assess the results of a surgical procedure step by step (Steven et al. 2013; Ehlers et al. 2014a,b; Tao et al. 2014).

Although a growing number of studies are highlighting the clinical potential of this emerging technology (Chong et al. 2009; Scott et al. 2009; Muni et al. 2010; Ehlers et al. 2013a, b,c, 2014a,b; Juthani et al. 2014), it is not without its shortcomings: it is more expensive than a standard surgical microscope and has a limited area of visualization within the central 30-degrees of the posterior retina.

In addition to microscope-mounted OCTs, others have analysed the feasibility of an intra-operative OCT system that provides real-time feedback but through intra-ocular fibre probes or integrated instruments (Han et al. 2008; Joos & Shen 2013; Song et al. 2013). Several studies have reported on the use of different probes, during surgical procedure such as tumour resection, neurosurgery and microvascular anastomosis (Chen et al. 1997; Boppart et al. 2004; Zysk et al. 2007; Jafri et al. 2009; Zhang & Kang 2011; Kang et al. 2012). The use of a hand-held OCT probe could offer several advantages (Huang et al. 2012). First, vitreoretinal surgeons are familiar with hand-held instruments. Second, a hand-held probe is small and would permit evaluation of structures, such as the peripheral retina and the ciliary body, otherwise inaccessible to microscopes with an integrated OCT. Third, a hand-held probe-scanning ability is not influenced by external opacities.

Hand-held scanning probes are divided into two categories based on their region of inspection: side scanning and forward scanning.

In this study, we report the use during selected vitreoretinal procedures of a novel intra-ocular side-scanning probe originally, approved for endovascular OCT imaging (Bezerra et al. 2009; Prati et al. 2010; Ferrante et al. 2013).

Materials and Methods

A 23-gauge, side-scanning SD-OCT probe in a 20-gauge catheter (C7 Dragonfly™ Imaging Catheter-St Jude Medical LightLab, St. Paul, MN, USA), was used to acquire the intra-operative OCT images during selected vitreoretinal procedures. The SD-OCT system (C7 System; LightLab Imaging, Inc/St Jude Medical, St. Paul, MN, USA) consists of a computer console containing the data acquisition board, an imaging engine and a patient interface unit that connects to the intravascular OCT catheter. The device originally approved for endovascular OCT imaging has been modified for intra-ocular use. In particular, the free end of the probe has been shortened and protected at the extremity with a non-reflective transparent plastic cap (Fig. 1).

The device uses a super-luminescent diode (SLD) light source centred on 1300 nm, its axial resolution is 15 microns, and it provides a 6 mm scan length incorporating 450 scans per frame, 100 frames/second and 2 mm tissue penetration at a 4 mm working distance. The optical fibre is encapsulated within a rotating torque wire built in a rapid exchange 2.6-F (20,4G) catheter. The disposable probe scans in a so-called lighthouse fashion, meaning the scanning beam continuously rotates over 360°.

OCT analysis was performed online using the C7 system and offline using a dedicated OCT Review Workstation (St Jude Medical LightLab, St. Paul, MN, USA). Proprietary patented software generates, after confirming proper calibration settings of the Z-offset, a mask of the OCT lumen image defining a plurality of scan lines and identifying the lumen/tissue interface along each scan line. The image obtained displays a 360° circumferential scan around the tip of the probe within the 4 mm working distance, and the images are read in a clock quadrant-like fashion, so the top of image on the screen represents the top of the scanning probe.

The study protocol was approved by Institutional Review Board (IRB) of the AMC, University of Amsterdam, and all patients signed an IRB-approved informed consent. Patients consented to prospective data collection, and the study was conducted according to the Declaration of Helsinki.

Patients with a retinal detachment of various levels of complexity were selected. Three patients had rhegmatogenous retinal detachment (RRD) with anterior and posterior proliferative vitreoretinopathy (PVR), one patient had a primary RRD, one patients had tractional retinal detachment (TRD) due to proliferative diabetic retinopathy (PDR), one had

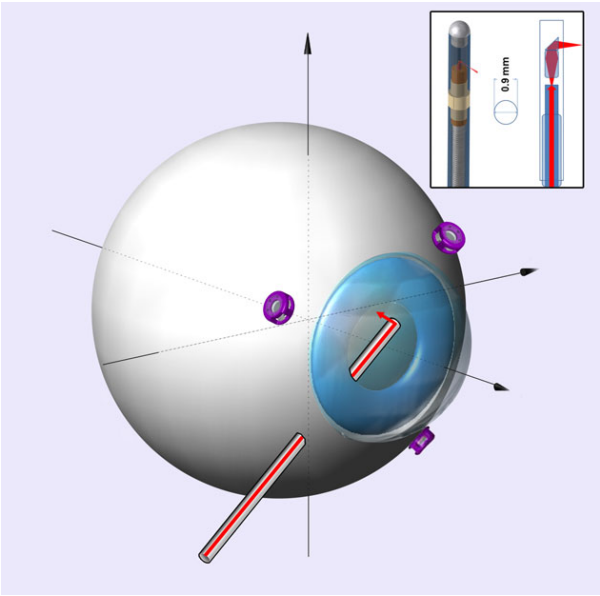

Fig. 1. This figure represents the surgical setting with three trocars 25+ Gauge (pink) inserted via pars plana and the OCT probe inserted via 20-gauge enlarged pars plana sclerotomy.

combined tractional–RRD due to sickle cell retinopathy, and one patient had dense vitreous bleeding and RRD due to blunt trauma. The patients were operated between March 2011 and December 2012 by a single surgeon (MM). Mean follow-up was 22 months (range 15–36 months).

Twenty-five gauge pars plana vitrectomy was performed in every patient in a standard fashion before the insertion of the OCT probe. A chandelier light was used, in every surgery. A core vitrectomy was followed by shaving the peripheral vitreous body with the aid of double triamcinolone acetonide injection for better vitreous visualization, except in the patient with PDR and combined TRD-RRD, where bimanual dissection was necessary to free the posterior hyaloid before peripheral vitreous shaving was possible. After enlarging the temporal sclerotomy to a 20 gauge port, all the patients were scanned with the intra-ocular side-scanning SD-OCT and several real-time movies were recorded along the different steps of the surgery based on surgeon needs.

Scans were recorded in real time and directly evaluated on a screen during surgery. When possible in selected circumstances, an attempt was made to assess OCT-guided real-time surgery. No superimposed image was available in the microscope during the surgery.

Steps facilitated by the use of the OCT were in random order: difficult visualization of retina due to blood, the presence of membranes on or under the retina, surgical plane identification, the absence of visible peripheral breaks and the presence of residual vitreous. An internal search was performed at the end of the surgery to identify possible iatrogenic retinal breaks. Silicone oil tamponade was used in five patients, one patient received air and one received SF6 20% gas. All patients were pseudophakic before surgery with the exception of the trauma patient who underwent a lens extraction in the course of his surgery. Patient pre-, post-best-corrected visual acuity, intra-ocular pressure, retinal status and intra- and postoperative complications related to the OCT use were recorded. Extra time necessary for the scan was also recorded.

Results

Patient characteristics are reported in Table 1.

In all the patients, it was possible to acquire real-time intra-ocular scans of the central and peripheral retina, including vitreous base and ciliary body. It was also possible to perform a number of surgical manipulations under direct OCT guidance. The brightness of the illumination source did not interfere with the quality of the OCT images. The intra-ocular SD-OCT was able to provide a clear visualization of ocular structures in the following situations:

(1) The detection of thin poorly visible epiretinal membrane (ERM) (patients 1–3; Figs 2 and 3).

(2) The identification of subretinal membranes, otherwise not visible due to the presence of substantial retinal oedema and thickened retina (patients 1 and 2; Fig. 4).

(3) Confirmation about the completeness of membrane removal in patients with epiretinal and subretinal membrane proliferation over 360° of the peripheral retina (patients 1–3).

(4) Detection of residual vitreous exerting traction on peripheral breaks, not otherwise visible, despite the intra-operative stain of the vitreous body with triamcinolone acetonide (patient 4; Fig. 5).

(5) The identification of small retinal breaks especially in patients with very light-coloured fundi impossible to detect with standard internal search (patient 4; Fig. 6).

(6) The detection of a cyclitic membrane (patient 3; Fig. 7).

(7) The identification and localization of a cleavage plane in patients with TRD and combined TRD-RRD (patients 5–6; Figs 8 and 9).

(8) Timely recognition of the retina in case of dense vitreous haemorrhage, with still attached vitreous in a young patient (Patient 7; Fig. 10).

(9) The detection of residual subretinal fluid, perfluorocarbon or silicone oil in the macula area and peripherally in an air-filled eye or an eye with hazy optical media.

Discussion

In recent years, OCT has become an irreplaceable tool for the diagnosis, management and prognosis of many vitreoretinal diseases (Sakata et al. 2009; Kiernan et al. 2010; Adhi & Duker 2013). However, the idea of having OCT as an adjuvant during surgery is relatively new (Ray et al. 2011). The first report describing the use of a hand-held OCT device has been published in 2009 (Ehlers et al. 2011, 2013a,b,c; Hahn et al. 2013). Binder et al. (2011) described the appli-

Table 1. Patient demographics and clinical characteristics.

Patient	Age (years)	Sex	Diagnosis	BCVA preoperative (decimals)	BCVA postoperative (decimals)	OCT Time (min)	OCT findings	Adverse events
1	60	F	RRD-PVR	1/60	0.32	10	ERP-SRM	NONE
2	65	M	RRD-PVR	HM	0.5	11	ERP-SRM	NONE
3	58	M	RRD-PVR	1/300	0.2	13	ERP	NONE
4	52	M	RRD	0.1	0.6	5	CV-MB	NONE
5	42	M	TRD	0.1	0.4	8	CP-FVA	NONE
6	38	F	TRD-RRD	HM	0.3	10	CP-FVA	NONE
7	28	M	RRD-VH TRAUMA	LP	0.2	15	RLCVB	NONE

BCVA preoperative, best-corrected visual acuity preoperative; BCVA postoperative, best-corrected visual acuity postoperative (after 12 months); HM, hand motion; LP, light perception; OCT, optical coherence tomography; RRD-PVR, rhegmatogenous retinal detachment with anterior or posterior proliferatve vitreoretinopathy; RRD, rhegmatogenous retinal detachment; TRD, tractional retinal detachment; VH, vitreous hemorrhage; ERP, epiretinal proliferation; SRM, subretinal membrane; CV, residual vitreous with traction; MB, micro-retinal breaks; CP, cleavage plane; FVP, fibrovascular proliferations; RLCVB, retina localization through vitreous hemorrhage.

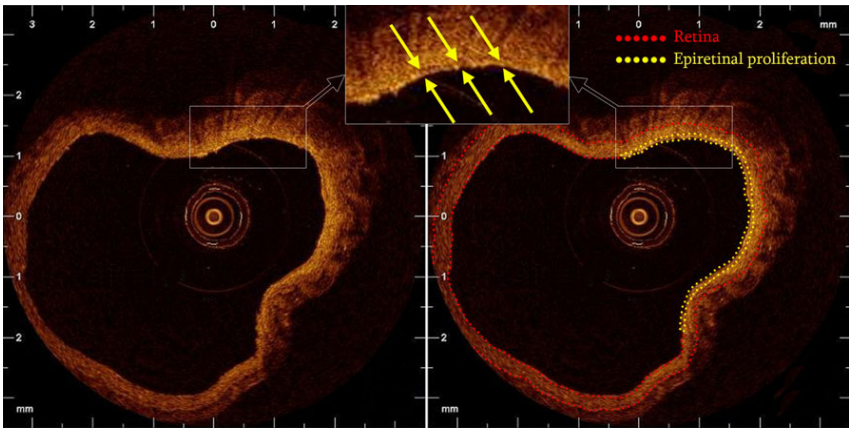

Fig. 2. Epiretinal proliferation [proliferative vitreoretinopathy (PVR)]. The picture shows an epiretinal proliferation (PVR, dashed yellow line; yellow arrows in the magnification box) grown on the retina (dashed red line). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

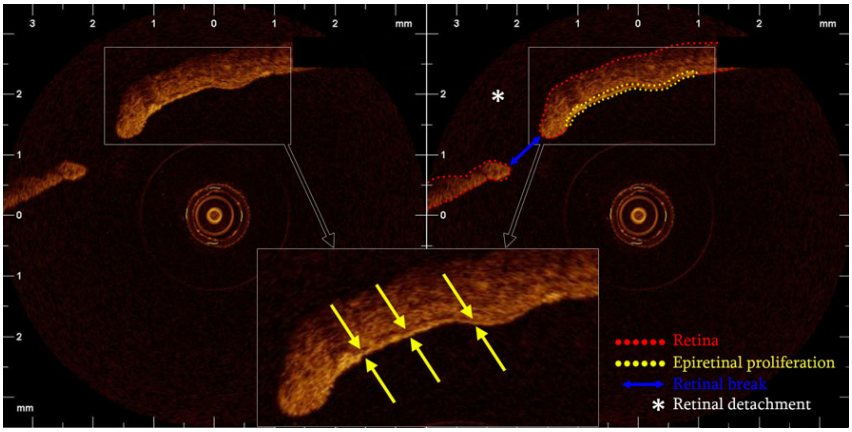

Fig. 3. Epiretinal proliferation [proliferative vitreoretinopathy (PVR)]. The picture shows an epiretinal proliferation (PVR, dashed yellow line; yellow arrows in the magnification box) grown on the retina (dashed red line) associated with retinal break (blue arrow) and retinal detachment (asterisk). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

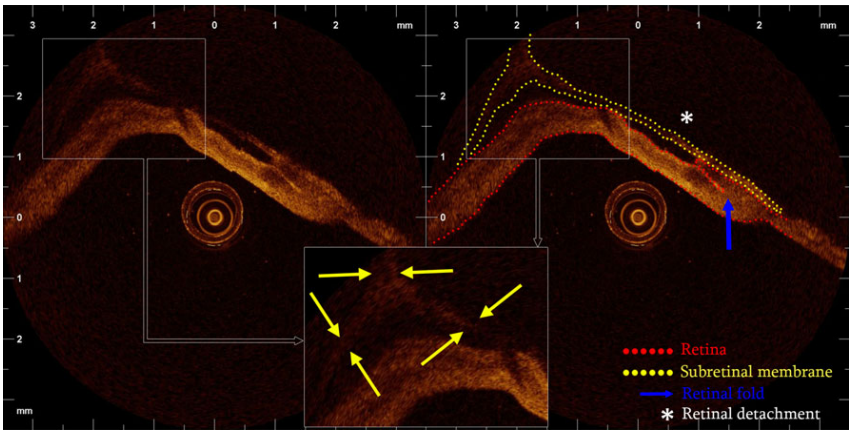

Fig. 4. SRM: Subretinal membrane [proliferative vitreoretinopathy (PVR)]. The picture shows a subretinal membrane (PVR, dashed yellow line; yellow arrows in the magnification box) grown below the retina (dashed red line) associated with a retinal fold (blue arrow) and retinal detachment (asterisk). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

cation of a standard OCT system, mounted into the operating microscope. Due to its inherent technical limitations, such as limited mobility, the microscope-mounted OCT can only be used to obtain scans of the central macular area, to assess the completeness of the macula peeling of ERM and internal limiting membrane, to identify local iatrogenic damage postmembrane peeling and to evaluate the retinal alteration that occurs during macular hole surgery (Ehlers et al. 2014a,b). This device can also be used to assess the presence of subretinal fluid in the macula area in cases of retinal detachment. The use of a static microscope-mounted standard OCT device offers very limited possibilities in a dynamic surgical environment. The device described by Binder et al. (2011) and Ray et al. (2011) does not allow more peripheral areas of the eye to be examined, while this is possible using an intra-ocular probe. The intra-ocular probe described in the present study offers the advantage of dynamic and real-time imaging during surgery without the need of a tracking and an image stabilization system. Furthermore, the time spent to acquire the scans was relatively short. The use of a 1300-nm SLD as light source offers the advantage of visualization of the highly reflective retinal structures even in the presence of dense vitreous bleeding. In these challenging cases, it becomes easier to remove vitreous without the risk to cut healthy underlying obscured retina especially in young patients with no separation between vitreous and a mobile detached retina. The intra-ocular OCT probe was shown to be useful at various times during the surgical procedure. The identification of an epiretinal proliferation makes it possible to perform ERM peeling in these patients without the use of any staining that potentially can be toxic, especially in detached retina. Furthermore, identification of early PVR or the presence of posterior hyaloid remnants can be very difficult even with the use of staining adjuvants. The possibility to identify and remove proliferative tissue from the subretinal space, with the help of real-time SD-OCT probe images, avoids the need for larger retinotomies. This reduces unnecessary iatrogenic damage and leads to less exposed retinal pigment epithelium and to diminished induction of inflamma-

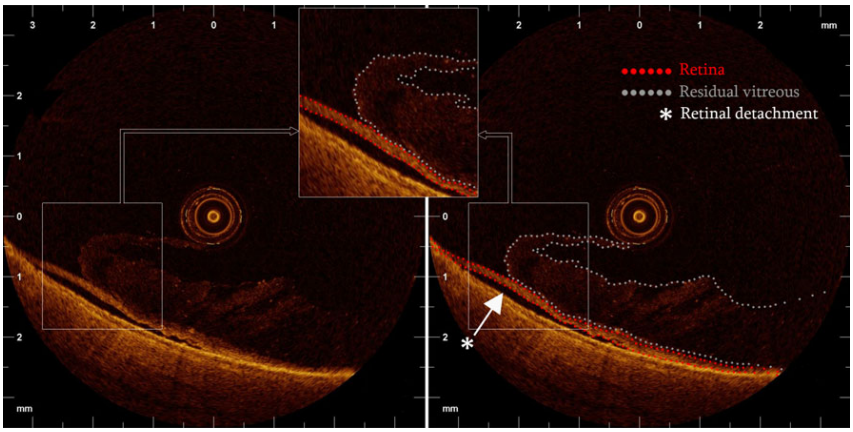

Fig. 5. Residual vitreous. The picture shows residual vitreous (dashed grey line) firmly attached to the retinal surface (dashed red line) associated with a retinal detachment (asterisk). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

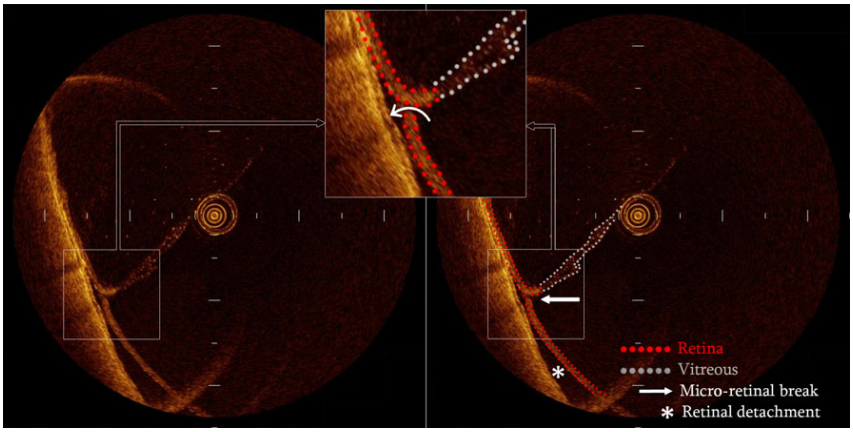

Fig. 6. Micro-retinal break with vitreous traction. The picture shows residual vitreous (dashed grey line) attached to the retinal surface (dashed red line) exerting traction resulting in a micro-retinal break (white arrows) associated with a retinal detachment (asterisk). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

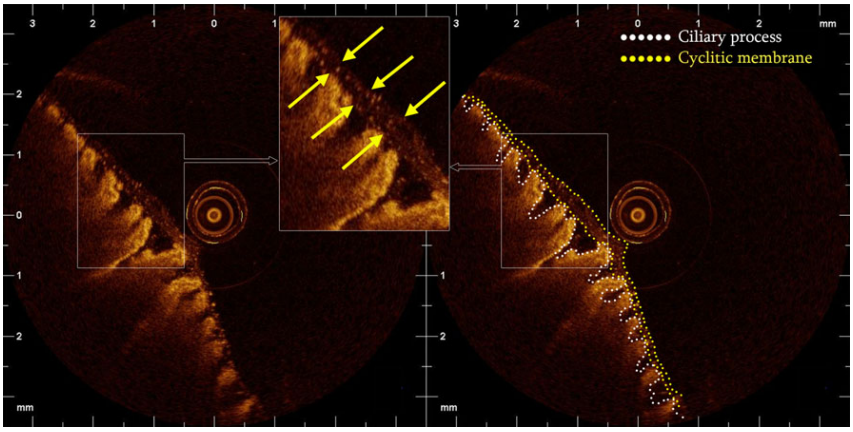

Fig. 7. Cyclitic membrane. The picture shows cyclitic membrane (dashed yellow line; yellow arrows in the magnification box) grown on the ciliary process (dashed white line). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

tion due to the use of laser, all positive effects that may lead to a better outcome for the patient. The use of an intra-ocular OCT probe for scanning is also advantageous in cases of opacified media or in air-filled eyes where the visibility is poor. In those cases, visualization of the retina becomes challenging and it becomes impossible to identify, for example, residual perfluorocarbon (PFCO) liquid or the presence of subretinal PFCO/oil/fluid, which if not properly removed can lead to retinal folds and poor visual prognosis. The possibility to perform an OCT real time during pars plana vitrectomy gives more assurance of a complete removal of vitreous traction. As a routine, vitreous shaving was performed in all patients with the aid of triamcinolone, but upon completion, a significant amount of vitreous was still present when checked with the intra-ocular OCT probe. Small retinal breaks can sometimes be missed especially in patients with very light-pigmented fundi (Tan et al. 2009). In these patients, a scan of the periphery with the intra-ocular OCT probe can highlight breaks otherwise invisible and possibly reduce the rate of redetachment. In our patients, the OCT intra-operative scanning allowed us to recognize the presence of several primary breaks particularly in areas of retinal thinning, where their identification is otherwise difficult. In cases of fibrovascular proliferation, such as PDR, it can sometimes be challenging to find the correct cleavage plane. The intra-operative OCT helps to identify the correct plane, thus facilitating and guiding the dissection. The opportunity to perform OCT-guided intra-operative manoeuvres with this probe is possible, in contrast with the OCT systems integrated with the surgical microscope, by positioning the hand-held probe in order to avoid the shadowing with the other instruments used during the surgery. Neither the OCT device nor the probe was developed for intra-ocular use. The wavelength of 1300 nm and the total energy generated by the rotating light beam are well below the levels associated with any damage to the retina. The design of the probe could be improved for vitreoretinal surgery. For example, the manoeuvrability of the probe needs to be

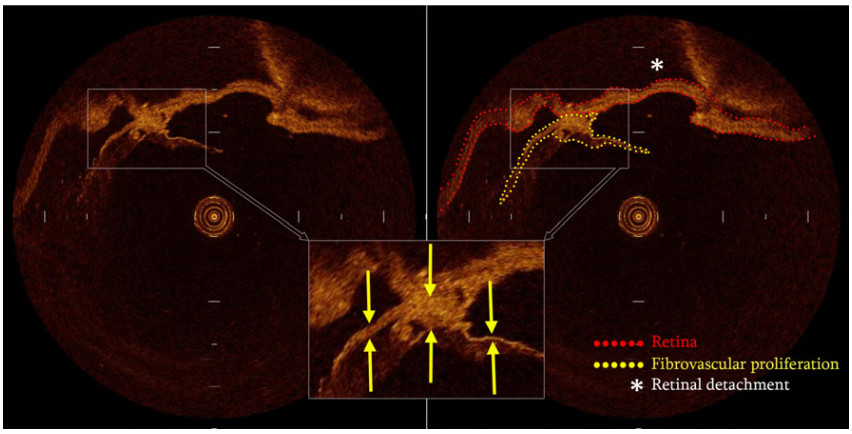

Fig. 8. Fibrovascular proliferation [tractional retinal detachment (TRD)]. The picture shows a fibrovascular proliferation (TRD, dashed yellow line; yellow arrows in the magnification box) grown on the retina (dashed red line) associated with a retinal detachment (asterisk). Optical coherence tomography (OCT) probe is visible in the centre of the picture.

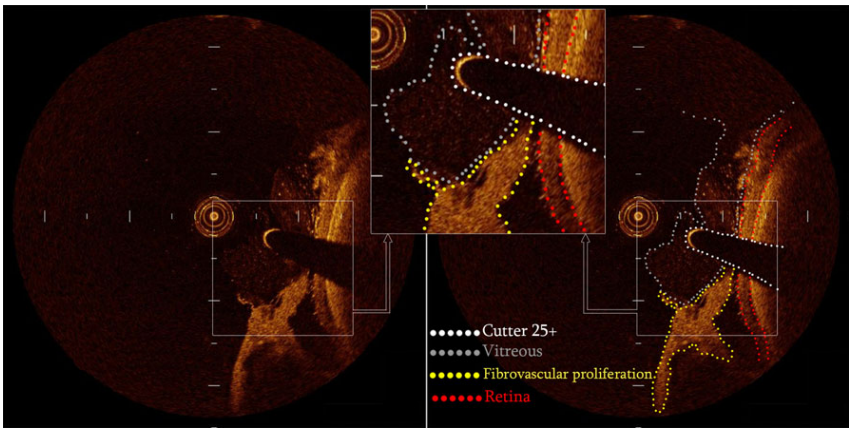

Fig. 9. Fibrovascular proliferation [tractional retinal detachment (TRD)]. The picture shows a fibrovascular proliferation (TRD, dashed yellow line) with residual vitreous (dashed grey line) attached to the retina (dashed red line). The 25+ gauge vitreous cutter (dashed white line) is in sight. Optical coherence tomography (OCT) probe is visible in the centre of the picture. The retina looks convex due to the scleral depression made by surgeon.

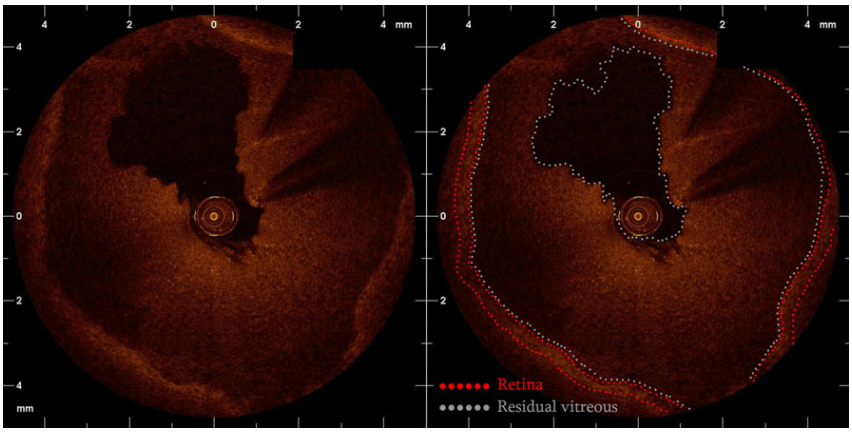

Fig. 10. Dense vitreous haemorrhage in trauma. The picture shows dense vitreous (dashed grey line) due to haemorrhage trauma attached to the retinal surface. Optical coherence tomography (OCT) probe is visible in the centre of the picture surrounded by an optically empty area (black area) created by vitrectomy before the OCT probe insertion.

improved as well as its flexibility as it is somewhat difficult to direct the probe in the desired direction. The image now is presented on an external screen that complicates the use of the device. The surgeon needs to be more fully in control of the device, and for that reason, the image should be projected into the operator's microscope field. The representation of the image should be made more intuitive especially for the guidance side of its use and needs an initial training of the surgeon. In conclusion, the intra-ocular SD-OCT endoprobe provides valuable and useful surgical information, helping physicians in the decision-making process especially in more complex retinal pathology. It allows surgeons to perform surgical manoeuvres with greater ease and confidence with potential improvement of precision and safety for better surgical outcomes.

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