OCT Artifacts in Glaucoma

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Introduction

Recent evidence indicates that OCT imaging artifacts are a common finding in clinical practice. Poor scan quality can affect the ability of OCT to detect glaucoma and monitor its progression. In addition, these technological devices have biological, engineering, and biophysical limits so these devices cannot be 100% specific and 100% sensitive at all times. Therefore, it is important for clinicians to identify the various OCT imaging artifacts and critically evaluate test results to apply that knowledge to the interpretation of testing results. Otherwise, they will be managing false-positive 'Red Disease' and possibly over-treating patients. Errors in data acquisition due to media opacity, extreme myopia, difficulties comparing to normative databases, operator misalignment, individual blink, or software analysis difficulties can confound interpretation of OCT data and may falsely change the classification to abnormal. The factors that are correlated to the artifacts can be classified into patient-dependent, operator-dependent, and device-dependent factors.

On the other hand, recognition of false-negative 'green disease' is of importance in diagnosing and treating glaucoma. Understanding the limitations of imaging technologies coupled with the evaluation of serial OCT analyses, prompt clinical examination, and structure–function correlation is important to avoid missing real glaucoma requiring treatment. For example, progressively decreasing retinal nerve fiber layer (RNFL) thickness may reveal the presence of progressive glaucoma that, because of green labeling, can be missed by the clinicians. Ocular

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conditions that can increase RNFL thickness (i.e. uveitis, diabetic macular edema, peripapillary choroidal neovascularization) can also lead to 'Green disease' and make the diagnosis of coexisting glaucoma difficult.

Blink Artifact

Blink artifact is usually recognized by a black horizontal band on the RNFL thickness map. It blocks the OCT signal and if it overlays the calculation circle can lead to 'Red Disease'. Interpretation of the OCT printout should be made carefully in these cases.

Case 1-Blink Artifact

OCT scan of a 55-year-old woman with ocular hypertension of her right eye and pseudoexfoliation glaucoma of her left eye (Fig. 1). IOP was 21 mmHg OD with latanoprost and 26 mmHg OS with topical latanoprost and dorzolamide-timolol fixed combination.

Case 2-'Red Disease' Due to Blink Artifact

Another case of blink artifact in a glaucomatous patient. The OCT image has low quality due to poor cooperation. The blink artifact affects the calculation circle and optic nerve head analysis of both eyes. The average RNFL is 22 μm OD and 0 μm OS; both these thicknesses are less than floor, indicating artifact (Fig. 2a). The scan was repeated multiple times. In an improved scan (Fig. 2b), the blink artifact does not affect the measurement circle, and a wedge defect in the superior quadrant is evident in the right eye. The average RNFL is 77 μm OD (Fig. 2b), which is similar to his RNFL thickness 4 years ago. The visual field reveals inferior arcuate defect in the right eye and normal in the left eye, which corresponds with the RNFL wedge defect in the right eye.

'Red Disease' Due to Contour Shift

Patients demonstrate RNFL bundle peaks superotemorally and inferotemporally. However, the OCT normative database does not factor in anatomic variation in RNFL bundle peak locations. If a patient has a contour shift, i.e. a shift in their RNFL bundle peak locations in comparison to the normative database, this can

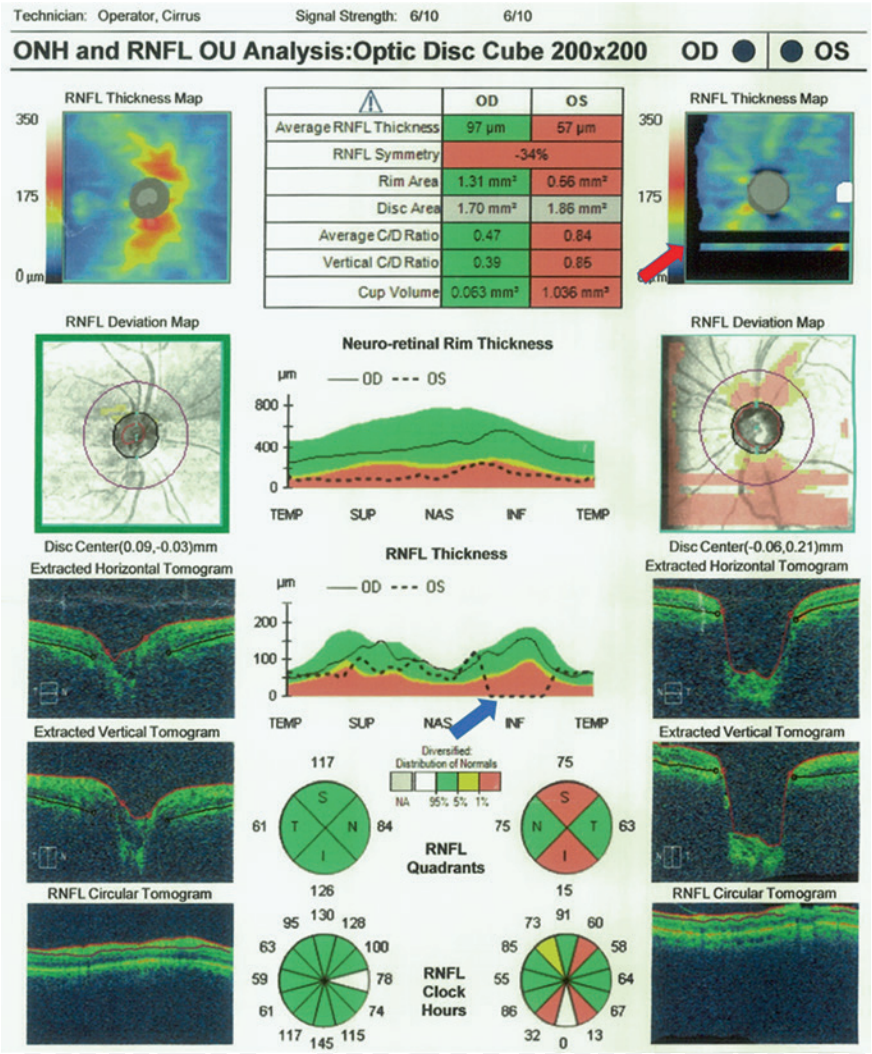


Fig. 1 Cirrus SD-OCT RNFL and ONH report. The quality of the scan is acceptable (Signal Strength = 6/10) in both eyes. The RNFL thickness map of the left eye shows blink artifact as an area of scanning blockage (red arrow). The segmentation of the inferior quadrant failed on the RNFL circular tomogram because the artifact coincides with the calculation circle in that area. The average RNFL thickness of the inferior quadrant is zero on the RNFL TSNIT (blue arrow) and pie graphs, which cannot occur due to floor effect

lead to an erroneous interpretation of RNFL thinning in healthy eyes. Contour shifts are most commonly seen in patients with high refractive errors. Contour shifts have been studied most extensively in myopic eyes. These studies have demonstrated that the superotemporal and inferotemporal bundles tend to converge temporally in myopic eyes [1].

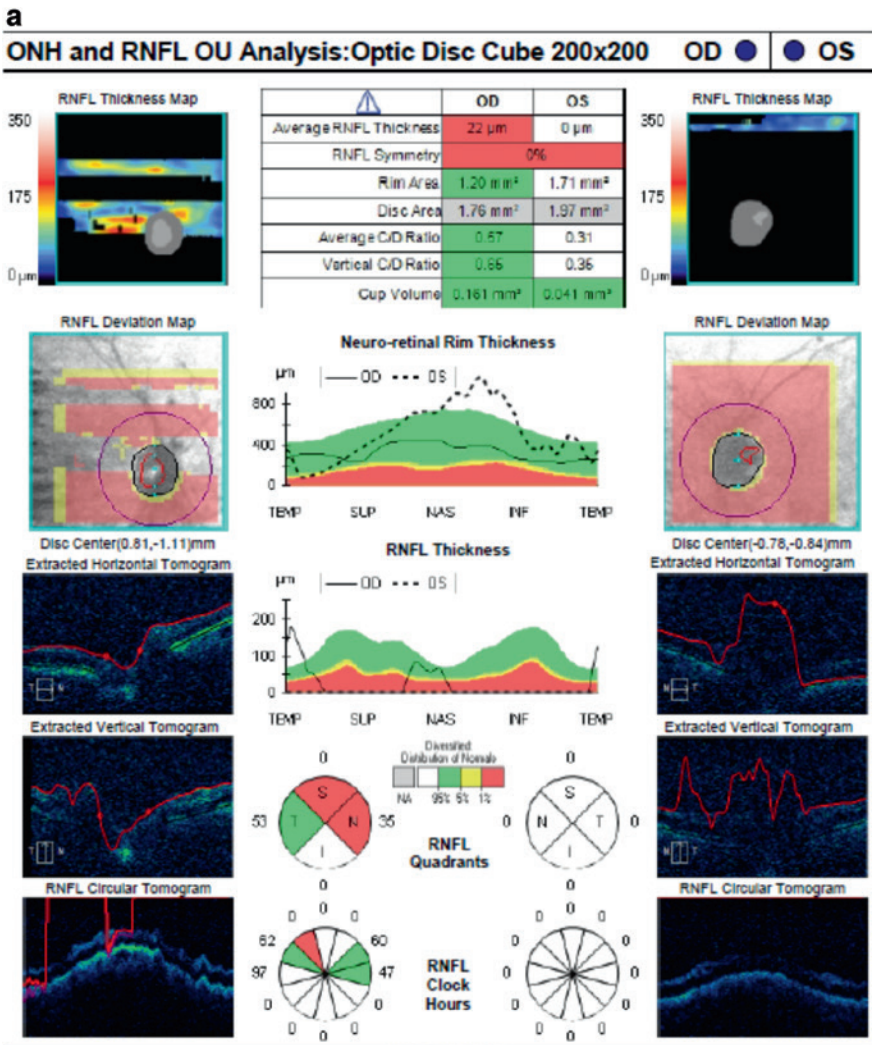


Fig. 2 **a** Cirrus SD-OCT RNFL and ONH report. The OCT image has low quality due to poor cooperation. The blink artifact affects the calculation circle and optic nerve head in the right eye. The average RNFL is 22 µm in the right eye. **b** The OCT is repeated. In this report, the blinking artifact does not affect the measurement circle, and the wedge defect in the superior quadrant is evident in the right eye. The average RNFL is 77 mm in right eye, which is similar to his RNFL thickness 4 years ago. **c** Visual Field indicating corresponding defects in the superior field in right eye. The visual field in left eye is full

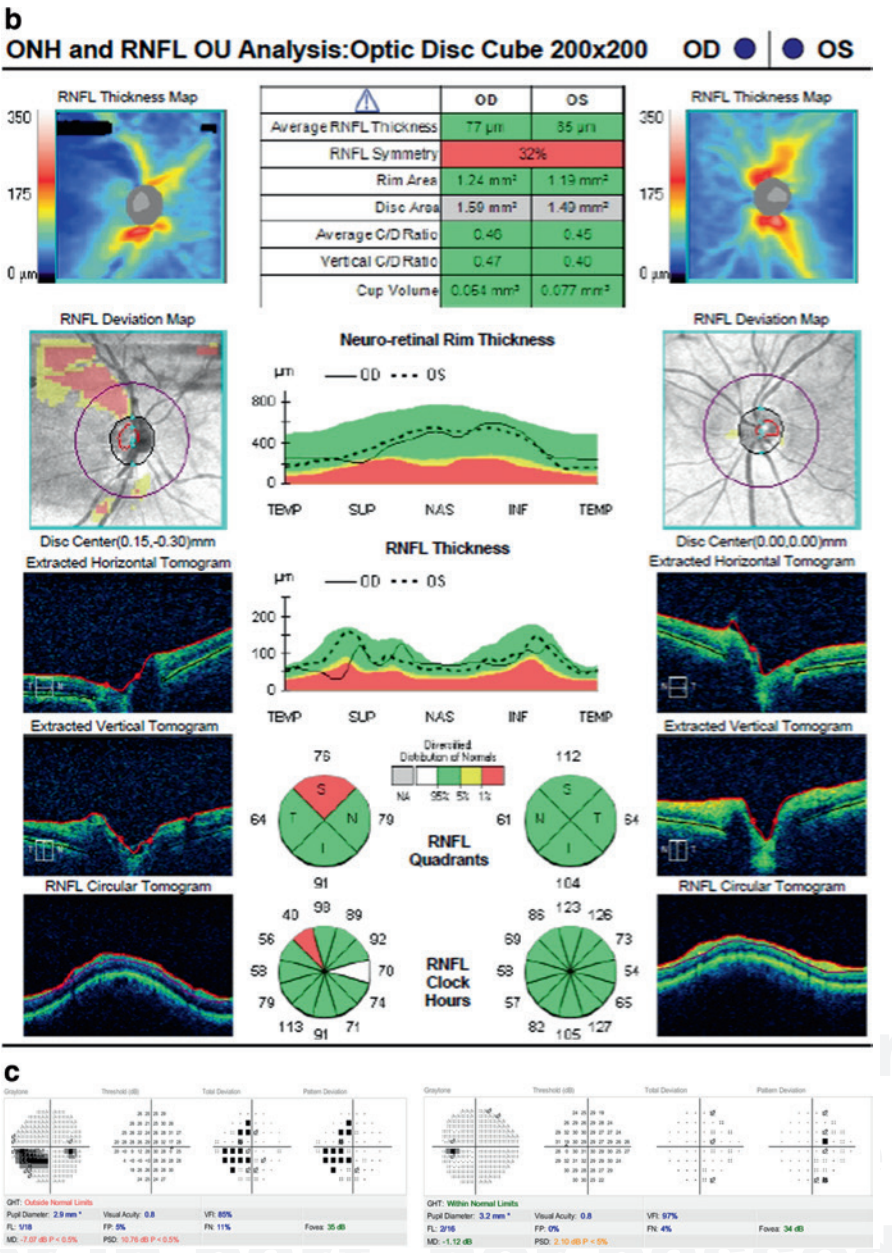


Fig. 2 (continued)

Case 3-'Red Disease' Due to Contour Shift

A 58-year old female with normal appearance of the optic nerve but a borderline IOP is referred for further work-up. Fundus examination and 24-2 visual field were normal. The patient had an OCT with reported abnormalities on the RNFL clock hours (Fig. 3). Contour shift is an anatomic variation from the average axis

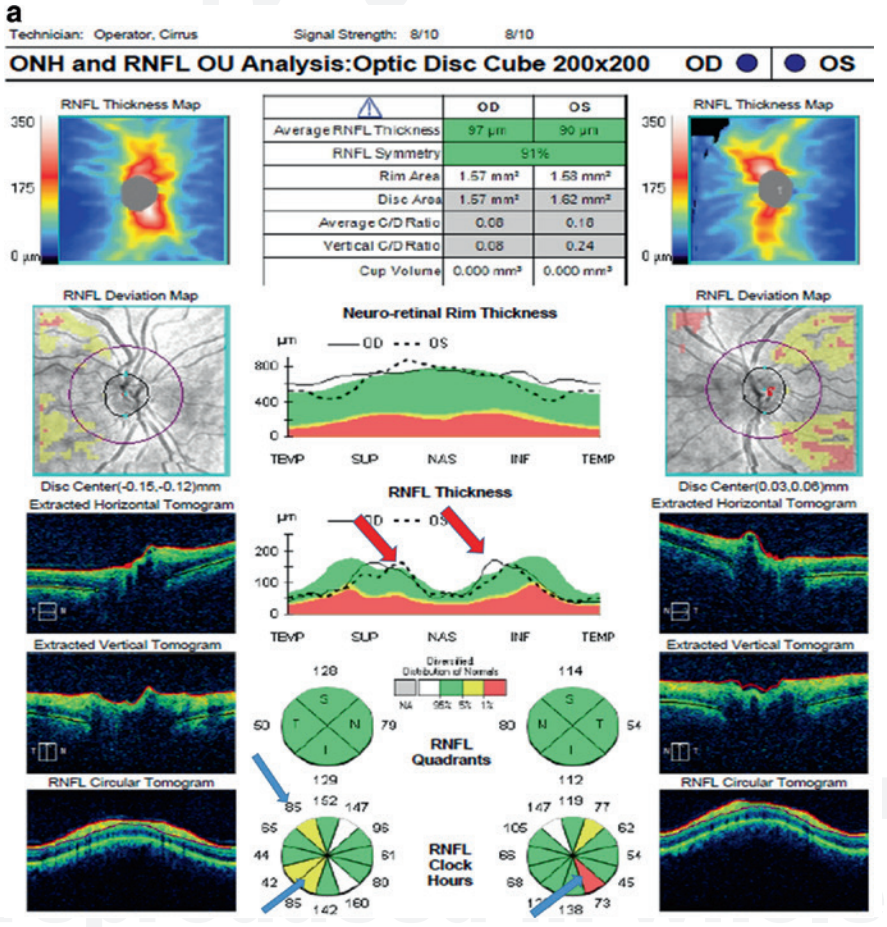


Fig. 3 **a** Cirrus SD-OCT RNFL and ONH report. The OCT image shows RNFL defects OU and the average RNFL thickness values were classified as normal by the normative database in both eyes. Inferotemporal and supratemporal RNFL thickness in both eyes and superior RNFL thickness in the left eye are outside of normal limits (blue arrows). The artifact is related to the nasal shift of the inferior and superior RNFL bundles (red arrows). If the RNFL thickness peaks were not shifted to the nasal area, the RNFL thickness lines would fit the normative database values. Note that ONH analysis (cup to disc ratio, rim area, and neuroretinal rim thickness) is within normal limit. **b** GCIPL OU analysis-Ganglion Cell Analysis of the patient shows the normal doughnut appearance in thickness map and green sectors

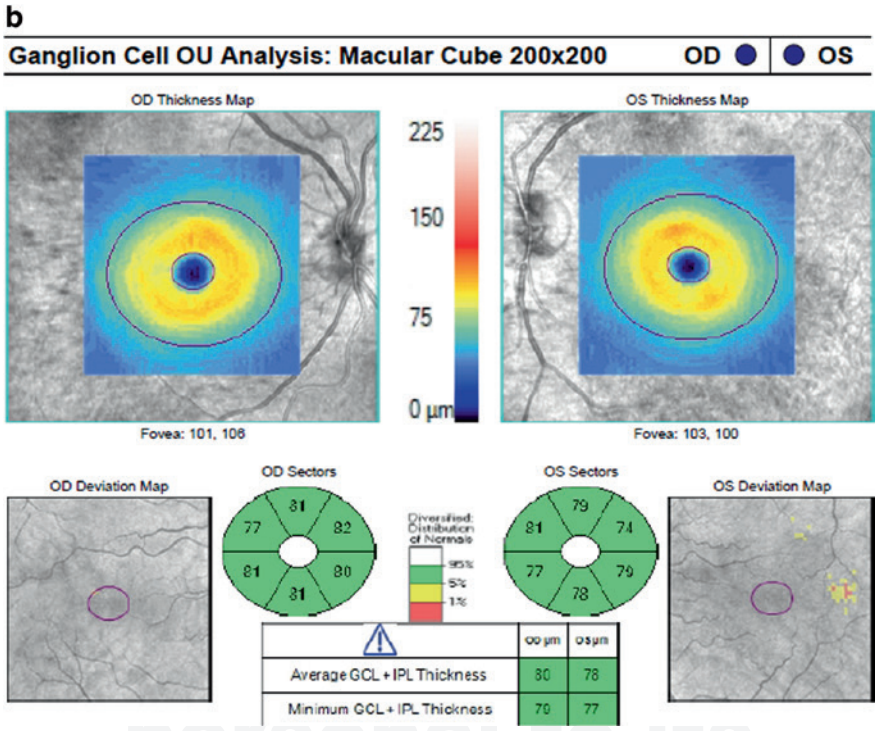


Fig. 3 (continued)

of a person's peak RNFL thickness. Note that the GCIPL OU report and ONH rim plot are normal. This is an example of red disease due to anatomic variation from the normative database and most commonly is seen in patients with high refractive errors. The locations of peak RNFL thicknesses in TSNIT profiles largely associated with the angles of major retinal vessels [2].

Case 4-'Red Disease' Due to Contour Shift

A 73-year old man is referred to clinic due to a reported abnormal RNFL OCT. His IOP was 21 mm Hg OD and 22 mmHg OS. CCT was 534 and 537 µm in right eye and left eye, respectively. The optic nerve head exam was normal, and no RNFL defect was found. RNFL OCT showed inferotemporal thinning in both eyes. However, a contour shift can be observed on the TSNIT plot with nasal shift of the inferotemporal RNFL bundle. This reassuring exam was confirmed by normal visual fields in both eyes. Glaucoma was excluded (Fig. 4). No further testing was performed and no treatment was started given the lack of glaucomatous optic neuropathy and artifactual thinning of the RNFL OCT.

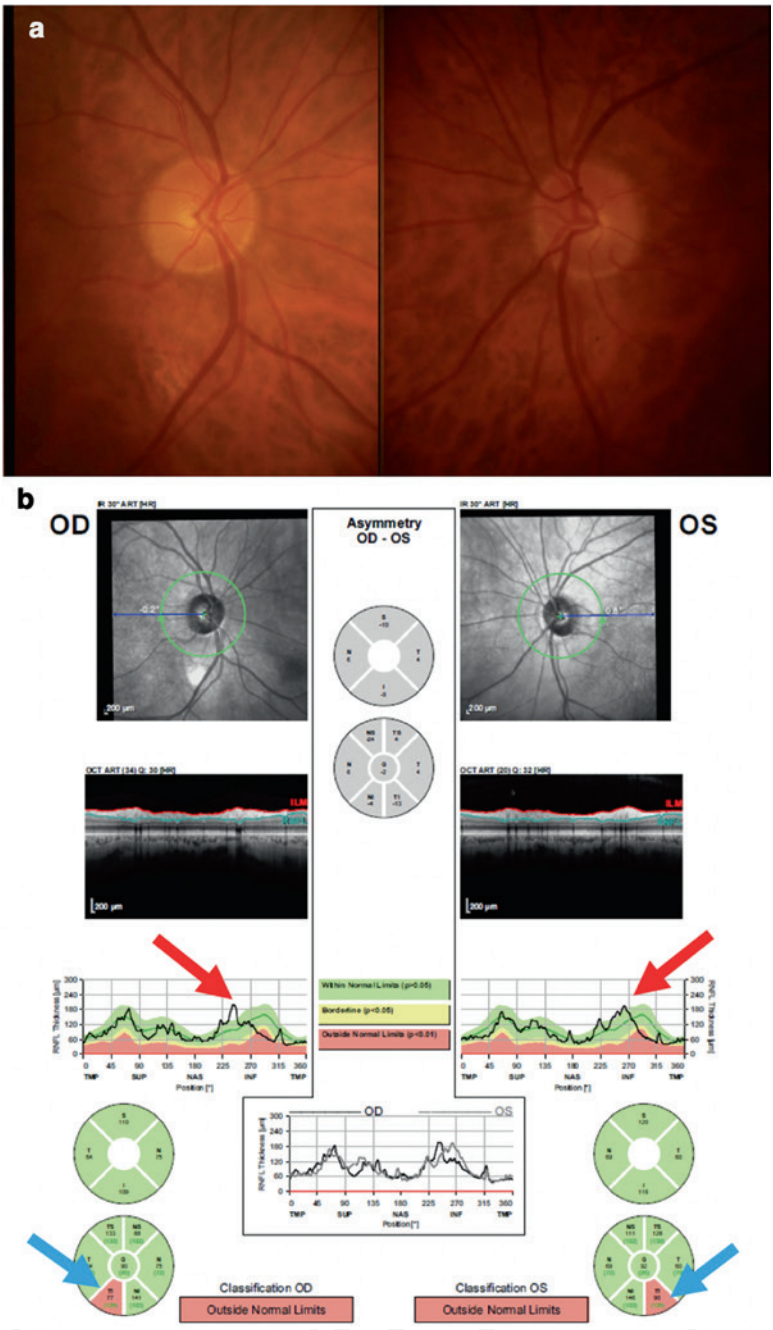


Fig. 4 **a** Optic nerve photos of right and left eyes demonstrating normal rim widths. **b** Contour shift of the RNFL OCT with nasal displacement of the inferotemporal RNFL bundles (red arrows) leading to artifactual inferotemporal thinning (blue arrows)

Case 5-Contour Shift: 'Red Disease' and 'Glaucoma'

A 67-year old female presented with suspicious optic nerve head excavation but a normal IOP of 18 mmHg right eye and 21 mmHg in the left eye. Gonioscopy showed open angles in both eyes. She is myopic −4.0 Diopter in both eyes. Central corneal thickness was 519 μm in the right eye and 521 μm in the left eye. On funduscopy, the right optic nerve was tilted. The vertical cup to disc ratio was borderline OU. RNFL OCT showed thinning of the inferior and superior quadrants. However, the peak of the RNFL was displaced temporally on TSNIT plot. Although the 'red disease' might be due to this displacement in the right eye, a decrease in the thickness of superior peak can be observed in left eye. This demonstrates that the wedge defect in the superior quadrant of the left eye is due to the glaucomatous process. This is confirmed by normal 24-2 visual field in right eye and inferior nasal step in the left eye (Fig. 4b). Prostaglandin analogue was prescribed for her left eye (Fig. 5a–c).

Case 6-High Myopia

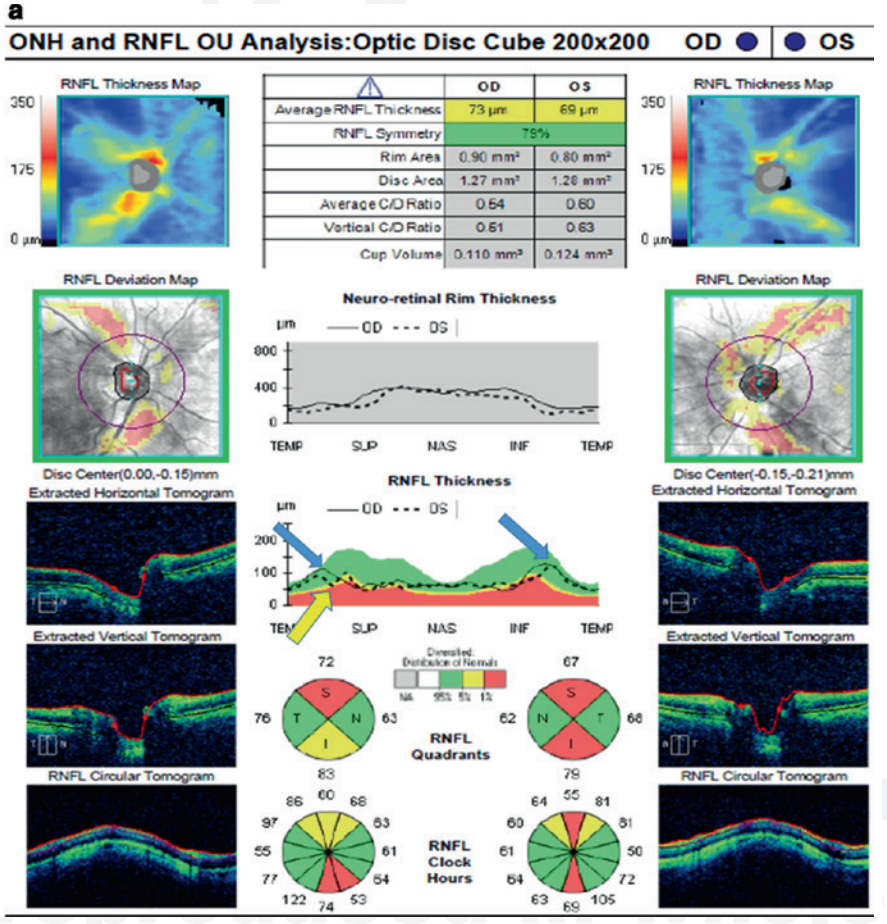
A 66-year-old man is referred to the glaucoma clinic because of suspicious OCT printout. IOP is 17 mmHg OU. The optic nerve head is tilted without excavation OU. Previous visual field from 7 years prior shows a nonprogressive inferior arcuate defect in the right eye and a fairly normal visual in field left eye. RNFL OCT (Fig. 6a) demonstrates a different artifact like segmentation errors, and low signal strength. Nero-retinal TSNIT plots are normal as is the clinical rims. The patient is diagnosed as high myopic healthy subject. Stable scotoma has been reported in high myopic healthy eyes in Chinese population. Although macula scans are more helpful than RNFL thickness in high myopic patients, the patient shows diffuse GCIPL thinning in the GCIPL OU report (Fig. 6b). No raphe sign was observed. Diffuse GCIPL thinning can be seen in high myopic healthy eyes.

Case 7-Peripapillary Atrophy (PPA)

PPA is choroiretinal thinning and interruption of RPE in the peripapillary area and can interfere with proper segmentation of the RNFL. Below is an OCT scan of a 37-year-old woman with pathologic myopia: −21.00 diopter OD and −19.00 diopter OS. She had tilted discs, peripapillary atrophy, and staphylomas OU (Fig. 7).

FoDi Misalignment

On average, the fovea is located 7° below the level of the center of the ONH, but the angle can vary from 6° above to 29° below [3]. If these variations in fovea to disc (FoDI) axis are not taken into account, it may lead to artificially large



	OD	OS
Average RNFL Thickness	73 µm	69 µm
RNFL Symmetry	78%	
Rim Area	0.90 mm²	0.80 mm²
Disc Area	1.27 mm²	1.26 mm²
Average C/D Ratio	0.54	0.60
Vertical C/D Ratio	0.61	0.63
Cup Volume	0.110 mm³	0.124 mm³

Fig. 5 **a** Cirrus SD-OCT RNFL and ONH report. The OCT image shows thinning of the inferior and superior quadrants. However, the peak of the RNFL is displaced to the temporal on TSNIT plot (blue arrows). Although the 'red disease' might be due to this displacement in the right eye, a decrease in thickness of superior peak can be observed in left eye (yellow arrow), suggesting glaucomatous damage in the left eye. **b** GCIPL OU analysis-Ganglion Cell Analysis of the patient Cirrus HD-OCT Macula GCL + IPL analysis shows the thinned area in the inferotemporal and inferior sectors in the left eye (blue arrow) with the typical Raphe sign in the thickness map (red arrow). **c** Visual field is normal in right eye and shows inferior nasal step in the left eye, corresponding to superior thinning of RNFL in right eye

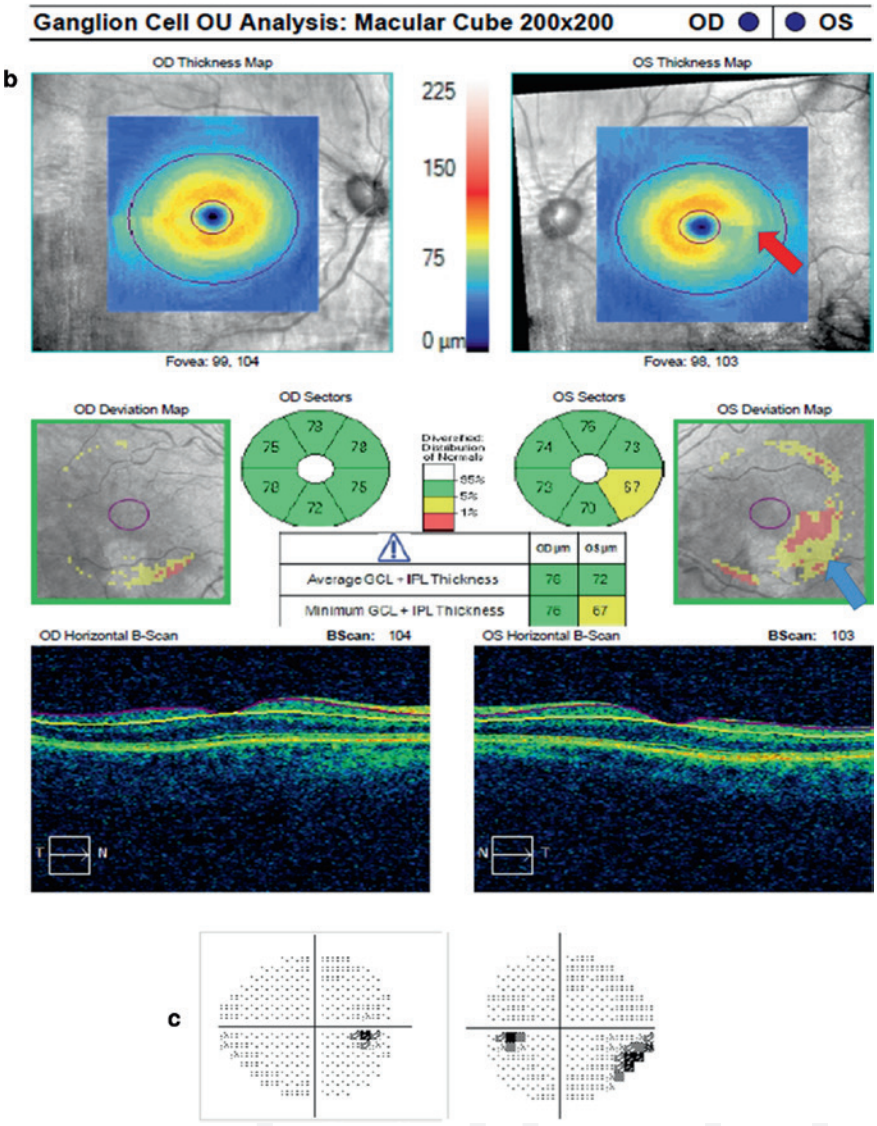


Fig. 5 (continued)

inter-individual differences in sectoral measurements, reducing the diagnostic precision of the device. Spectralis scan is automatically aligned with the FoDi axis. However, if FoDi is displaced from its true anatomical position, there would be a shift in the orientation of classification sectors relative to the normative database.

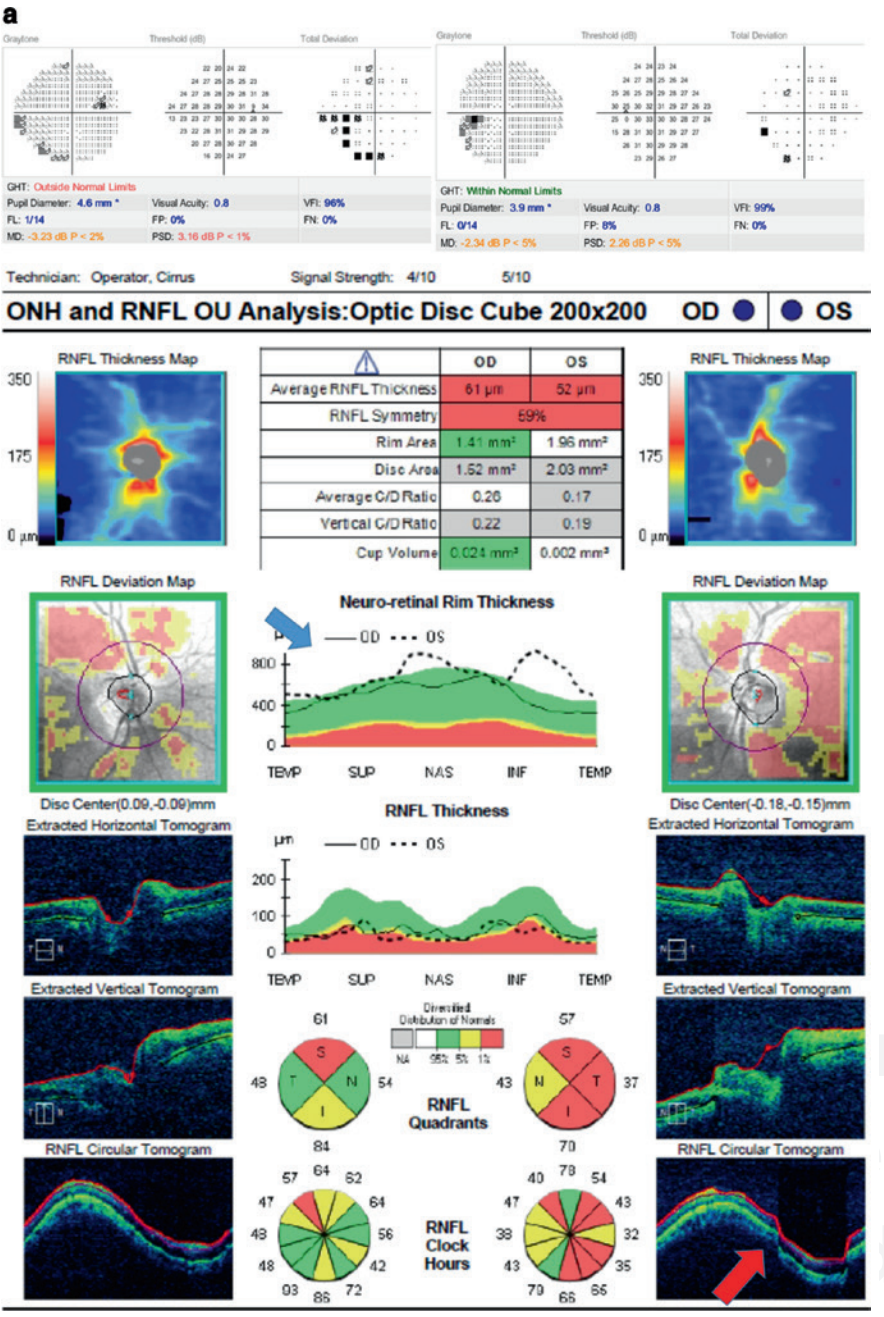


Fig. 6 **a** Cirrus SD-OCT RNFL and ONH report. Although this OCT report shows extensive RNFL defects OU on thickness map and pie charts, the signal strength is less than 6 OU, and segmentation errors can be seen on tomograms (red arrow). Rim thickness is normal throughout the plot (blue arrow). Note that, the validity of BMO in OCT images on high myopic eyes should be carefully investigated. **b** GCIPL OU analysis-The OCT image demonstrates diffuse GCIPL thinning in both eyes. No raphe sign was observed

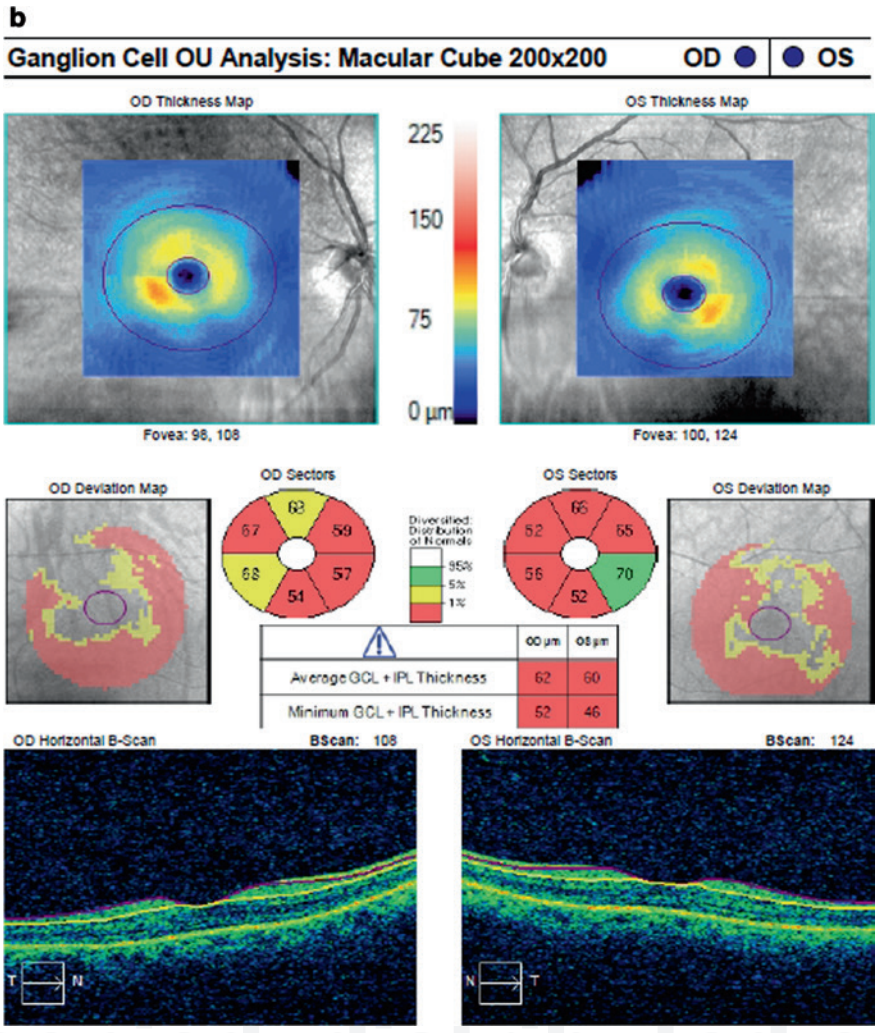


Fig. 6 (continued)

Case 8-'Red Disease' Due to FoDi Misalignment

OCT scan of a 52-year-old woman with diagnosis of primary angle closure glaucoma (Fig. 8a, b). Laser peripheral iridotomy was performed. IOP was 20 mmHg OD with latanoprost and 18 mmHg OS with latanoprost and dorzolamide-timolol. The C/D ratio was 0.4 OD and 0.85 OS. Spectralis OCT shows a displaced FoDi axis in the right eye. If FoDi is displaced from its true anatomical position there is a shift in orientation of the classification sectors relative to the normative database. After correction of FoDi alignment the sectoral thickness was classified as "within normal limits."

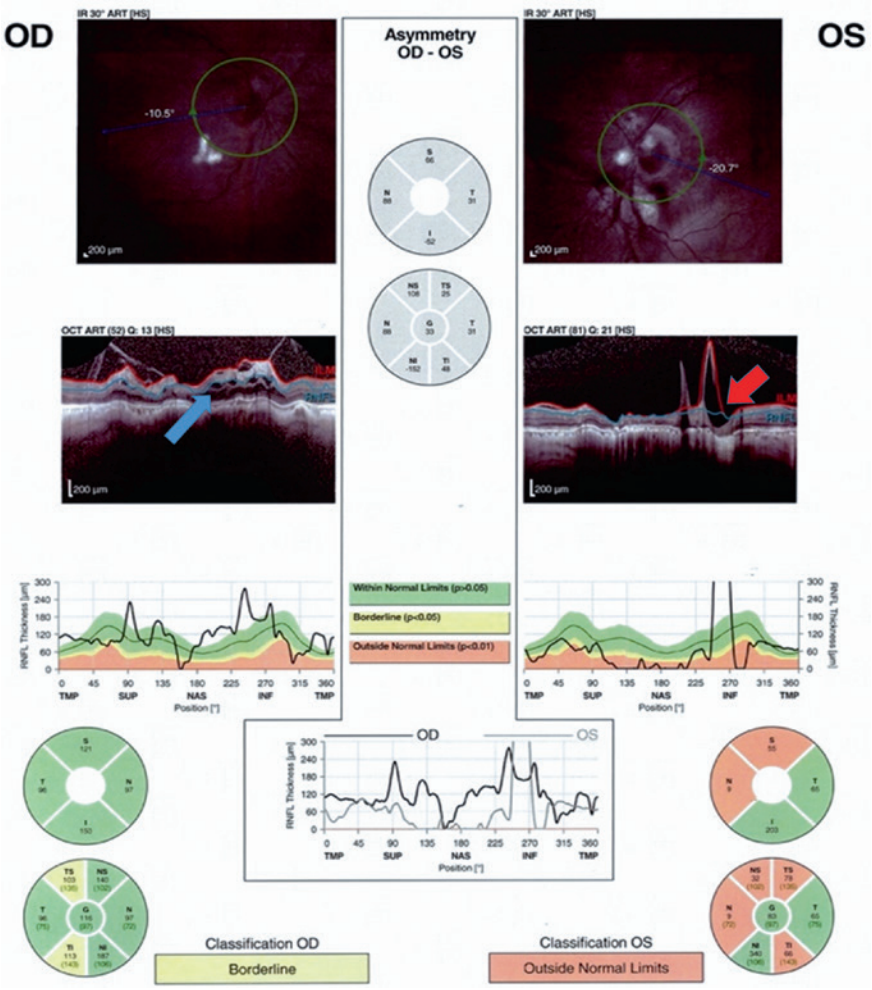


Fig. 7 SpectralisRNFL OU report. The scan quality of the right eye is low. Myopia and high axial length could be associated with low scan quality, as in the right eye of this patient. In her left eye, there are segmentation errors due to areas of peripapillary atrophy and vitreoretinal tractional band (red arrow). Multiple schisis cavities can also be found in the peripapillary area in RNFL Circular Tomogram of right eye (blue arrow)

Case 9-'Red Disease' Due to FoDi Misalignment

Another case of "Red Disease" due to the misalignment of the Fodi axis. The patient is healthy with an IOP of 16 mmHg and normal visual field. The average RNFL is 94 µm. Note that after the correction of the FoDi axis, the average thickness does not change. However, the RNFL profile shifts to the right, and the sectoral thickness are now green (Fig. 9).

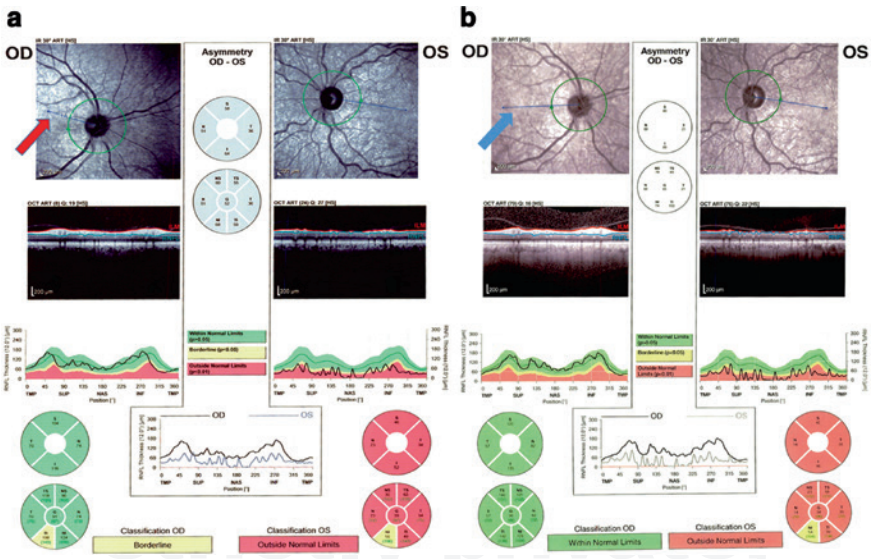


Fig. 8 **a** SpectralisRNFL OU report. As the left eye has advanced glaucoma, the RNFL became thin. But the reason of decreased RNFL thickness of nasal quadrant is posterior segmentation error. On the right eye, there is no segmentation error. But, the fovea is improperly positioned which result in alignment error. Spectralis scan is automatically aligned the FoDi axis (red arrow). If FoDi is displaced from its true anatomical position, there would be a shift in orientation of classification sectors relative to the normative database. The true anatomical position of the fovea of this patient is lower than selected location in the this OCT. Although the average global thickness is within normal limits and the temporal-inferior thickness appeared thinner than normative database. **b** The scan of the same patient. The alignment of FoDi is corrected (blue arrow) and the sectoral thickness is within normal limits

Case 10-'Red Disease' and Vitreous Floater

Vitreous opacities can cause red disease artifacts in the deviation map. However, when they are not overlying the calculation circle, the tabular data can be reliable and used cautiously (Fig. 10a, b).

Segmentation Artifacts

Anterior and Posterior RNFL Misidentification

Estimation of the RNFL thickness relies on the ability of OCT to distinguish the RNFL from the other retinal layers, a process known as segmentation. Several mechanisms may be responsible for inaccurate RNFL segmentation, such as OCT signal attenuation with decreased reflectance of the RNFL induced by ocular media opacities, shadowing of superficial retinal vessels, motion artifacts, or

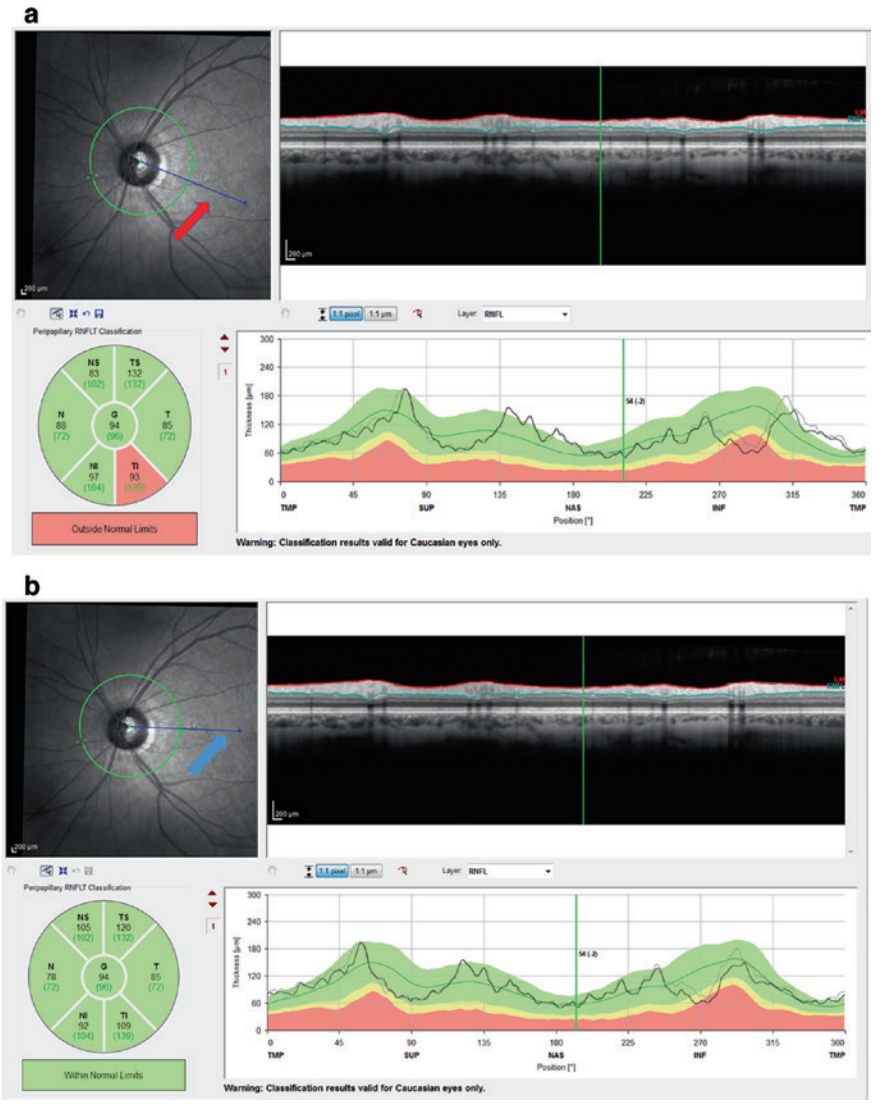


Fig. 9 SpectralisRNFL OU report with misalignment of FoDi (red arroew) and after correction of FoDi axis (blue arrow). The abnormal sector in the upper image is due to shift in the RNFL profile (**a**), which improves after the correction of FoDi axis (**b**)

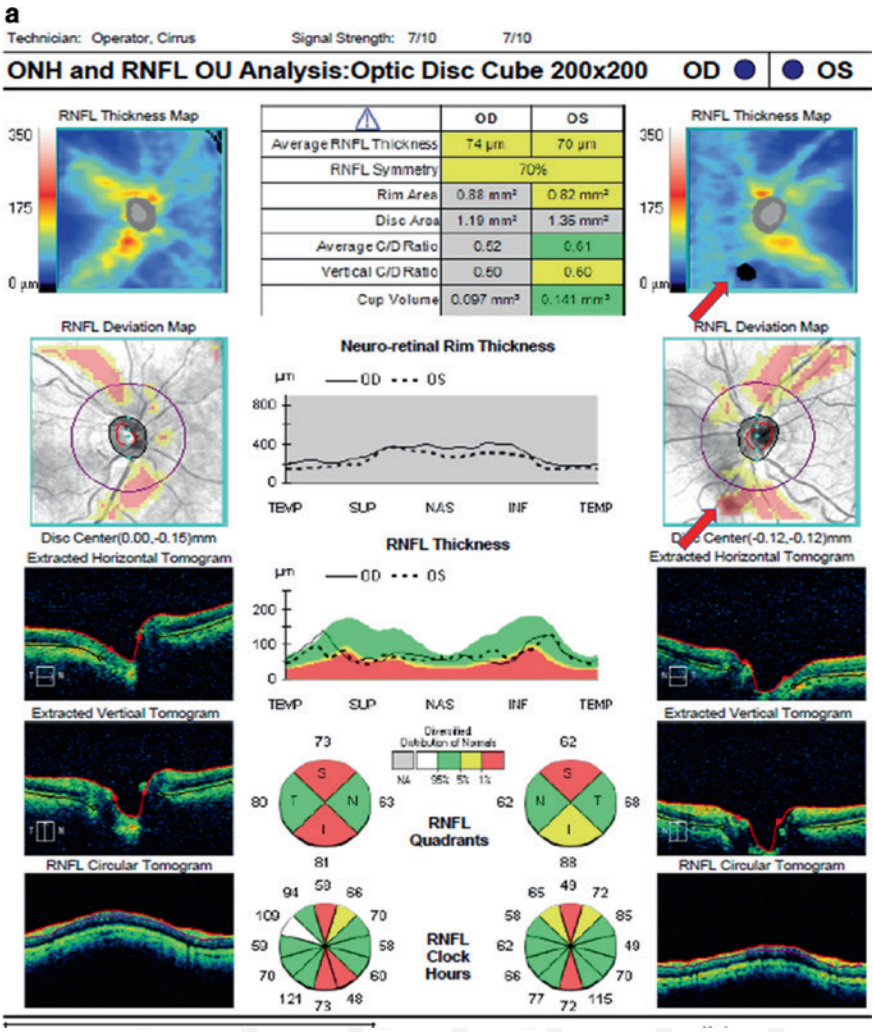


Fig. 10 **a** Cirrus SD-OCT RNFL and ONH report of a patient with glaucoma. The vitreous opacity is present in the scan in the left eye, and blocks an area close to the calculation circle (black area in the thickness map of the left eye). However, its position during the scan does not coincide with the calculation circle and does not affect the pie charts (red arrow). **b** Cirrus SD-OCT RNFL and ONH report of the same patient 3 years later. The vitreous opacity is in the periphery of the cube scan in the left eye (red arrow). The average RNFL thickness is approximately the same as the scan before

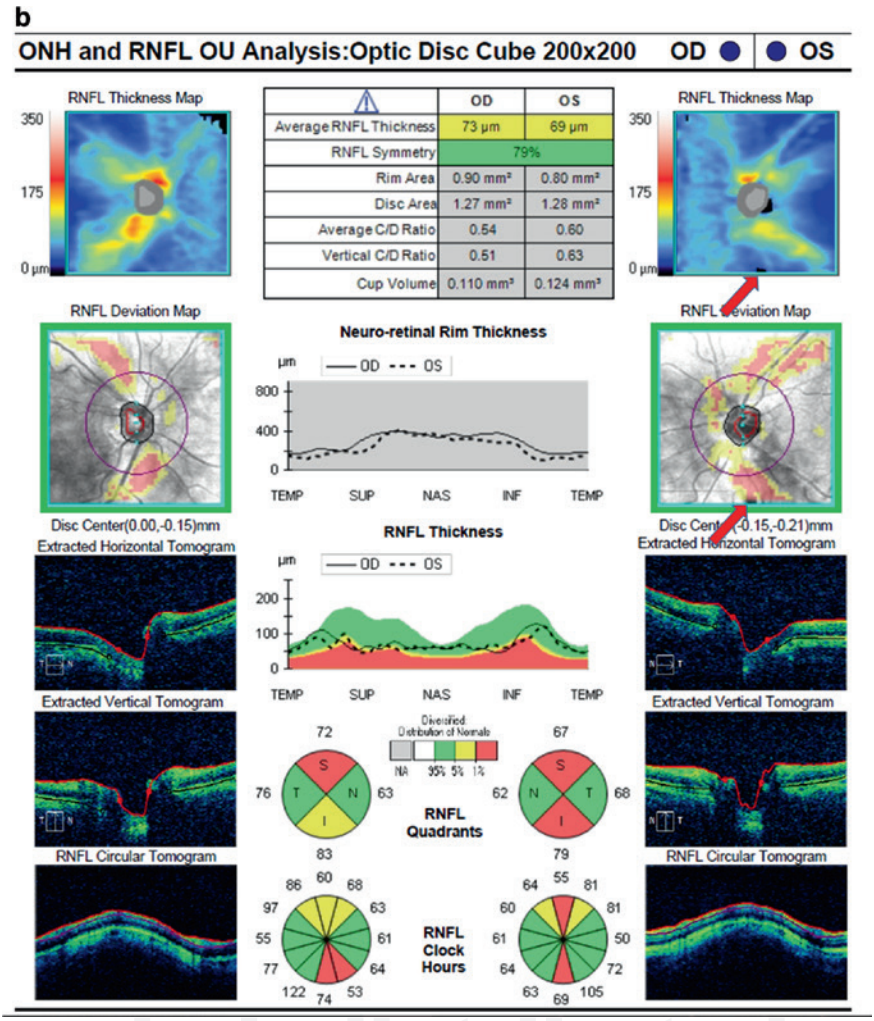


Fig. 10 (continued)

vitreoretinal interface problems. The posterior border of RNFL could not be segmented accurately in the areas of posterior shadowing. The segmentation error from poor scans or vitreoretinal interface problems may lead to an erroneous conclusion of RNFL thinning or thickening.

Case 11-'Green Disease' Due to Segmentation Artifact

OCT scan of a 62-year-old woman with diagnosis of ocular hypertension. The IOP was 28 mmHg OD and 26 mmHg OS, without any medication. Her BCVA was 20/20 OU (Fig. 11).

Case 12-'Green Disease' Due to Vitreoretinal Interface Problem

OCT scan of a 47-year-old woman who was referred to the clinic with primary open angle glaucoma. The measured IOP was 35 mmHg OD and 40 mmHg OS

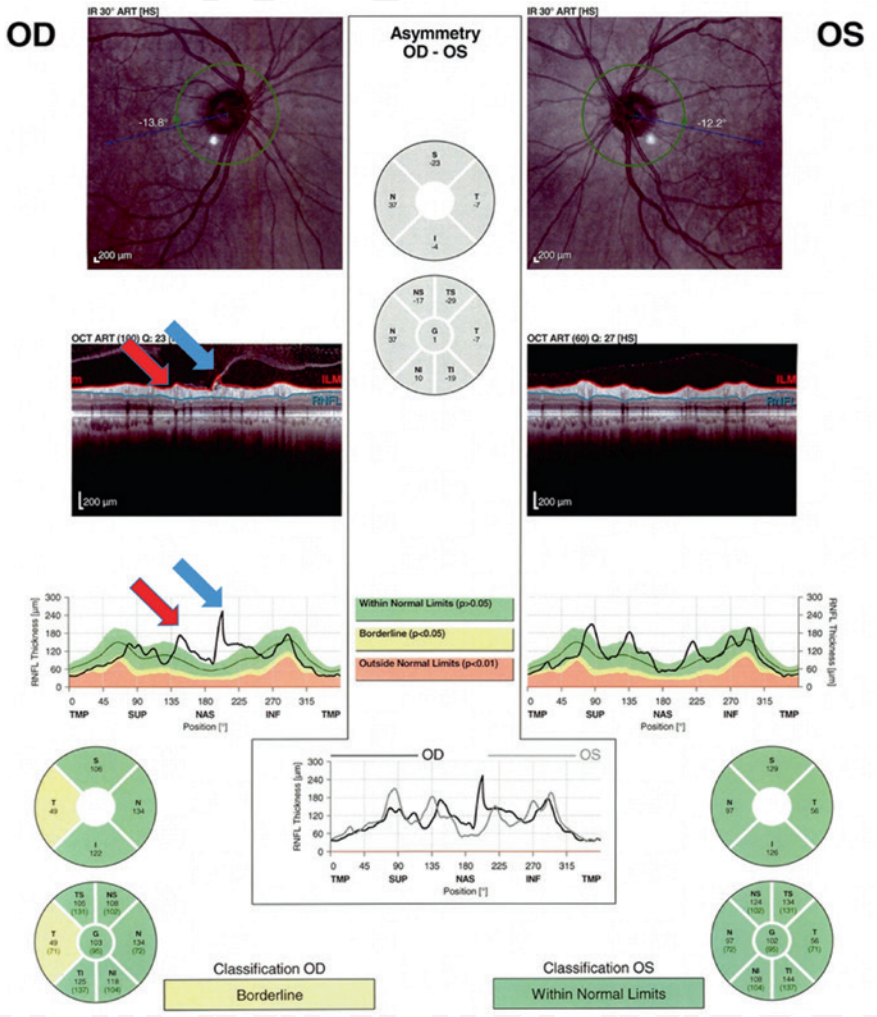


Fig. 11 Spectralis RNFL OU report. Global RNFL thickness is within normal in both eyes. Vitreoretinal traction is clearly visible on peripapillary raw image of the right eye. It causes RNFL thickness peaks in nasal quadrant (at 145°) (red arrow). It also causes misidentification of anterior RNFL in nearly 200° (blue arrow). The traction band is erroneously segmented as the anterior border of RNFL and causes an artifactual RNFL thickness peak in that zone

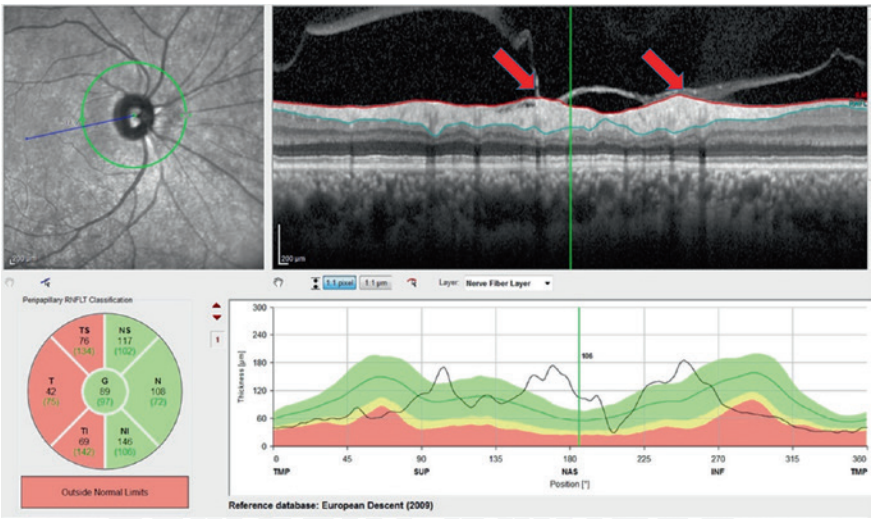


Fig. 12 Spectralis OCT scan. Vitreoretinal traction is visible on the peripapillary raw image of the right eye. The RNFL thickness peaks at the areas of the traction: supranasal, nasal and inferonasal segments

without any medication. On the Humphrey visual field test, MD was −8.20 DB and −17.34 DB for OD and OS, respectively (Fig. 12).

Case 13-'Green Disease' Due to Vitreoretinal Interface Problems

Another case of vitreoretinal interface problems in a 65-year glaucoma patient with a recent reduced vision in right eye. The patient has been on glaucoma medication because of presenting IOP of 25 mmHg and glaucomatous visual field defect since 5 years ago. An extensive epiretinal membrane can be seen in infrared image (Fig. ac). The RNFL Exam Report and The Posterior Pole Asymmetry Analysis Report shows area of thickness in peripapillary area and macula. The presence of an ERM can also cause the RNFL to falsely measure thicker than it actually is on OCT analysis. This is an example of 'Green Disease'.

Case 14-'Green Disease' Due to Narrow RNFL Defect

A very narrow RNFL defect might not be classified as 'outside normal limit' in pie charts and is an example of false negative for color-coded charts.

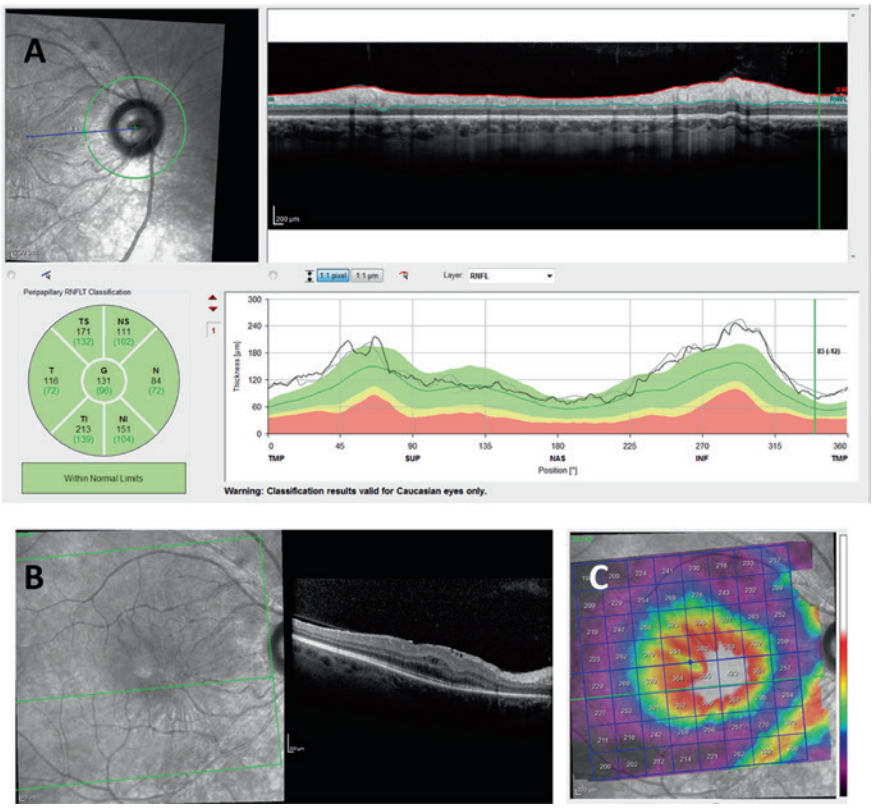


Fig. 13 **a** Spectralis RNFL circle scan demonstrates thickening of RNFL in RNFL Profile. Pie charts are all green with the thickness values higher than expected of healthy eyes. **b** An extensive epiretinal membrane can be seen in infrared image. **c** Posterior pole map shows that the epiretinal membrane in the macula of the right eye has caused macula thickening

A 63-year old monoocular female presented as a glaucoma suspect with IOP 20 mmHg in right eye. On fundus exam, there was rim thinning in both the superior pole and inferior pole. In addition, a narrow inferotemporal RNFL defect can be seen. Visual field is normal.

The Spectralis OCT images were misclassified as normal using the mean RNFL thickness values and in the Pie charts. Careful examination of RNFL Profile shows very narrow thinning corresponded to the location of the RNFL defect in optic disc photo. Interestingly, in The Minimum Rim Width Analysis Report abnormal inferotemporal thinning can be detected in the pie chart. The patient received antiglaucoma medication. In the follow-up of the patient the following year, although visual field was still normal, the RNFL defect is wider in OCT RNFL Profile and is reflected in pie chart as yellow color in the inferior quadrant (Fig. 14a–d).

Case 15-'Red Disease' Due to Retinal Disease

A 63-year-old man with suspicion for glaucomatous optic nerve damage was referred to the clinic. The measured IOP was 19 mmHg OD and 20 mmHg OS. The cup to disc ratio was 0.5 OD and 0.7 OS. Humphrey visual field testing showed a superior arcuate scotoma in both eyes. Careful examination of the retina shows diffuse chorioretinal atrophy along the inferior vascular arcade. Multifocal ERG revealed the diagnosis as sectoral retinitis pigmentosa. This is a red disease: decreased RNFL thickness is secondary to causes other than glaucoma (Fig. 15a–c).

Artifact in Progression Analysis

Scanning artifacts or development of new ocular pathology can cause errors in the glaucoma progression report. Before reaching a conclusion, the physician must carefully evaluate all parts of the report to identify artifacts that can influence the progression results. The RNFL Circular Tomogram, TSNIT plots, and other values must be checked for artifacts and pathologies that can influence the results.

Case 16-Development of Pathology

A glaucoma suspect patient who was following in the glaucoma clinic brings us his recent progression analysis. In 2017 he had a sudden increase in RNFL thickness which can be seen in the RNFL Trend report (Fig. 16a). Careful look at his scans showed development of pathology in the outer retinal layer thought to be peripapillary choroidal neovascularization (Fig. 16c).

Case 17-Alternating Devices and Progression

A 78-year-old male glaucoma patient was referred to the clinic due to the worsening of glaucoma. Although the visual field did not show any change since 2

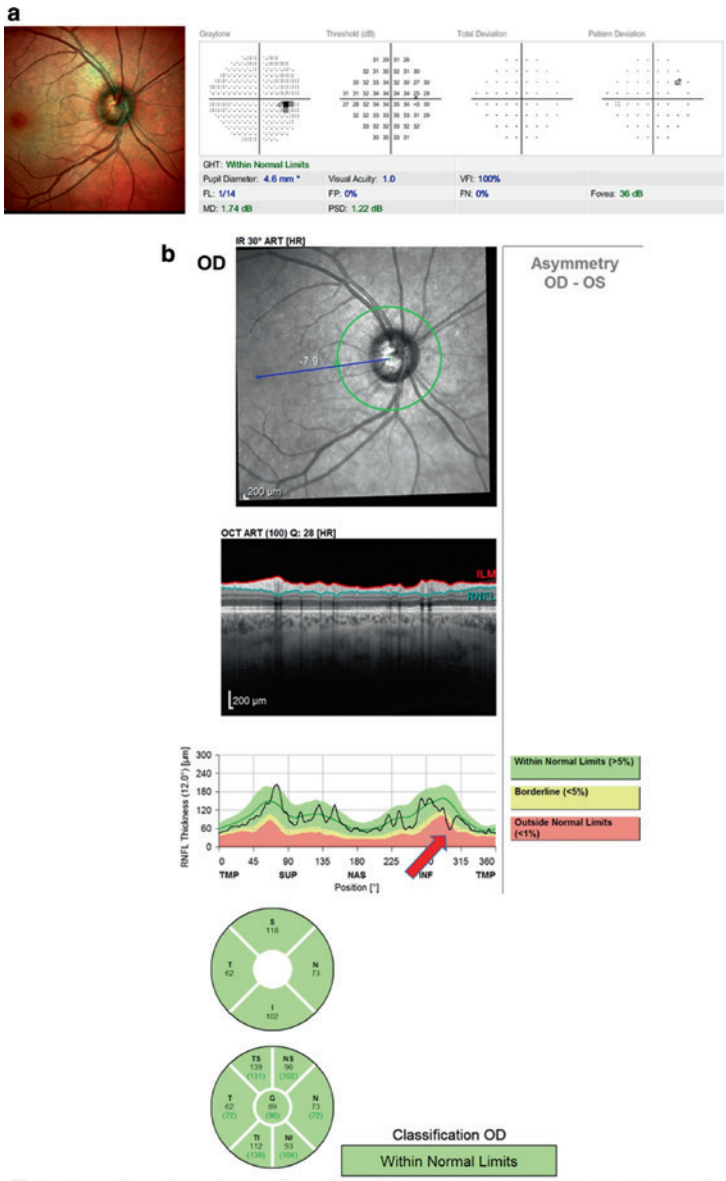


Fig. 14 **a** Narrow RNFL defect is obvious in the inferotemporal region. However the visual field is normal. **b** Spectralis RNFL Single report shows normal mean RNFL thickness values and normal sectoral value. Examination of the RNFL Profile shows very narrow thinning of RNFL corresponded to the location of RNFL defect in optic disc photo. **c** *The Minimum Rim Width Analysis Report shows* diffuse glaucomatous rim thinning in the right eye which is more pronounced in the inferotemporal sector. This eye is classified as outside normal limits. **d** Spectralis RNFL Single Report one year after the last visit. The RNFL defect is wider in OCT RNFL Profile and is reflected in the Pie chart as yellow color in inferior quadrant

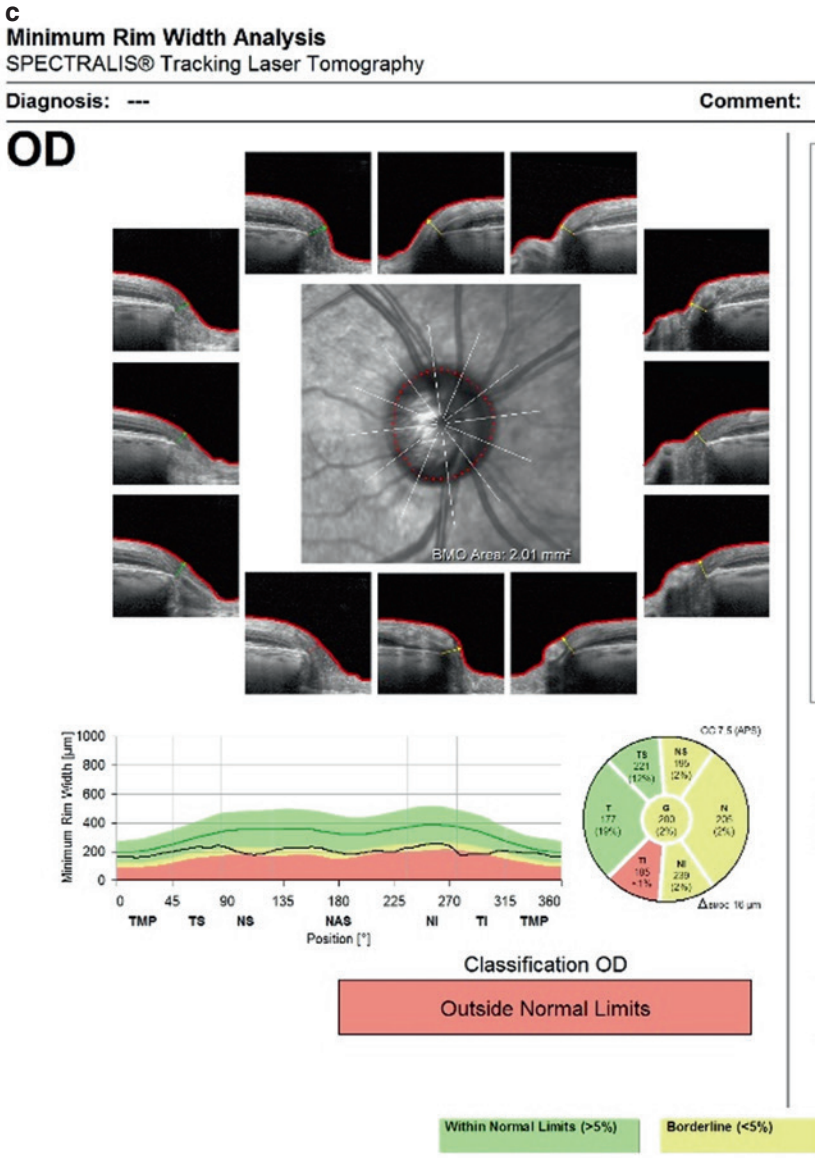


Fig. 14 (continued)

years ago, his Cirrus OCT demonstrates 9 µm thinning in right eye and 8 µm thinning in left eye compared to the OCT from 2 years ago (Fig. 17a, b). However, these OCTs were from different devices. A new OCT with Spectralis

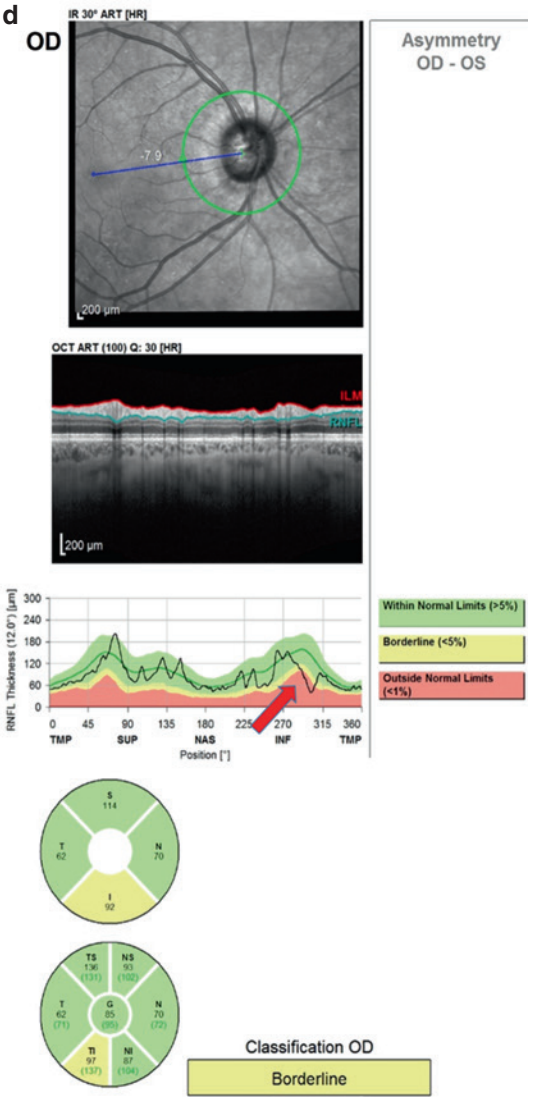


Fig. 14 (continued)

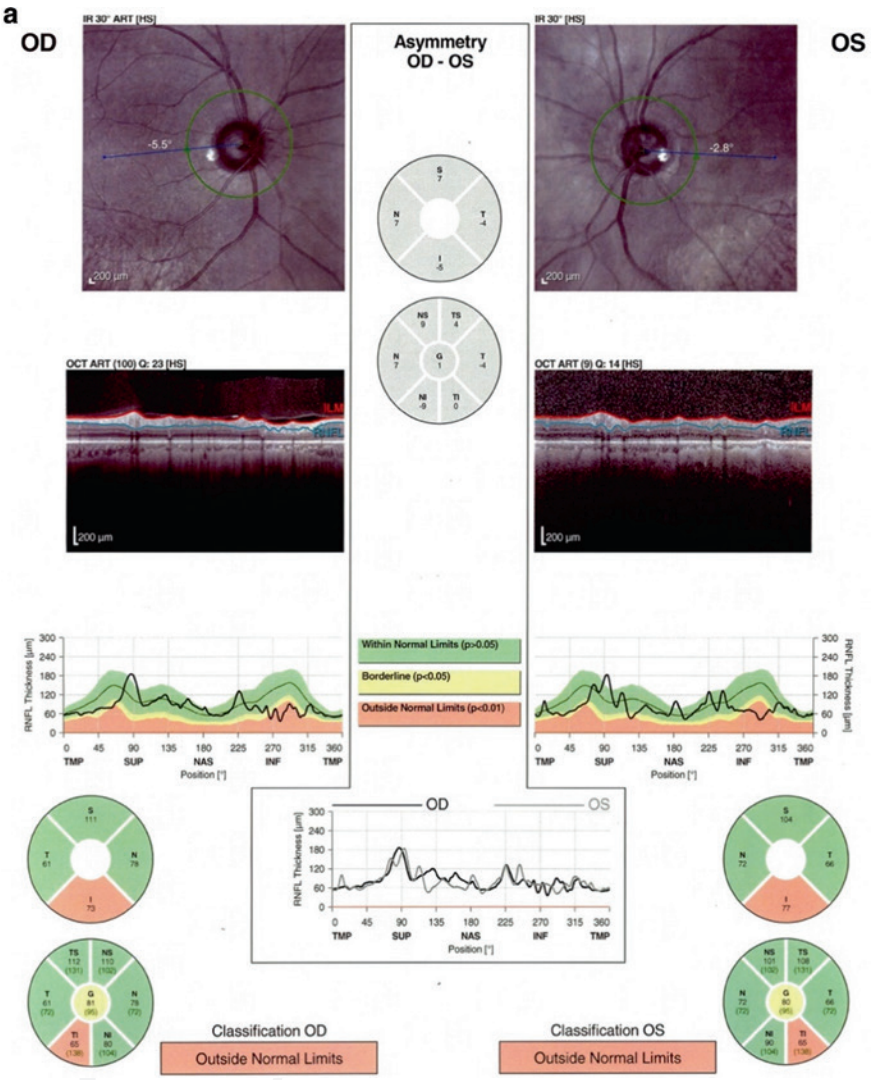


Fig. 15 **a** Spectralis OCT OU report. Global RNFL thickness is borderline. The RNFL thickness in inferior quadrant and inferotemporal segment are 'outside normal limits'. **b** The fundus photograph of the same patient. There is diffuse chorioretinal atrophy along the inferior vascular arcade which explains the RNFL loss on OCT imaging. Diagnosis of sectoral retinitis pigmentosa was made. This is an example of red disease: Decreased RNFL thickness is secondary to causes other than glaucoma. **c** Infrared and fundus *autofluorescence* image of the same patient. Inferotemporal chorioretinal atrophy is visible

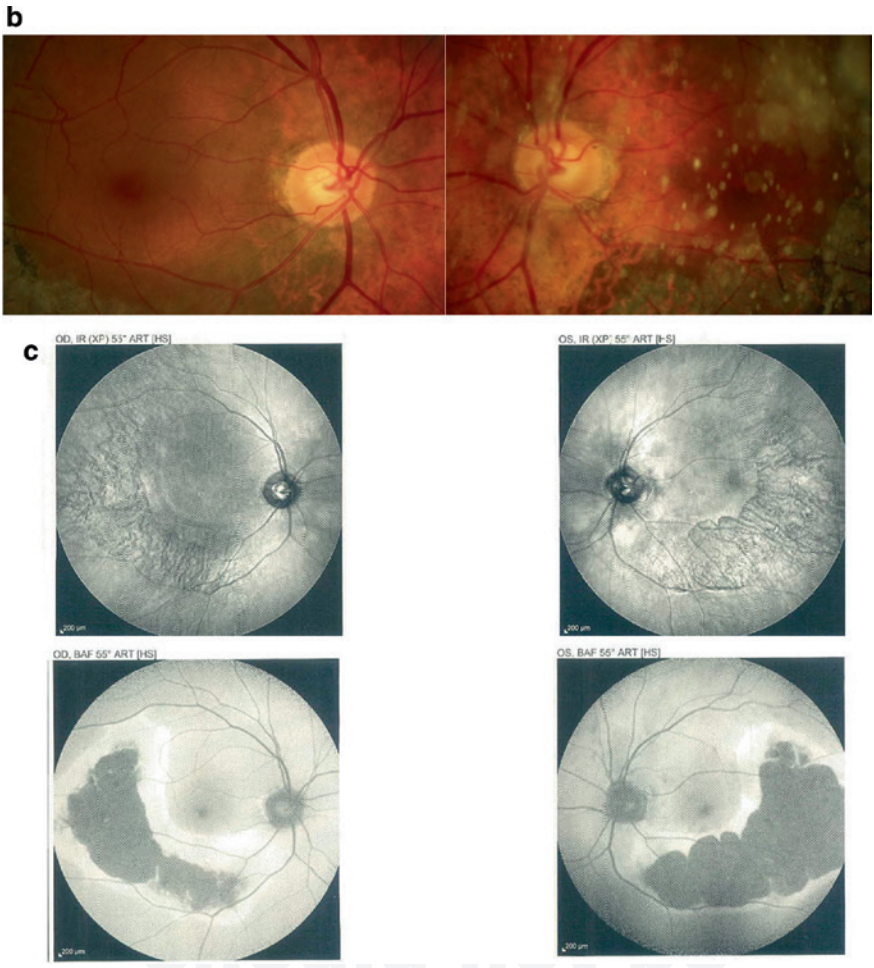


Fig. 15 (continued)

does not show any change from the values of Spectralis OCT 2 years ago. OCT values from different devices are not interchangeable. Cirrus HD-OCT gives lower values compared to Spectralis because the calculation circle in the former is larger than the latter.

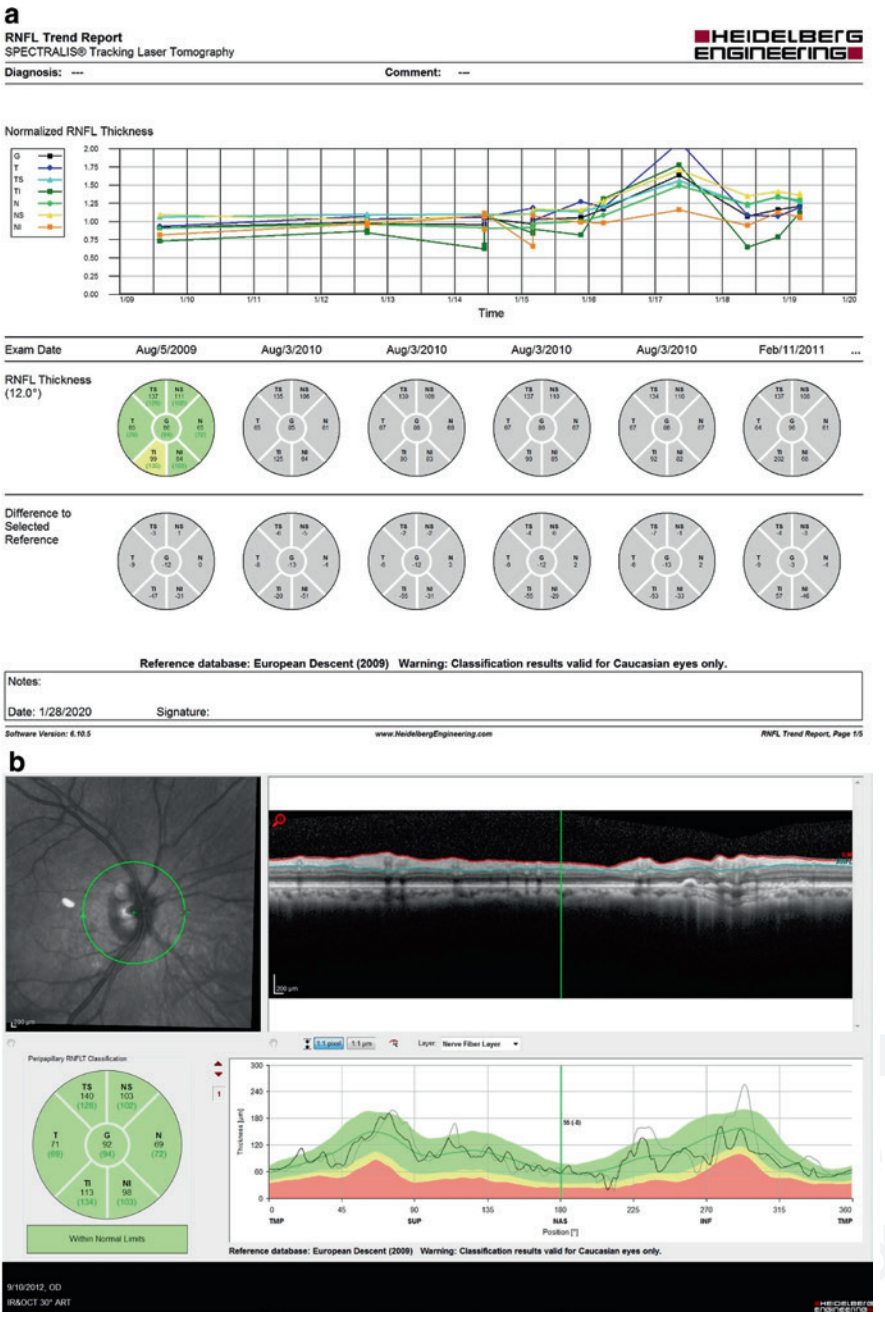


Fig. 16 **a** Spectralis progression Trend Report of the patient followed since 2010 showing an increase in 2016 to 2017 in most sectors. **b** Spectralis Single RNFL report. OCT images in 2012 shows slight blunting of RNFL peak in inferior region. **c** Spectralis Single RNFL report one year later. Right eye shows destruction of RPE and outer retina with area of thickening and edema, most probably due to peripapillary CNV. Segmentation error in the RNFL is also a cause of increase in RNFL thickness in this patient. Average RNFL thickness increase from 92 µm in 2012 (**b**) to 109 µm in 2017 (**c**)

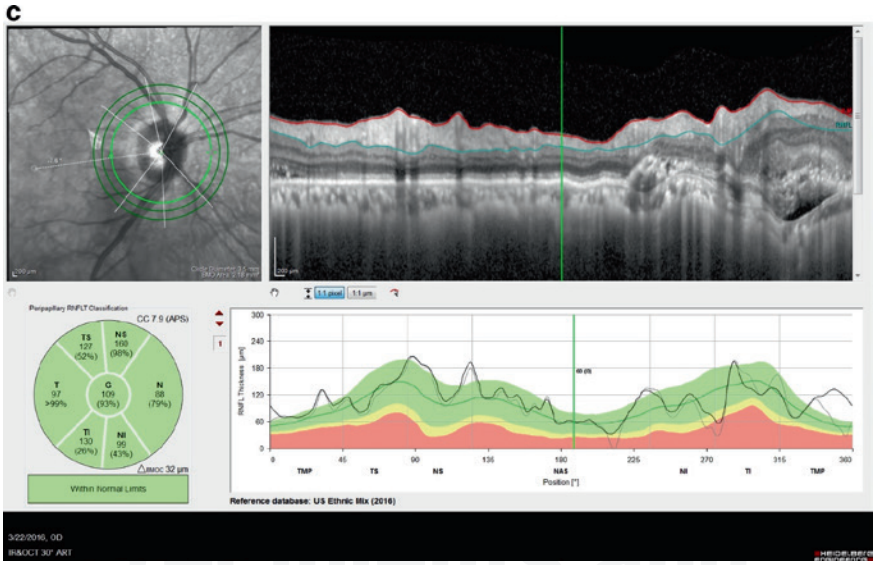


Fig. 16 (continued)

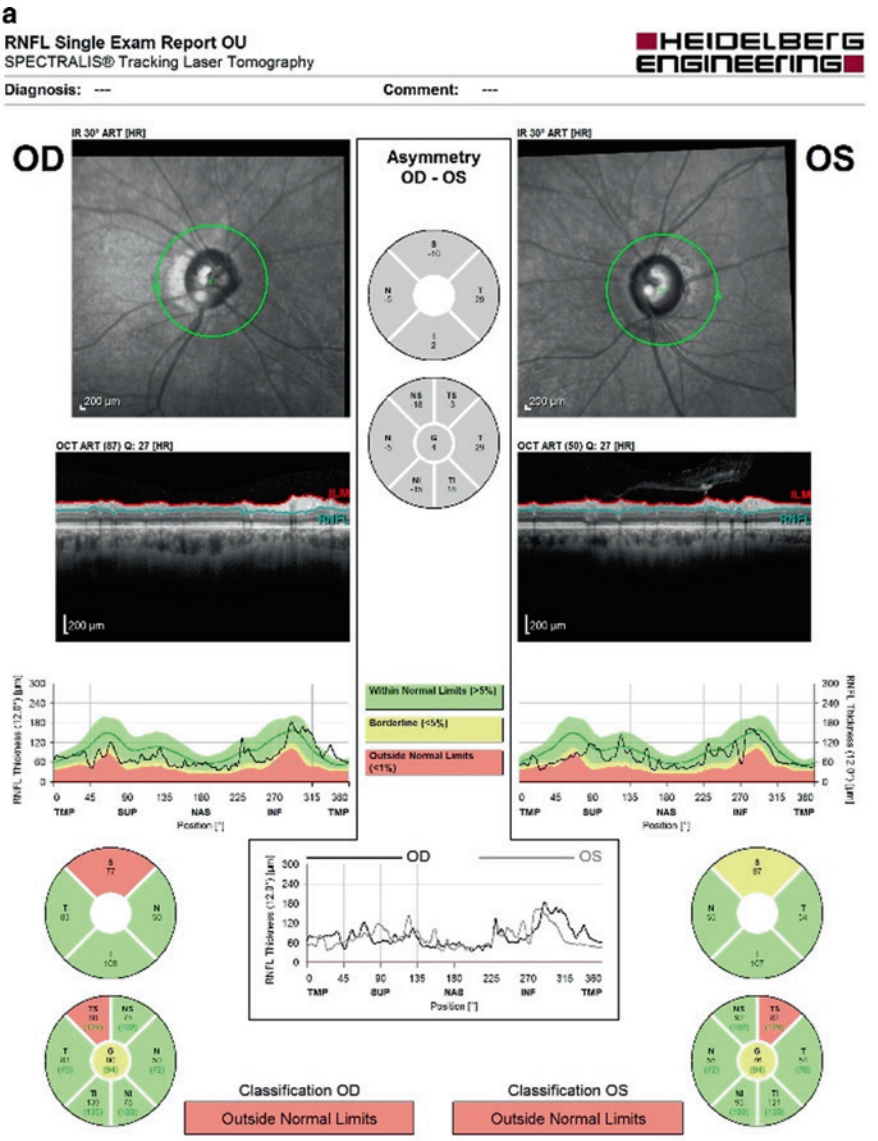


Fig. 17 **a** Previous Spectralis Single RNFL report in 2013 demonstrates supratemporal RNFL thinning and average RNFL thickness of 80 and 76 µm in right eye and left eye, respectively. **b** Cirrus HD-OCT OU report (current) showing superior quadrant wedge defect similar to Spectralis OCT 2 years ago (**a**). However, the average values are 9 µm thinner in right eye and 8 µm thinner in left eye than values. This is not necessarily mean progression as a new Spectralis OCT shows similar values to the Spectralis OCT 2 years ago (**c**). Measurements from different OCT devices are not interchangeable, and the determination of thinning should be assessed by the same device throughout follow-up. **c** Current Spectralis Single RNFL report in 2015 demonstrates supratemporal RNFL thinning and average RNFL thickness of 79 and 75 µm in right eye and left eye, respectively, which are comparable to the values of Spectralis Single RNFL report 2 years ago

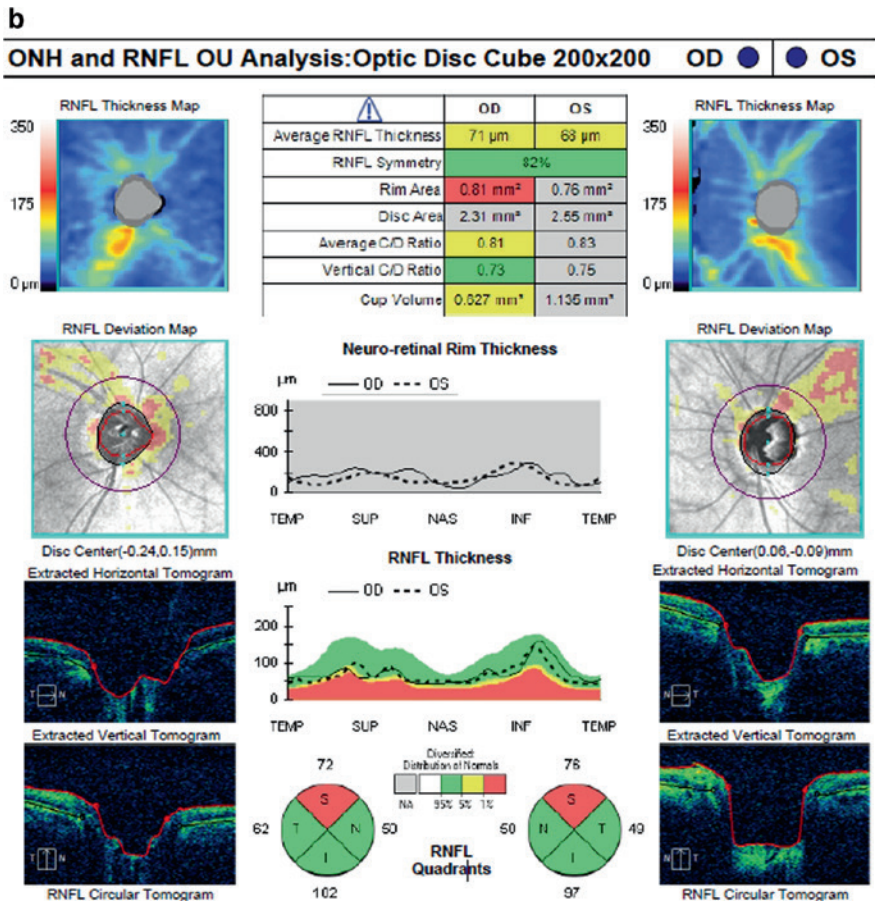


Fig. 17 (continued)

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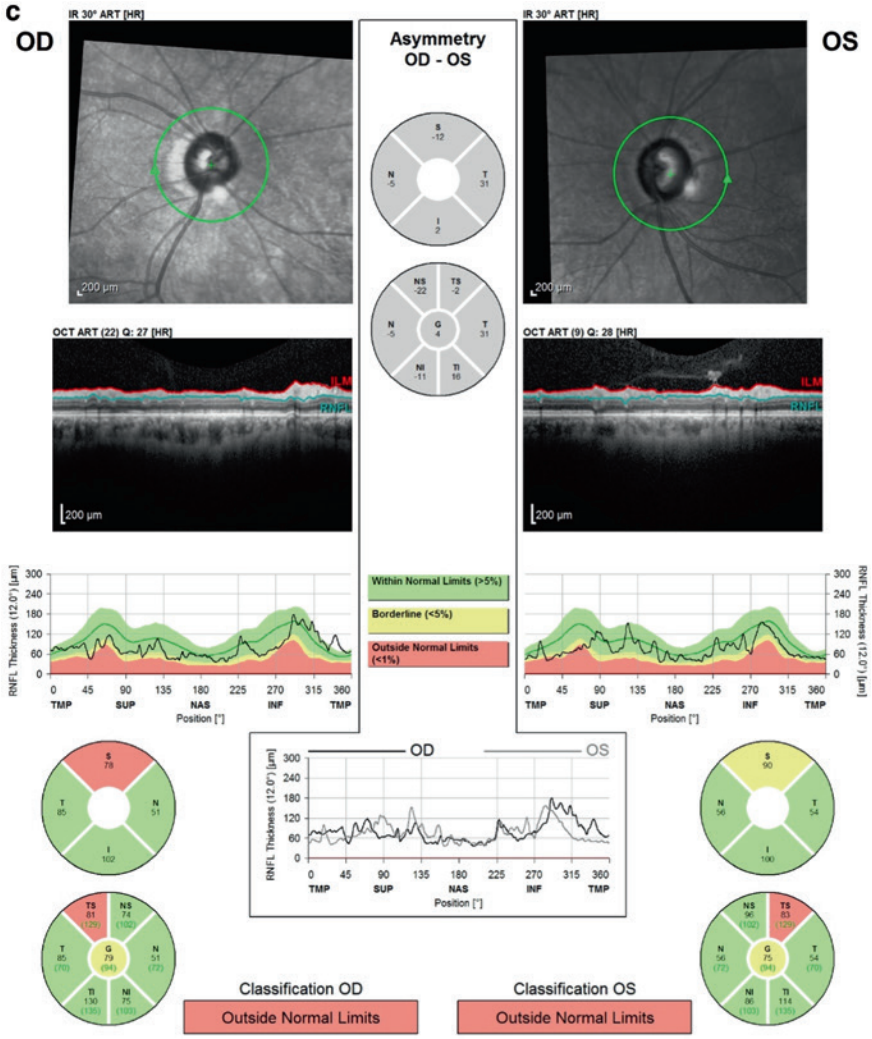

Fig. 17 (continued)

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