OPTICAL COHERENCE TOMOGRAPHY (OCT)

AUTHORS

Mark Dunbar: Bascom Palmer Eye Institute, University of Miami

Sarah McGowan: Mzuzu University

PEER REVIEWER

Jean-Sébastien Dufour: University of Montreal

INTRODUCTION

Optical coherence tomography (OCT) imaging can be used in many biological tissues, but has gained significant popularity amongst eye care providers for imaging structures of the eye, including the retina, optic nerve head, and the retinal nerve fiber layer (RNFL), for the purposes of clinical diagnosis and monitoring of human retinal and optic nerve disease. OCT technology, when applied for ophthalmic clinical use, offers a non-contact, non-invasive, qualitative, quantitative and repeatable imaging option to make diagnoses, as well as observe and monitor in vivo details of biological tissues in the eye that are otherwise invisible to the clinician during standard ophthalmoscopy and slit lamp examination. While OCT is not intended to make a diagnosis in lieu of a clinical exam, OCT technology has provided new insights into the pathology of ocular diseases and has rapidly become a component of the clinical management of certain disease processes.

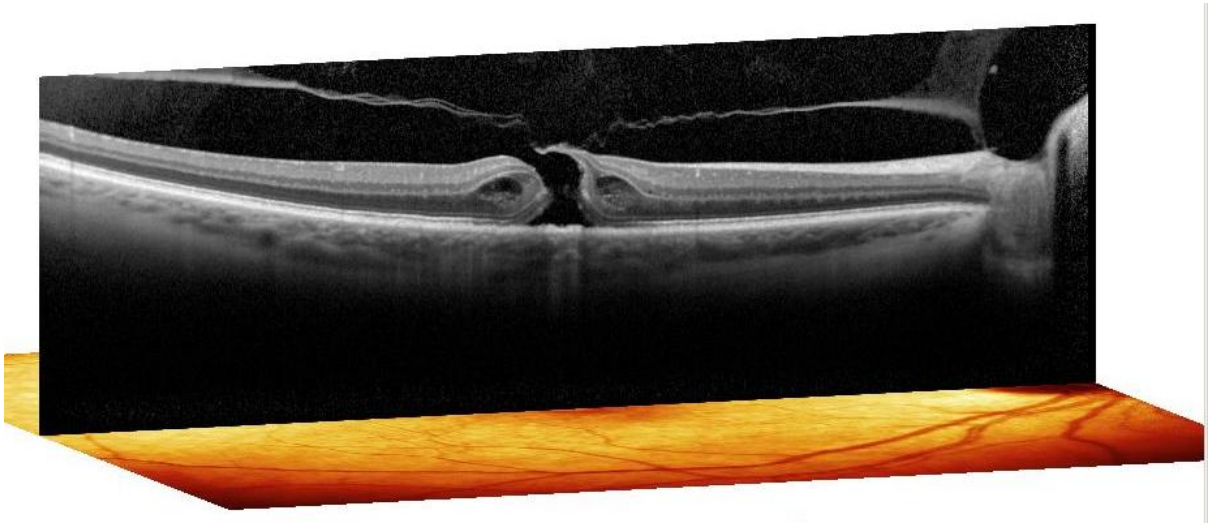

Figure13- 1. *OCT Spectralis (Heidelberg Engineering). Retinal scan, foveal cross-section superimposed over a 2-D false colour retinal image. Spectralis OCT has the software to produce video-style images through consecutive areas of retina as well as 3-D images of retinal anatomy and topography. With OCT technology, the retinal layers can be differentiated and retinal thickness can be measured.*

PRINCIPLES OF OCT

The image recovered with the OCT is similar to ultrasound B-scan imaging. Cross-sectional images of the retina are produced using the optical backscattering of light in a fashion analogous to B- scan ultrasonography, except that light is used instead of sound waves to formulate the image. The image is created by a superluminescent diode light laser (810 nm) that is scattered, reflected and absorbed by the tissue. The resultant cross-sectional image is made up of thousands of A-scans (one-dimensional images). The resolution of OCT systems is set by the coherence properties of the light source. A spatially uniform, low-coherent (white light) beam of light is generated from a superluminescent diode or laser diode to obtain high resolution images. Low coherence light allows for a propagation speed nearly one million times faster than sound.

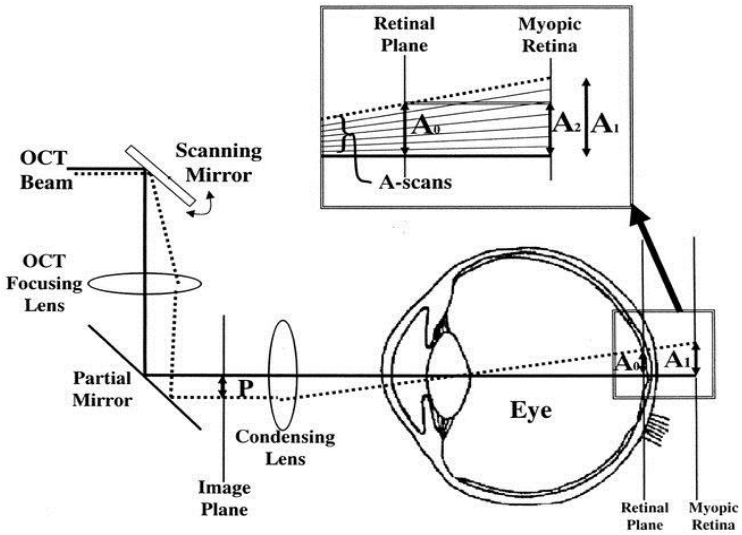

Figure 13-2. *Basic optical principles of a modern OCT setup. Light is transmitted into the eye via fiber optic delivery system. Prior to ocular transmission, the near infrared beam of light is split at a coupler into 2 separate paths. One beam is directed into a reference mirror (reference beam). The other is directed into the eye (probe beam). Light from both beams are then reflected back from the eye and recombined within a fiber-optic interferometer. The temporal (time or echo delay) information contained in the resulting interference pattern is the basis by which OCT images are constructed.*

The image is displayed by using a logarithmic "false colour" scale, in which the log of the backscattered light intensity corresponds to a colour scale. The intensity of the light is dependent upon the optical properties (index of refraction) of the tissue layer being imaged. Highly reflective (eg. pigment, blood) layers are shown in red. Although the OCT image can be displayed in colour, many clinicians prefer to use the black and white image because it often offers a greater perception of the details.

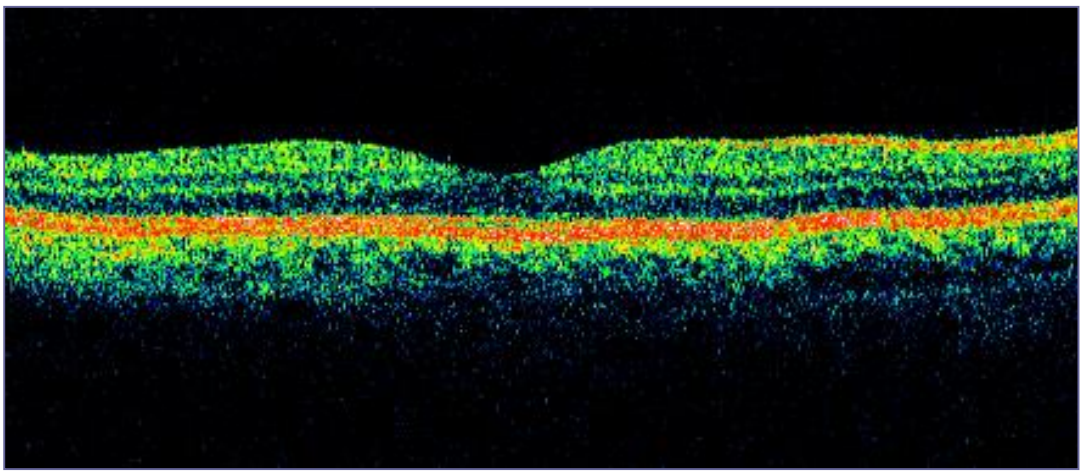

Figure 13-3*. Stratus OCT. Normal foveal pit and macula.*

CHOICE OF CLINICAL INSTRUMENT

OCT OR ULTRASOUND?

There are different factors involved in determining whether OCT or ultrasonography is of better clinical usage.

OCT

- Detailed imaging, 10 to20X higher resolution compared to ultrasound
- Image tissues that are optically accessible – if you can't see through it, neither can the OCT
    - Dense cataract, vitreous hemmorrhage, corneal opacity
- No corneal contact

Ultrasound

- Imaging through opaque media
- Direct corneal contact
- Tissue differentiation and dynamic properties, i.e. vascularity

BENEFITS TO OCT / ADVANTAGES OVER OPHTHALMOSCOPY

- Objective
- Quantitative
- Non-contact to patient (ophthalmoscopy is also a non contact technique)
- Operable by technician with minimal training
- Larger field of view
- Detailed imaging of retinal layers and abnormalities missed in ophthalmoscopy
- Repeatable and reproducible results
- Software for monitoring progression
- Optic disc, RNFL and retina can be imaged through an undilated pupil

Quantification combined with reproducibility and reliability of results allows for better/earlier determination of progression, earlier intervention, and determination of resolution of a disease. This can also be beneficial in a clinical context of monitoring efficacy of treatment with an unaltered visual acuity.

MEASUREMENT AND IMAGING ERRORS IN OCT

- Poor fixation
- Movement (less of a problem with SD-OCT)
- Blinking
- Improper placement in the machine (e.g. head not against forehead rest)
- Cloudy media
- Vitreous opacities
- Staphyloma,
- ONH and RNFL edge of retinal pigment epithelium (RPE) may be altered - peripapillary atrophy, degenerative myopia, high refractive error
- Tilted optic nerve
- Optic disc drusen
- Peripapillary sectoral pigmentary changes

POSTERIOR SEGMENT OCT

The original design of OCT was based on time and distance measurements and is identified as time-domain technology or a time-domain OCT (TD-OCT). The machine was setup to determine the echo time delay and intensity of reflected light (Hee et al 1995). Developed in the early 1990's (Huang 1991), OCT technology has developed into powerful imaging technology that can produce in vivo, real time imaging of tissues with a resolution between 3 and 15 µm.

Current devices

- Time domain OCT – 5-10 µm resolution
  - OCT Stratus (Carl Zeiss, Meditec, Dublin, CA)
  - Mechanical moving reference mirror performs each A-scan
- Fourier/Spectral/High speed/High Definition OCT– 3-5 µm resolution (Wojtkowski et al 2005) (diameter of a red blood cell is 7 µm)
  - Cirrus High Definiton OCT (HD-OCT) (Carl Zeiss, Meditech, Dublin, CA)
  - RTVue 100 (Optovue, Fremont, CA)
  - Spectralis HRA+OCT (Heidelberg Engineering, Vista, CA)
  - Optical Coherence Tomography RS-3000 Advance (Nidek, Japan)
  - OCT/SLO Combination Imaging System (Optos, Inc Dunfermline, UK)
  - 3D OCT-2000 Spectral Domain OCT (Topcon Medical Systems, Tokyo, Japan)

COMPARISON OF TD AND FD OCT

With TD-OCT, information accumulates along the longitudinal direction of the retina, one pixel at a time, and 1024 pixels per A-scan. In 1.28 seconds, 512 A-scans (1D) are collected and a B-scan (2D) image is created.

With FD-OCT, the reference mirror is stationary and the image is captured using a fast transfer rate CCD camera. A spectrometer analyses the signal by wavelength and the resulting spectral interferogram is converted by Fourier transform to a typical A-scan image. With new commercially available SD OCT, the speed of acquisition can go up to 68 000 A-scans per second, enabling higher resolution compared to time domain OCT. The speed is faster than eye movement so eye movement does not degrade the image quality to the same extent.

Technology is rapidly advancing with new manufacturers on the market. Competition is lowering the cost and increasing the accessibility and usage of OCT in optometry clinics.

New technology in SD-OCT

- Improving software
- Noise reduction/over sampling technology that provides higher resolution imaging
- Improvements in 3D rendering
- Enhanced depth imaging – imaging choroid
- Automatic Fovea Finding
- Progression analysis software
- Expanded normative data bases

It is important to remember that due to different imaging characteristics between OCT's (namely time domain versus spectral domain machines), the clinician must establish a new baseline data set if switching machinery when managing or following progression of disease on a patient.

CLINICAL APPLICATION

Posterior pole scanning using the "Fast Macular Scan" in which a 6 mm area is scanned (6 line scans), thereby providing a 2-D 360 degree thickness map divided into three circular macular sectors, 1mm, 3mm, and 6 mm from the fovea. Quantification of the retinal thickness is depicted in the parameter display. Thicker areas of retina are in red/yellow while thinner retinal areas are shown in blue. The normal fovea is 200 ± 20 um thick and displayed in blue. A difference of more than 30 um between the two eyes is often considered suspicious. This scan provides a rapid assessment of the entire macular area. A shortcoming of this, however, is that should a lesion fall between the six scanned line areas, it may be missed. In addition, the information between line scans is extrapolated, which leaves room for error.

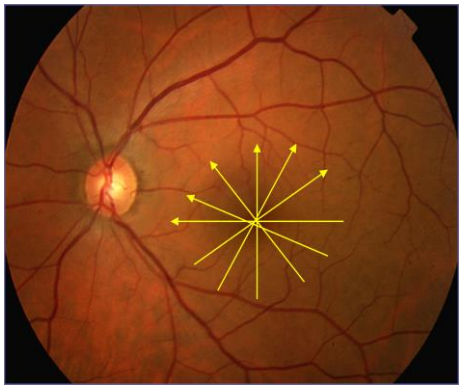

Figure 13- 4. *Retinal photo with overlay of macular scan as performed by Stratus OCT. Line scans in 6 directions in a circle centred on the fovea.*

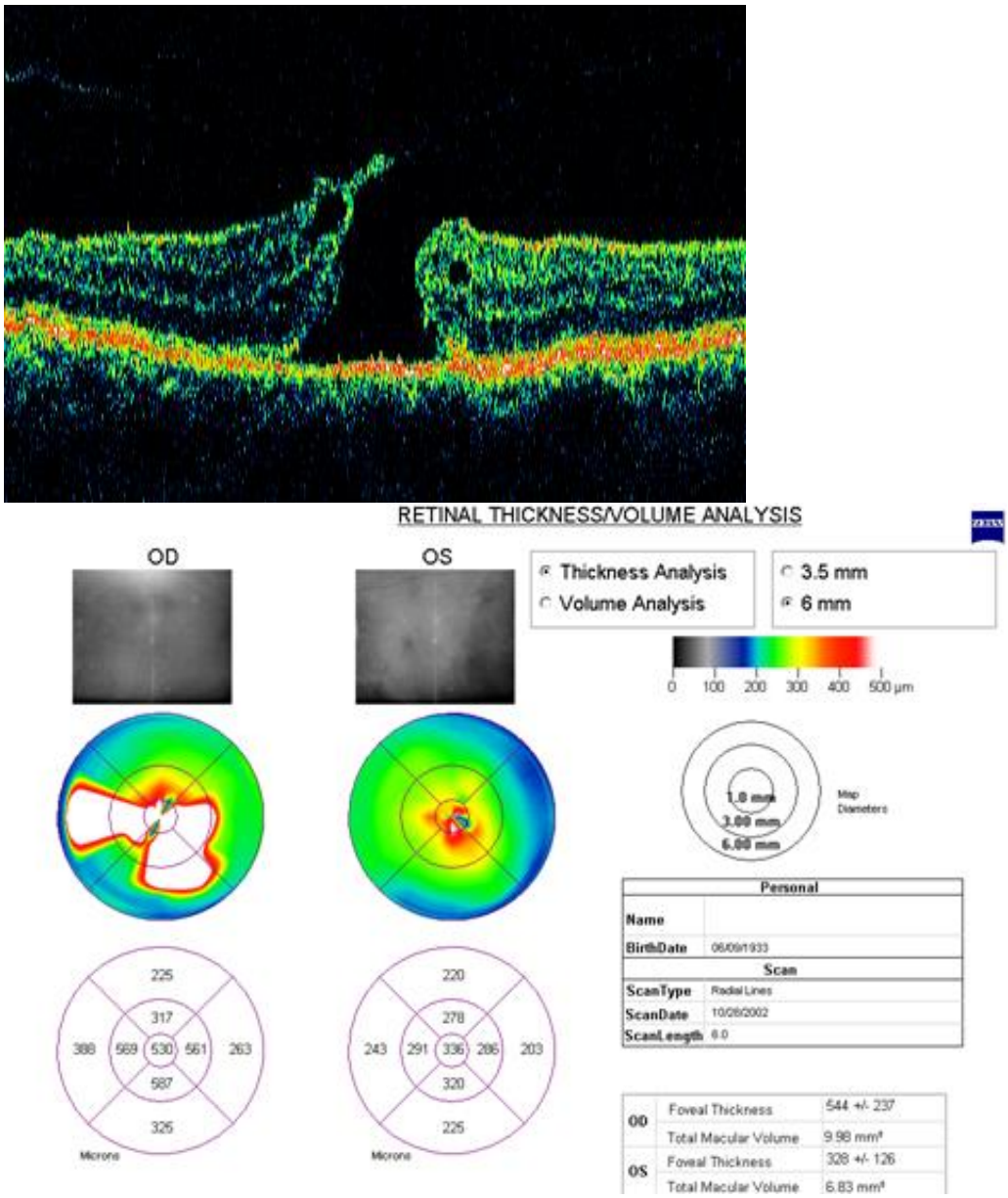

Figure 13- 5. *(1) Stratus OCT line scan through fovea with incomplete macular hole OD. (2) Corresponding macular thickness map.*

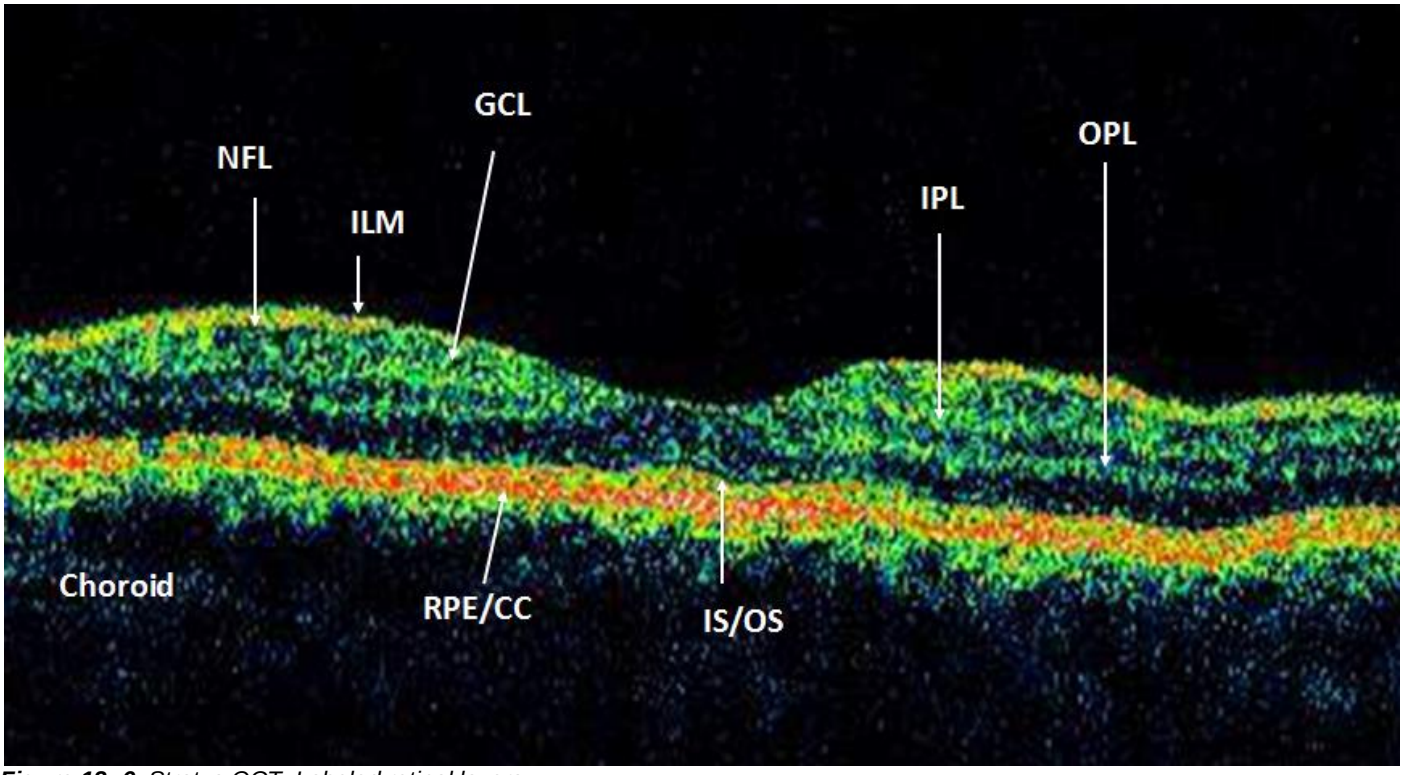

Figure 13- 6. *Stratus OCT. Labeled retinal layers.*

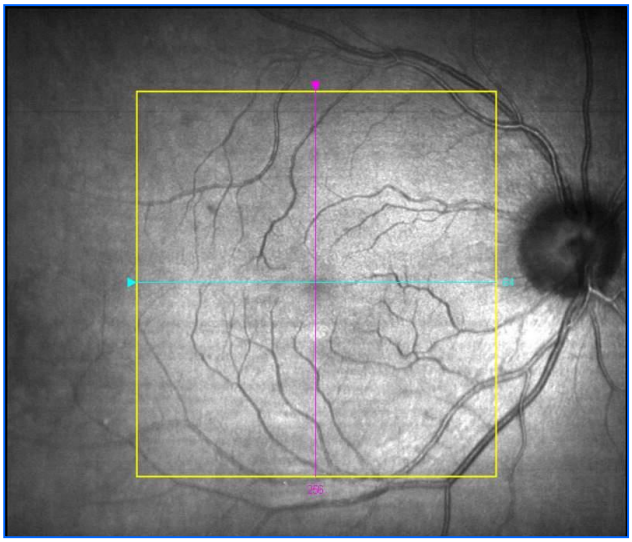

Figure 13-7*. Macular cube scan as seen with Cirrus HD-OCT centered on the fovea. Cirrus scans the entire area within the larger box.*

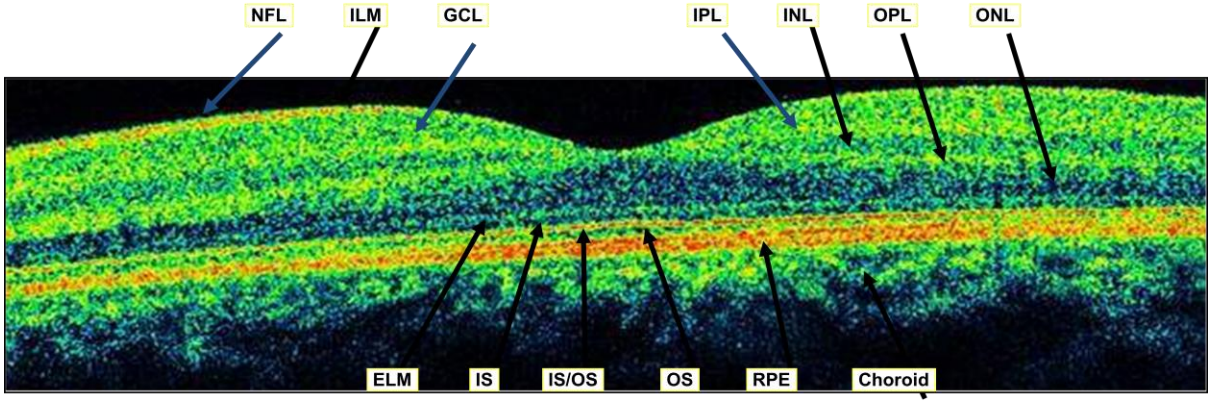

Figure 13-8*. Cirrus HD-OCT. Normal retina with layers labeled.*

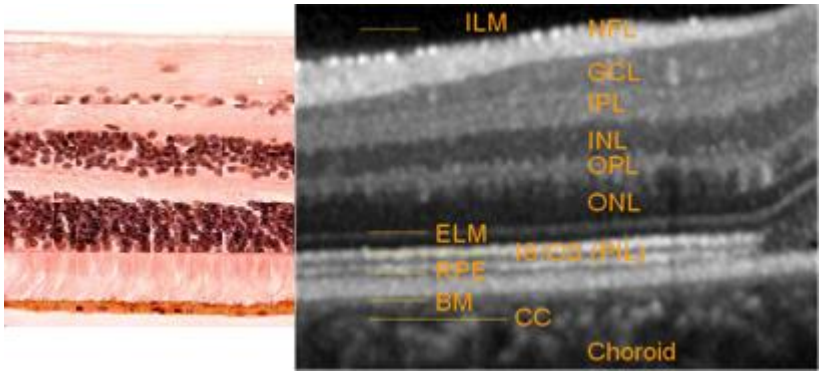

***Figure 13-9**. 50 µm histological section of retina. SD-OCT image indicating corresponding layers image.*

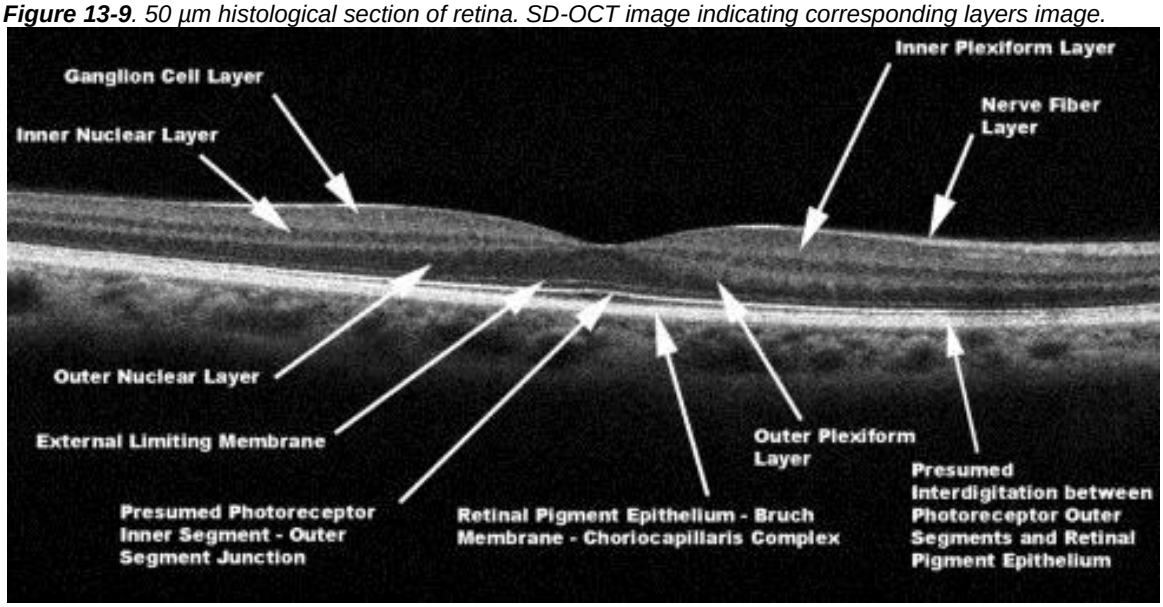

***Figure 13-10**: Retina layer (Cirrus HD OCT)*

Yellow square on LSLO fundus image represents the 6mm x 6mm margins of the scanned macular cube

Adjustable cross hair on fundus image shows precise location of the horizontal and vertical scans selected.

Horizontal B-scan comprised of 512 A-scans

Vertical B-scan comprised of 128 A-scans

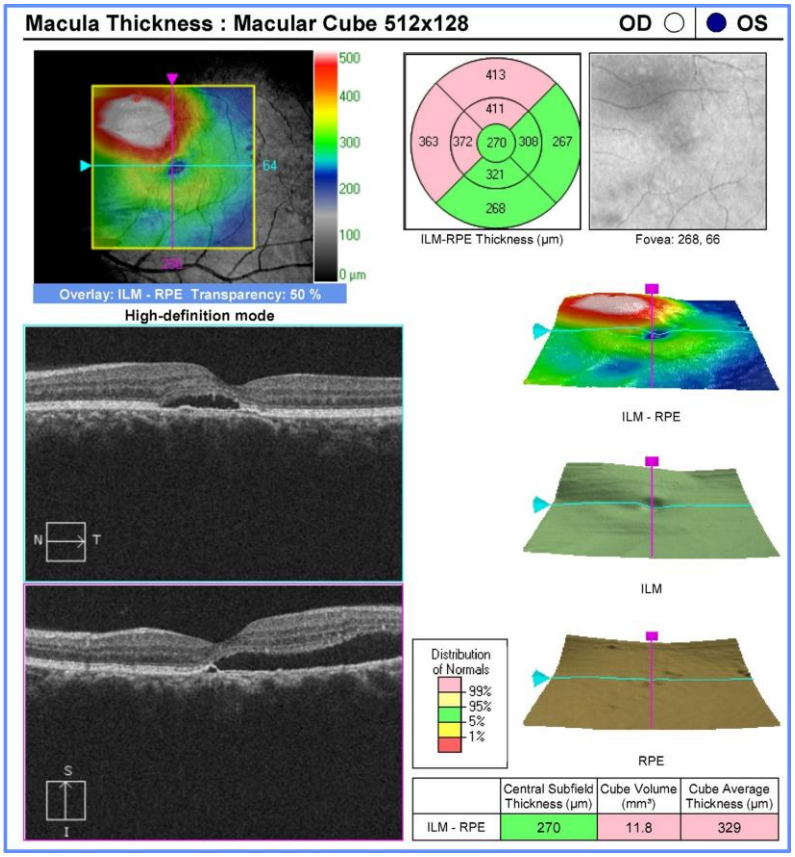

***Figure 13-11**. Cirrus HD-OCT printout Macular cube OS. Image is centered on fovea with adjacent retinal thickening.*

Another clinical application of high resolution OCT is visualization of the interface between the inner segments (IS) and outer segments (OS) of the retinal photoreceptor layer. The IS/OS line is termed the photoreceptor integrity layer (PIL), and, as such, an intact PIL imaged with OCT is an indication that the photoreceptor layer has maintained integrity in the presence of any ongoing pathological process. This interface is affected in disease of the outer retina and, intact or not, is invisible to the clinician with ophthalmoscopy.

GENERAL CLINICAL USE OF OCT

- High resolution evaluation of retinal anatomy
- Diagnosis of macular conditions difficult to establish with biomicroscopy
- Quantitative assessment of retinal and vitreoretinal anatomic alterations
- Objective means for monitoring disease progression and/or therapeutic response
    - For example, resolution of oedema following treatment, progression, repeatability. Oedema and thickness cannot be calculated with ophthalmoscopy,

COMMON PATHOLOGIES THAT ARE OBSERVED OR MONITORED WITH OCT

- Vitreomacular traction
- Optic neuropathies that affect the RNFL
- Outer retinal dystrophies (PIL)
- Retinal tumors
- Retinal detachment
- Retinoschisis
- Diabetic retinopathy
- Macular oedema
- Macular hole
- Central serous chorioretinopathy (CSCR)
- Macular degeneration
- Occult choroidal neovascular membranes (CNVM)
- Retinitis
- Choroiditis
- Choroidal degeneration.

CLINICAL EXAMPLES WITH CIRRUS HD-OCT

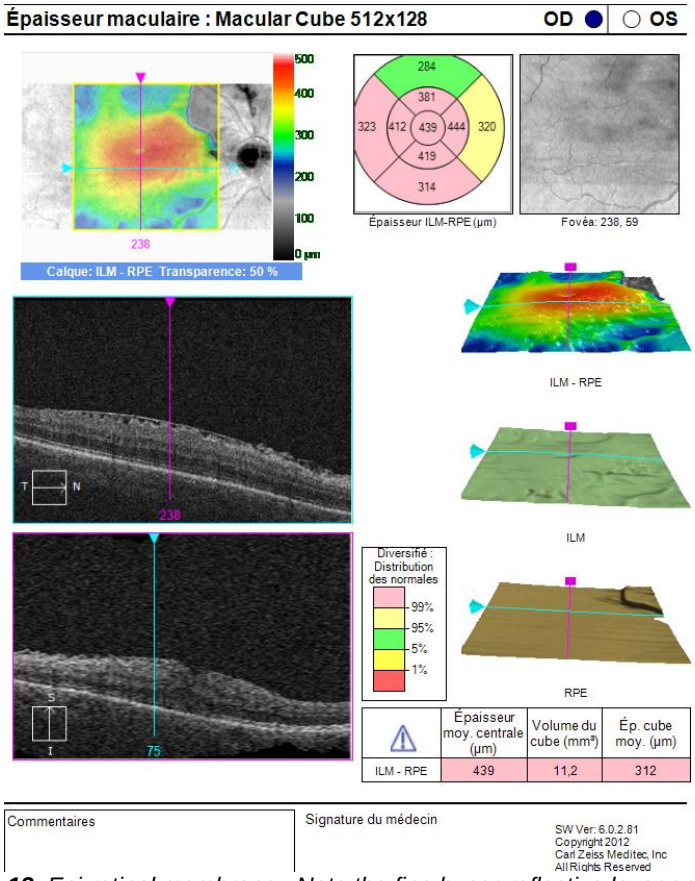

***Figure 13-12**: Epi-retinal membrane. Note the fine hyper-reflective layer on the surface of the retina. Epi-retinal membrane is often associated with an important thickening of the retina.*

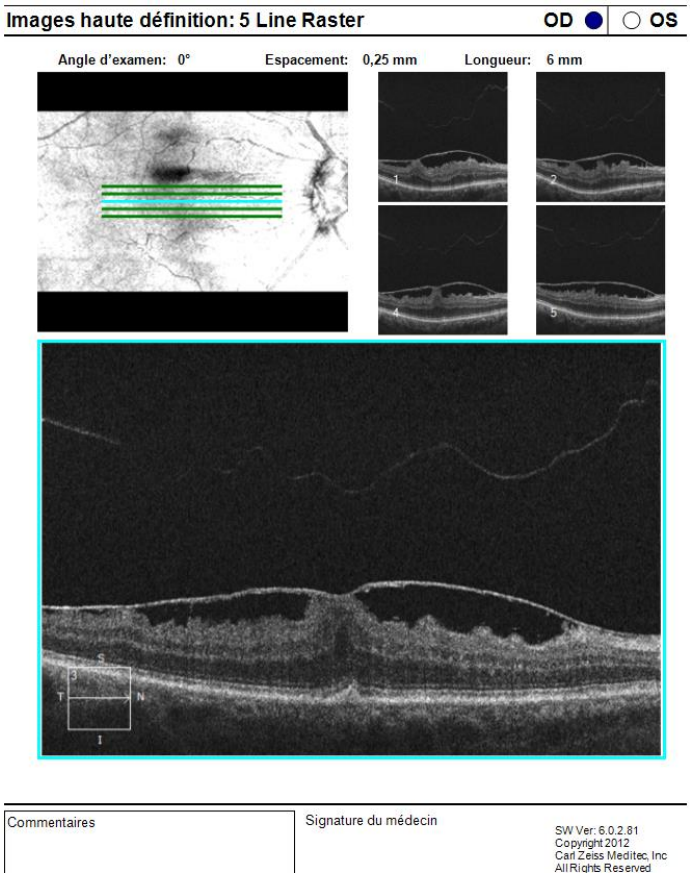

***Figure 13-13**: Epi-retinal membrane associated with an irregularity of the IS/OS layer*

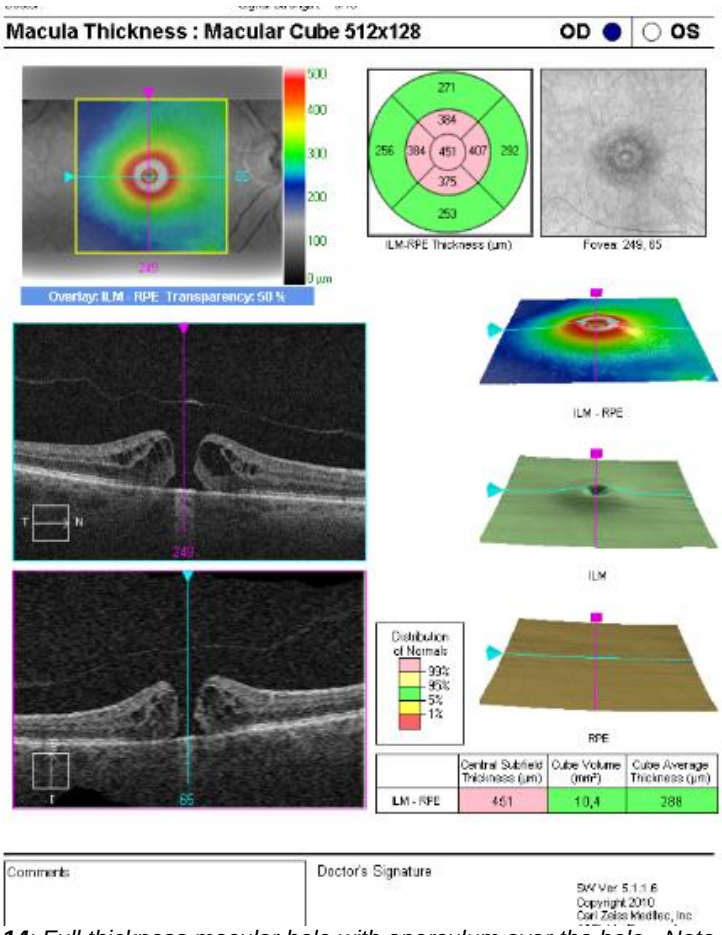

***Figure 13-14**: Full thickness macular hole with operculum over the hole. Note the important oedema at the edge of the hole.*

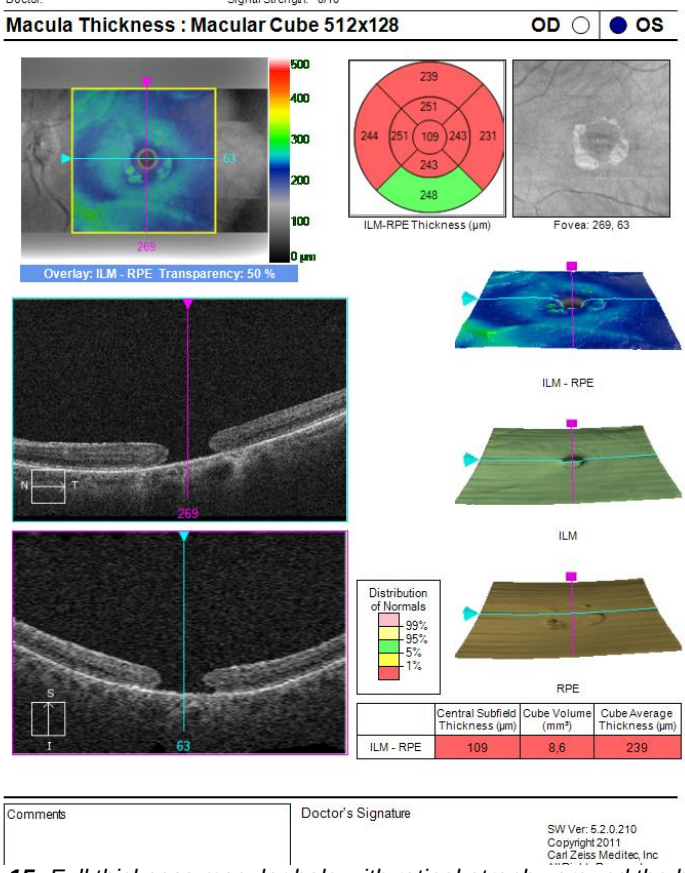

***Figure 13-15:** Full thickness macular hole with retinal atrophy around the hole*

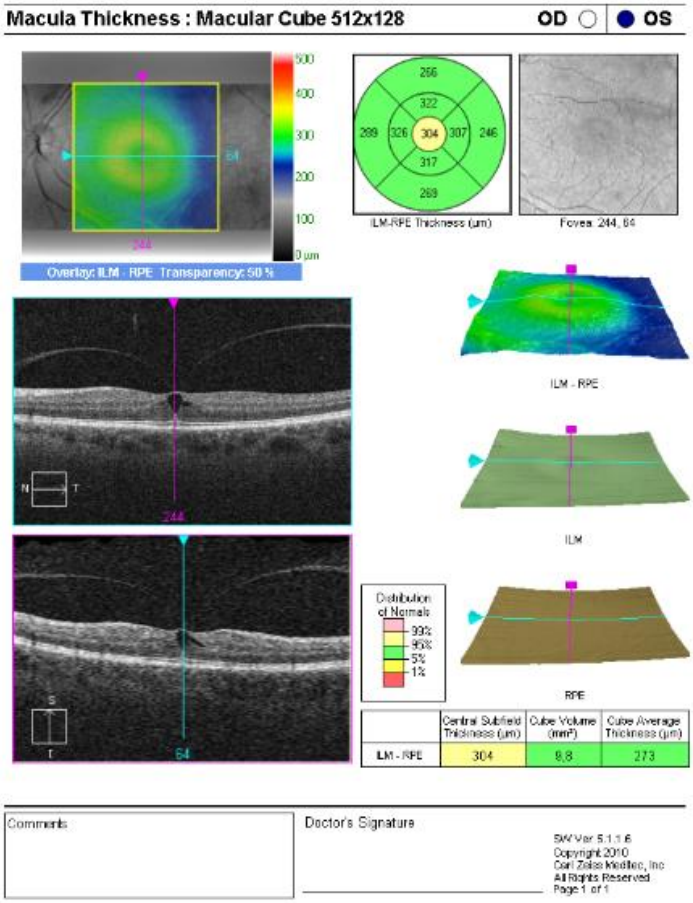

***Figure 13-16**: Stage 1 macular hole*

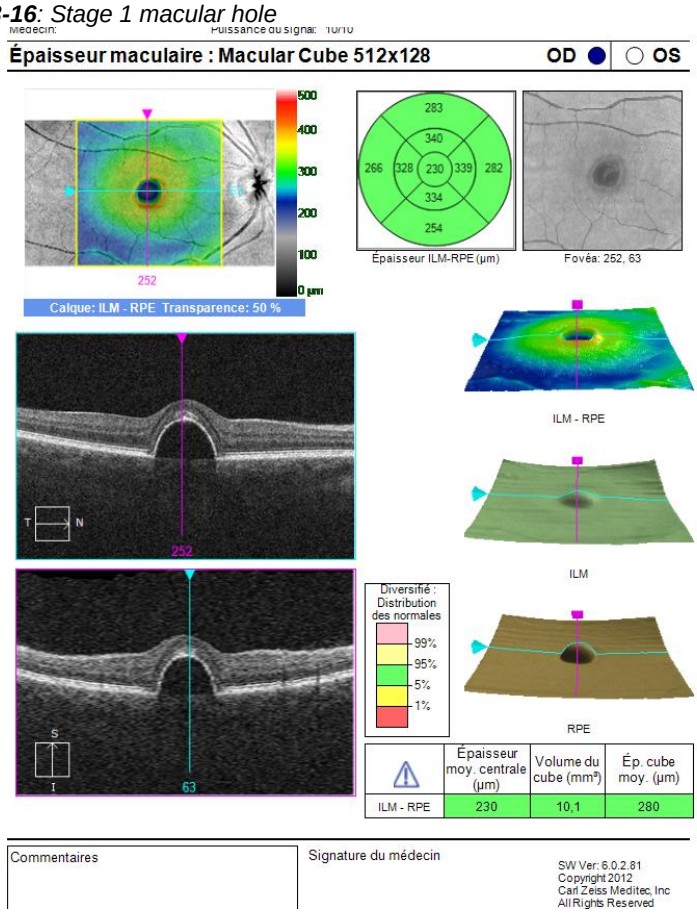

***Figure 13-17**: Pigment epithelial detachment (PED)*

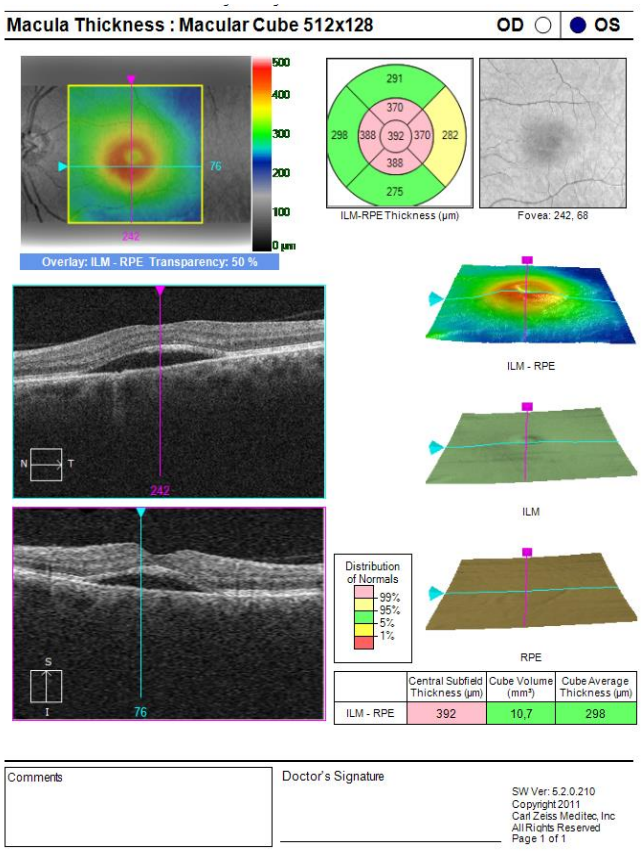

Figure 13-18: *Central serous retinopathy*

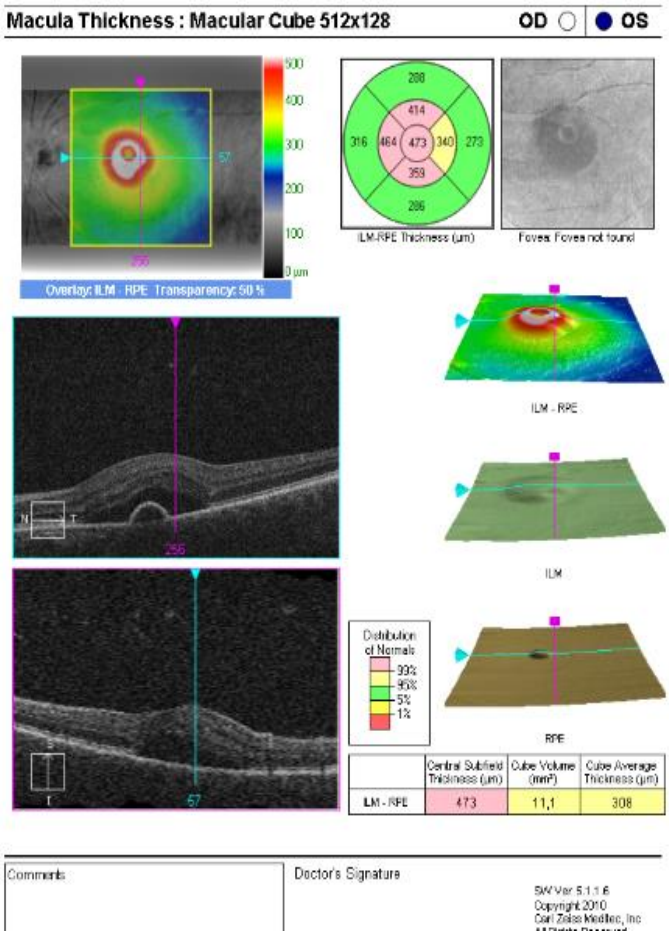

Figure 13-19: *Small pigment epithelial detachment with an overlying neurosensory retinal detachment, associated with central serous retinopathy*

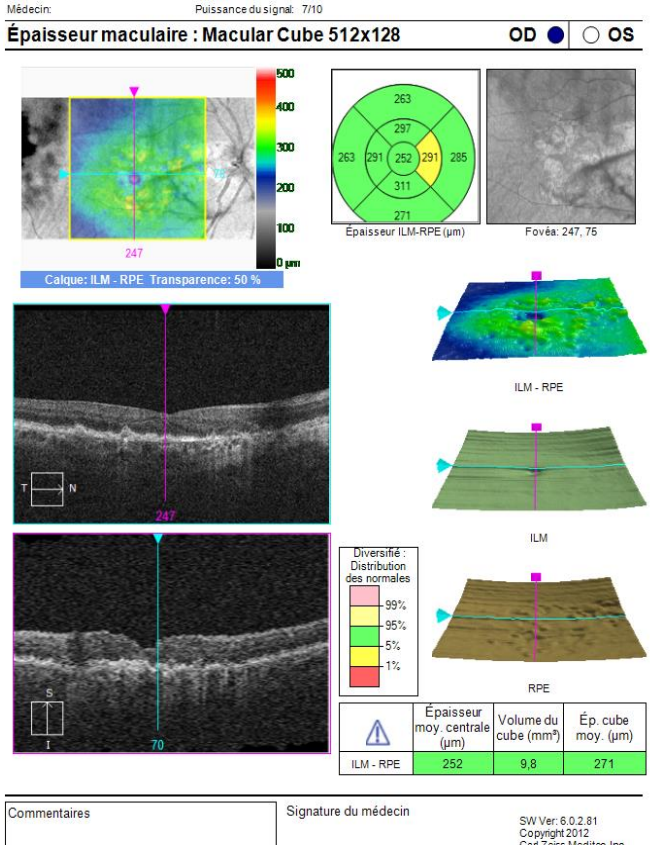

***Figure 13-20**: Macular degeneration: drusen*

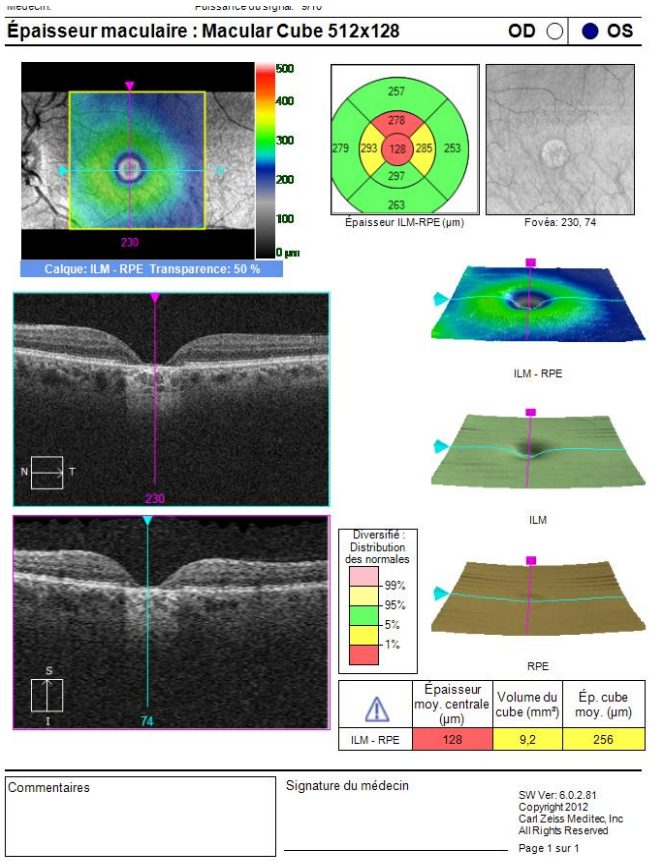

***Figure 13-21**: Macular degeneration: RPE atrophy*

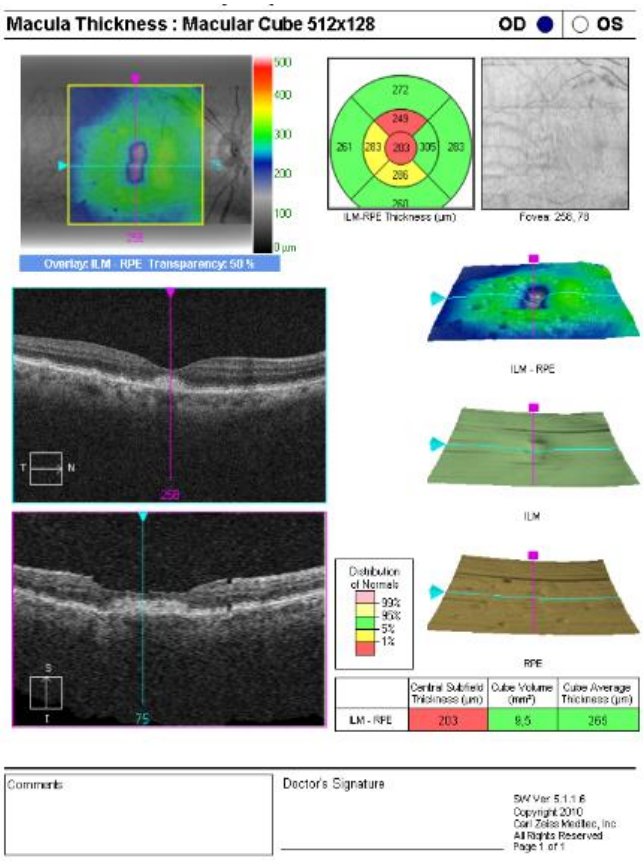

***Figure 13-22**: Pseudo-vitelliform degeneration*

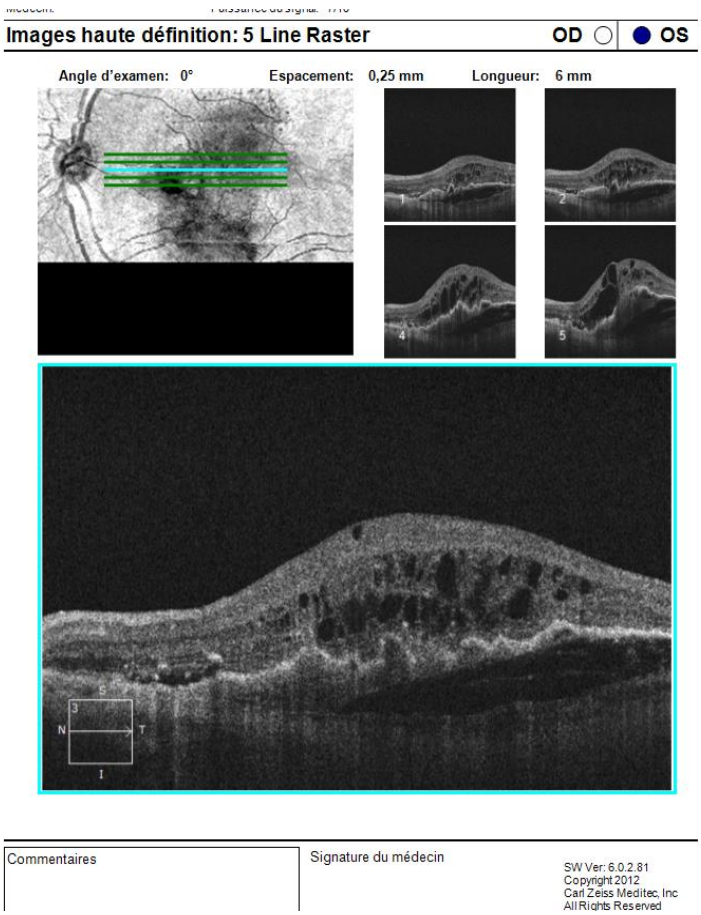

***Figure 13-23:** Macular degeneration: CNVM with sub-retinal and intra-retinal fluid*

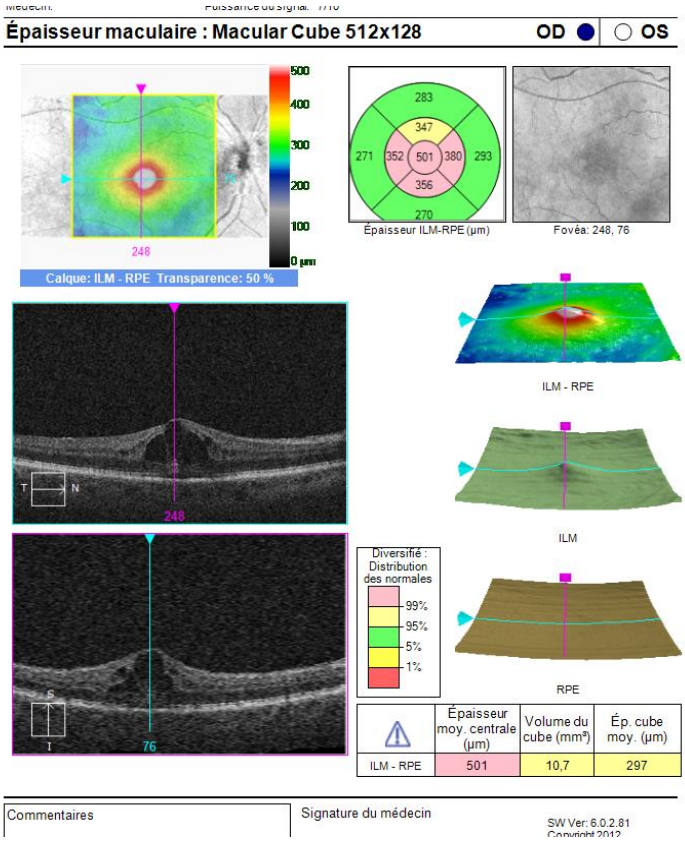

***Figure 13-24**: Cystoid macular oedema (CME) following cataract surgery*

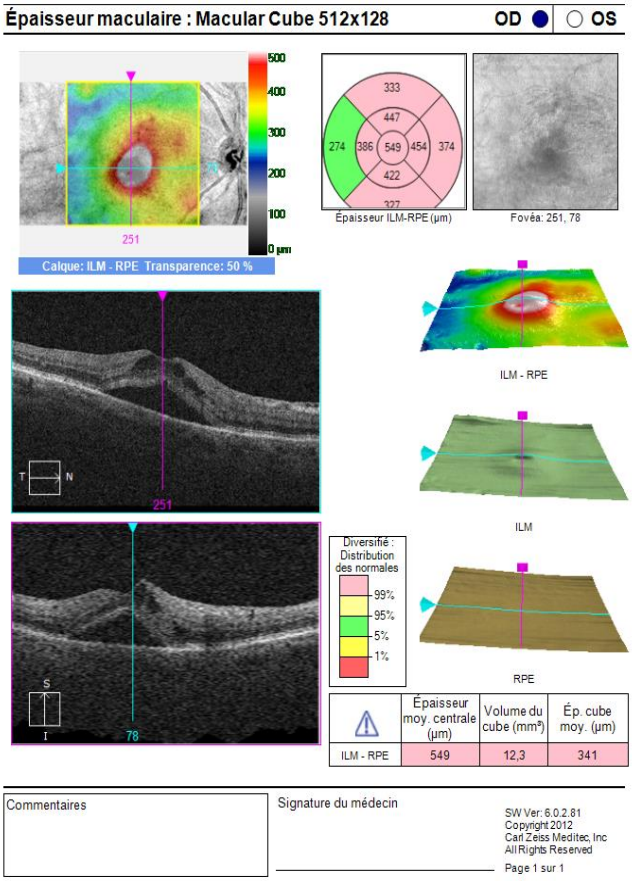

***Figure 13-25**: Serous detachment and CME secondary to Central Retinal Vein Occlusion (CRVO)*

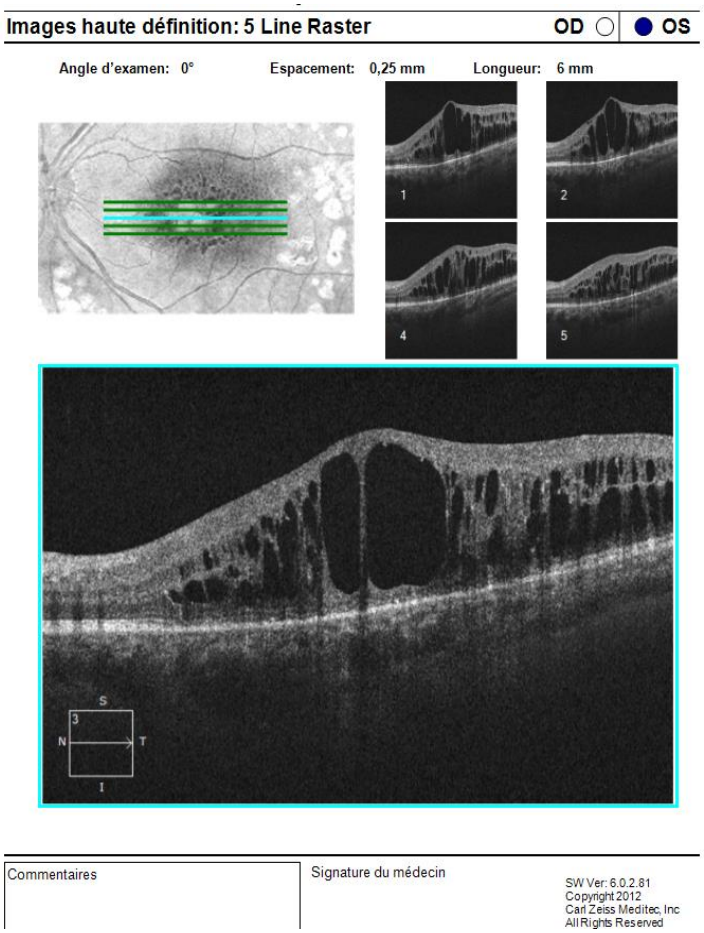

***Figure 13-26**: Macular oedema in a patient with diabetic retinopathy*

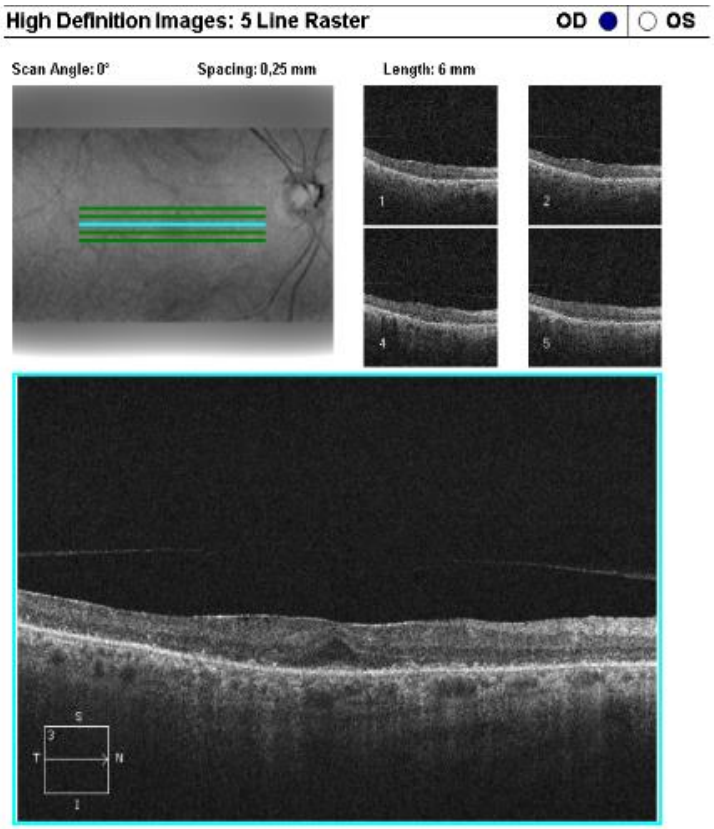

***Figure 13-27**: Hydroxychloroquine maculopathy with loss of the IS/OS junction*

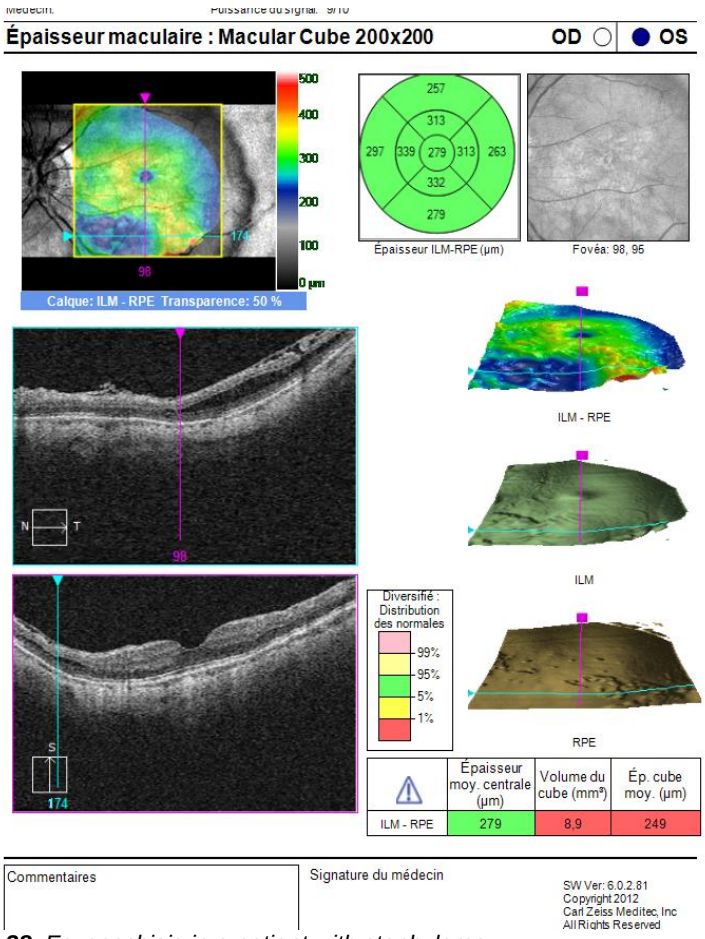

***Figure 13-28**: Foveoschisis in a patient with staphyloma*

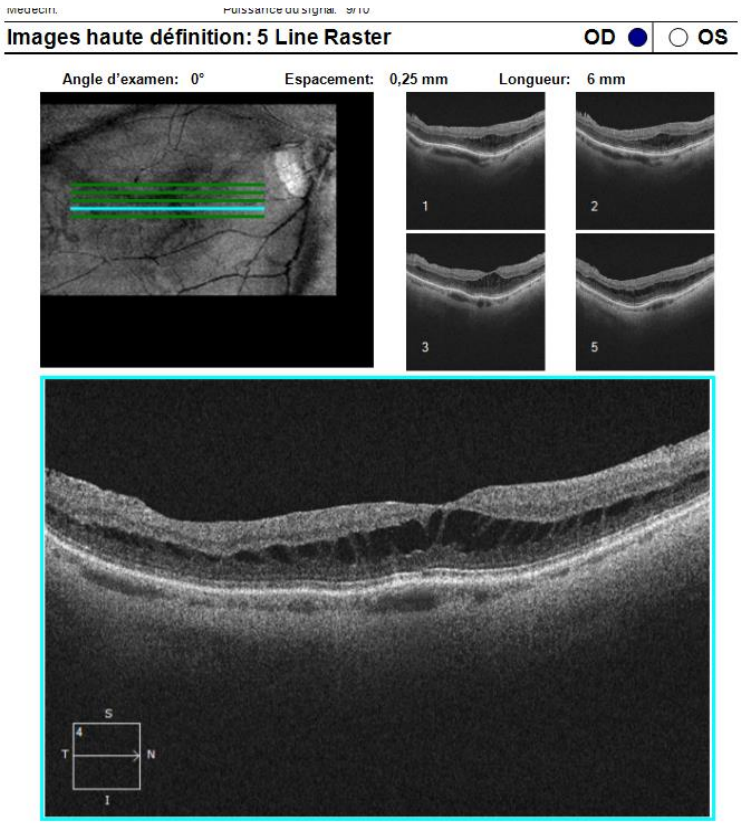

***Figure 13-29**: Foveoschisis in a patient with myopia*

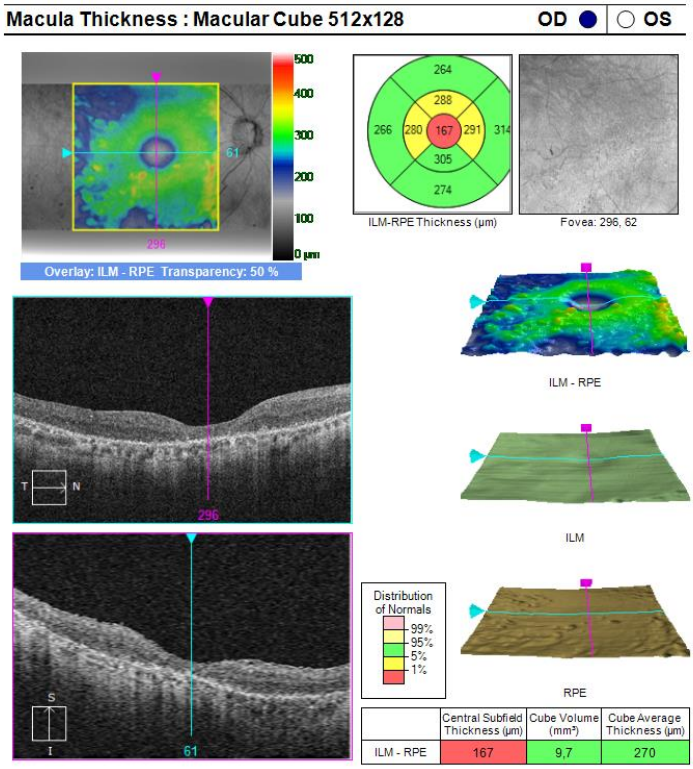

***Figure 13-30**: Retinitis pigmentosa. Note the lost of the IS/OS junction line*

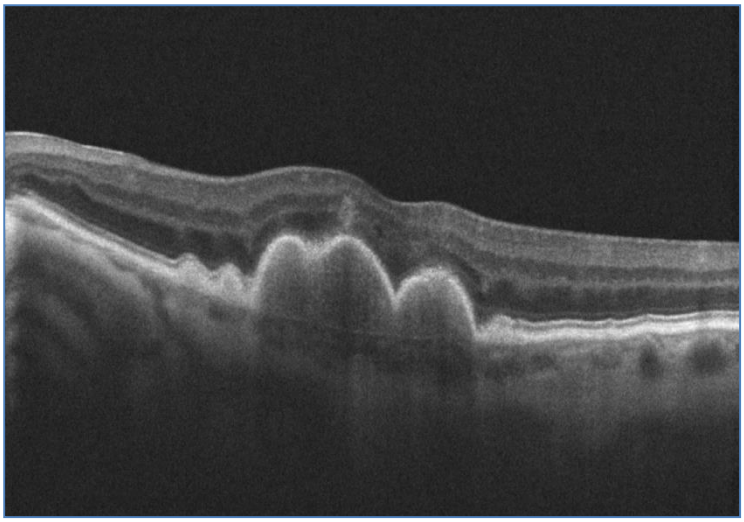

***Figure 13-31:** Drusen with pigment epithelial detachments showing Bruch's membrane*

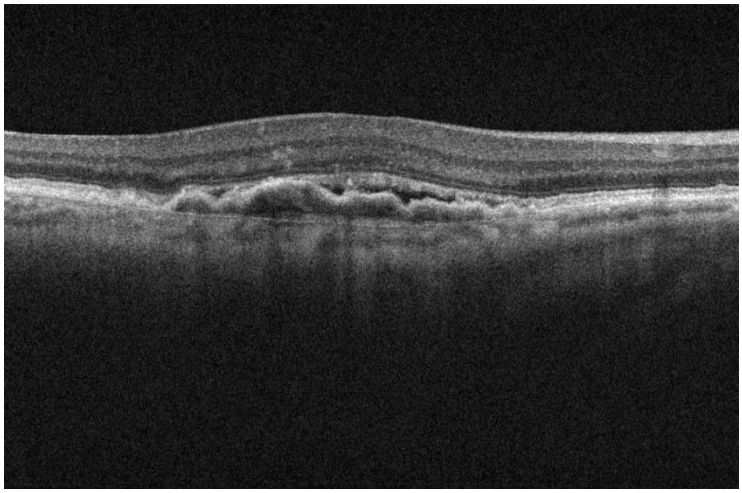

***Figure 13-32:** Choroidal neovascular membrane*

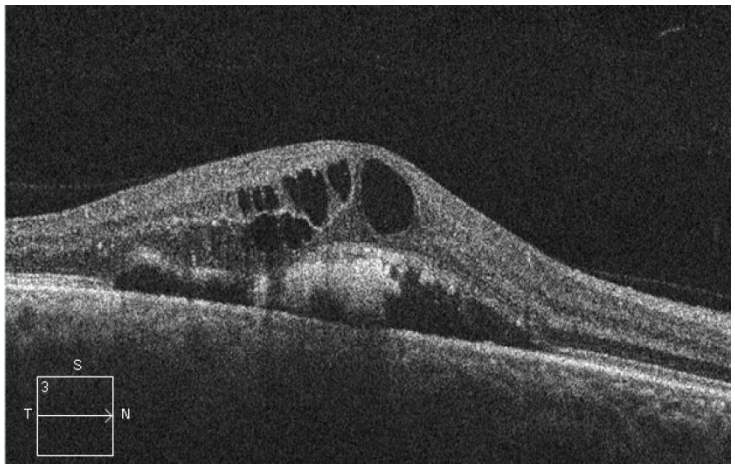

Figure 13-33: *Branch Retinal Vein Occlusion (BRVO) with cystoid macular oedema*

OCT IN GLAUCOMA

Compared to standard methods for diagnosis and monitoring of glaucoma (visual field, intraocular pressure (IOP), subjective evaluation of optic nerve), there is a need for objective testing that can reliably detect those patients who may have glaucoma and/or are at risk of developing glaucoma. Advanced software on newer OCT's allows for glaucoma progression analysis as well as analysis of the ganglion cell layer.

The Stratus OCT RNFL analysis uses a series of 4 mm long radial line scans at 12 clock hours around the disc allowing for topographic measurement of the optic disc as well as quantification of the RNFL thickness in four quadrants around the disc. The instrument uses the termination of Bruch's membrane to determine the edge of the disc. Disc parameters include cup volume, disc area, cup and rim area, and cup to disc ratios. RNFL thickness data are collected in a circular area 3.37 mm in diameter around the ONH. A peripapillary cross sectional image is obtained and displayed as a temporal-superior-nasal-inferior-temporal (TSNIT) curve. Using this scan protocol, the patient's curve is displayed within a 5-95% confidence interval of normative data for that patient's age group. The statistical significance of any abnormal areas is depicted in yellow (borderline) and red (outside) normal limits.

The protocol for ONH and RNFL analysis on the Cirrus OCT is similar with data collected in a 6 mm X 6 mm square area centred on the optic nerve head. The scan performed with Cirrus, as with the retinal scanning, covers the entire area of the disc with 200 A-scans performed to accumulate the data set. The Cirrus, like Stratus, offers detailed information about the ONH and RNFL and comparisons between eyes.

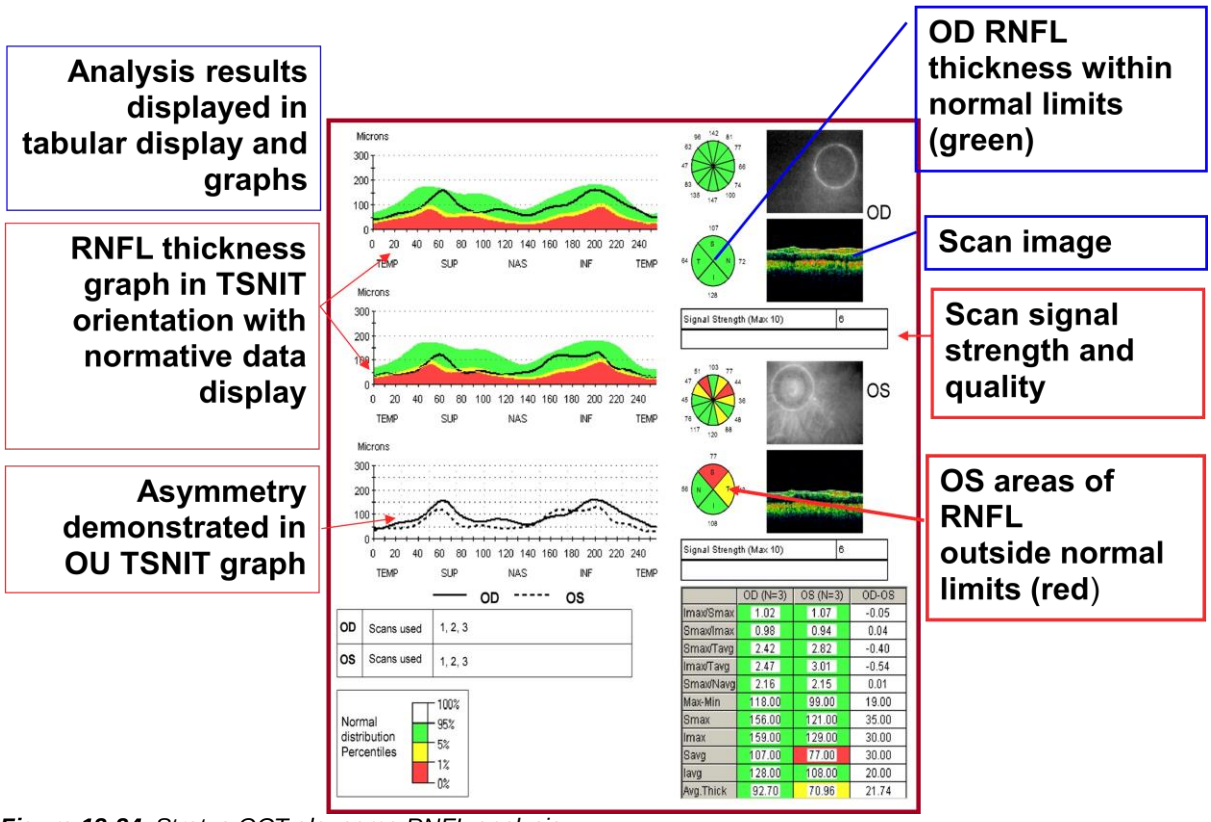

***Figure 13-34**. Stratus OCT glaucoma RNFL analysis*

RNFL THICKNESS MAP shows the patterns and thickness of the nerve fiber layer within the full 6mm x 6mm area

RNFL thickness and comparison to normative data is shown in circle, quadrants and clock hour display

RNFL DEVIATION MAP, overlaid on the OCT fundus image, illustrates precisely where RNFL thickness deviates from the normal range. Data points that are not within normal limits are indicated in red and yellow.

RNFL thickness along the calculation circle is displayed in graphic format and compared to age-matched normative data

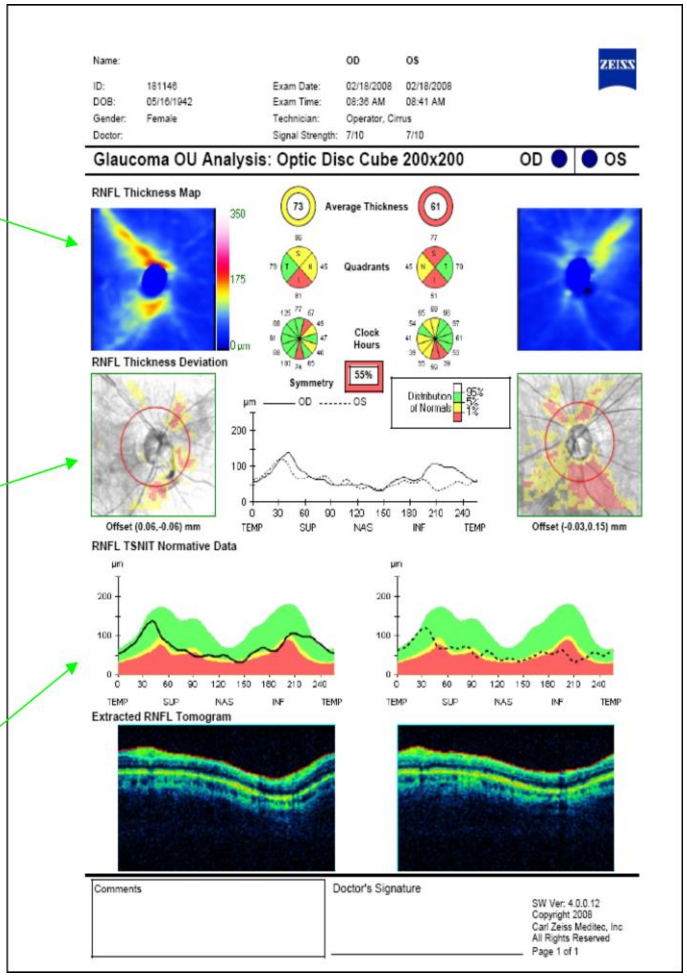

***Figure 13-35**. Cirrus OCT Glaucoma protocol*

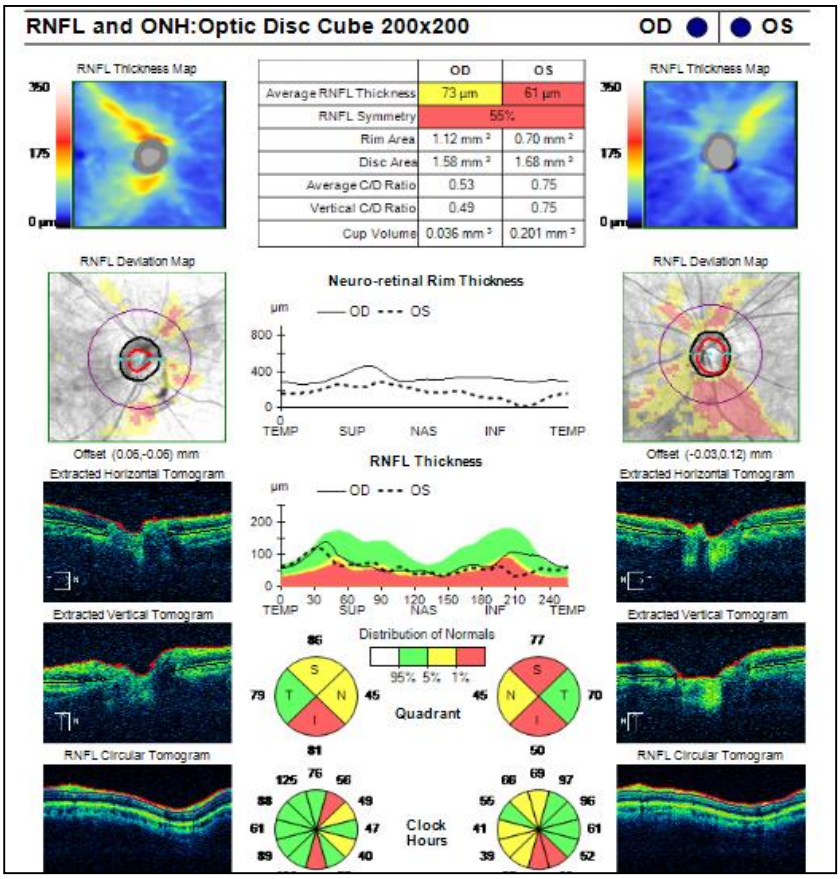

***Figure 13-36**. Cirrus OCT combined RNFL and ONH information printout with more detailed disc information in the box at the top of the printout.*

OCT also enables the practitioner to measure the complex formed by the ganglion cell and the inner plexiform layers in the macular area. Recent studies have shown that early glaucoma damage often takes place in the macular area and that the measurement of the ganglion cell and inner plexiform layer can help in the diagnosis and follow-up of patient with glaucoma.

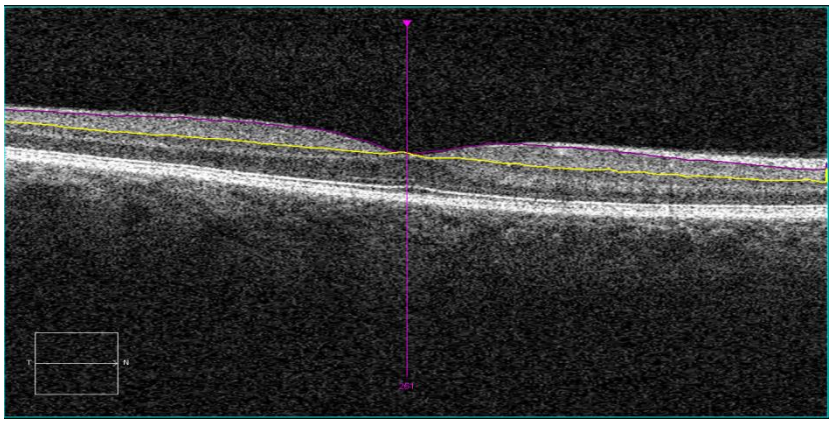

***Figure 13-37:** Measurement of the complex formed by the ganglion cell and inner plexiform layers in the macula can help in the diagnosis and follow-up of glaucoma.*

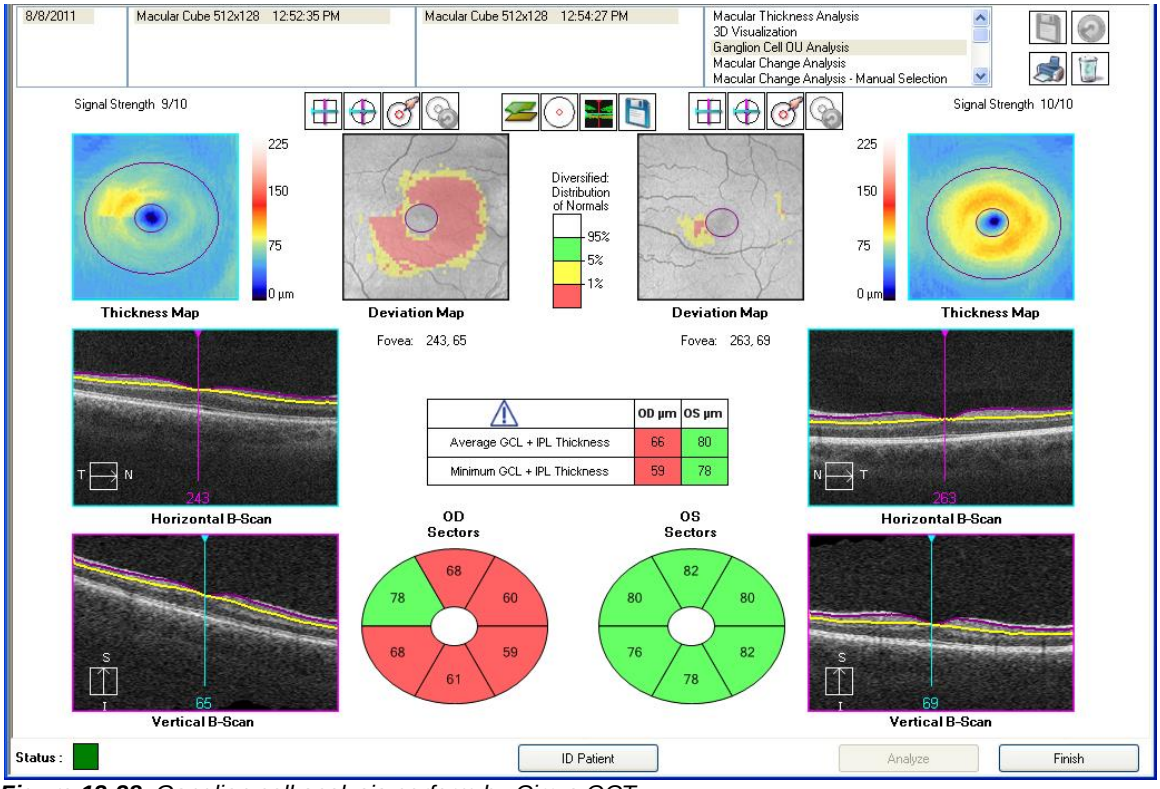

***Figure 13-38**: Ganglion cell analysis perform by Cirrus OCT*

Regarding glaucoma, clinical research has shown the following:

- OCT has the ability to detect early glaucoma change by measuring NFL thickness
  - Particularly inferior quadrant
  - Often before visual field (VF) loss
- The nasal side of the optic nerve is affected earlier and more than what is usually considered
- Average and quadrant NFL thickness have good correlation with associated mean deviation and visual field findings.

ADDITIONAL RESOURCES

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