Spectral domain-optical coherence tomography to detect localized retinal nerve fiber layer defects in glaucomatous eyes

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Abstract
This study examines the ability of RTVue, Cirrus and Spectralis OCT Spectral domain-optical coherence tomographs (SD-OCT) to detect localized retinal nerve fiber layer defects in glaucomatous eyes. In this observational case series, four glaucoma patients (8 eyes) were selected from the University of California, San Diego Shiley Eye Center and the Diagnostic Innovations in Glaucoma Study (DIGS) based on the presence of documented localized RNFL defects in at least one eye confirmed by masked stereophotograph assessment. One RTVue 3D Disc scan, one RTVue NHM4 scan, one Cirrus Optic Disk Cube 200×200 scan and one Spectralis scan centered on the optic disc (15×15 scan angle, 768 A-scans × 73 B-scans) were obtained on all undilated eyes within a single session. Results were compared with those obtained from stereophotographs. In 6 eyes the presence of localized RNFL defects was detected by stereophotography. In general, by qualitatively evaluating the retinal thickness maps generated, all SD-OCT instruments examined were able to confirm the presence of localized glaucomatous structural damage seen on stereophotographs. This study confirms SD-OCT is a promising technology for glaucoma detection as it may assist clinicians identify the presence of localized glaucomatous structural damage.

1. Introduction
Optical coherence tomography (OCT) is a non-invasive imaging technique that has found extensive application in ophthalmology [1]. OCT technology in glaucoma currently allows in-vivo quantification of retinal nerve fiber layer thickness (RNFL) and optic disc features to help clinicians identify glaucomatous structural damage [2–9]. With the advent of new generation Spectral domain-optical coherence tomography (SD-OCT) capable of providing faster acquisition speed and an increased depth resolution compared to previous technology [10–16], clinicians need now to determine how the new devices can benefit glaucoma diagnosis and management.

RTVue (Optovue Inc, Fremont, CA), Cirrus HD-OCT (Carl Zeiss Meditec, Dublin, CA) and Spectralis OCT (Heidelberg Engineering, Dossenheim, Germany) are 3 of the available commercial instruments that employ SD-OCT technology to obtain cross-sectional and three-dimensional images of the RNFL and the optic disc. These recently introduced devices, because of the high frame transfer rate and fast Fourier transform algorithm, can...
perform up to 27,000 A-scans per second with a depth resolution of approximately 5 microns [10–11].

Studies have shown that RTVue and Cirrus retinal nerve fiber layer (RNFL) thickness measurements are highly reproducible in glaucoma and normal subjects [17,18]. Also, SD-OCT has been shown to document morphologic features of dry age-related macular degeneration including drusen and retinal layer alternations both in the surrounding retinal tissue and in the atrophic area. [19–22]. To our knowledge, no studies have reported the ability of commercially available SD-OCT devices to document glaucomatous RNFL damage in the same glaucoma eyes. Therefore, the purpose of this study is to describe the ability of RTVue, Cirrus and Spectralis OCT instruments to detect the presence of localized retinal nerve fiber layer defects identified by stereophotography in glaucoma patients.

2. Methods

For this observational case series, the selection of patients was made based exclusively on the presence of documented localized RNFL defects in at least one eye confirmed by masked stereophotograph assessment (see below). Results obtained from SD-OCT devices were not a selection criterion. Four patients (8 eyes) were selected from the University of California, San Diego Hamilton Glaucoma Center and the Diagnostic Innovations in Glaucoma Study (DIGS), an ongoing study designed to evaluate optic nerve structure and visual function in glaucoma [23]. All methods were approved by the University of California, San Diego, Institutional Review Board. The study adhered to the Declaration of Helsinki for research involving human subjects.

All participants underwent a complete ophthalmologic examination including assessment of medical and family history, visual acuity testing with refraction, slitlamp biomicroscopy including gonioscopy, intraocular pressure measurement with Goldmann applanation tonometry, and dilated stereoscopic fundus examination. Visual sensitivity was tested using Humphrey Field Analyser (Humphrey-Zeiss Systems, Dublin, CA) 24-2 SITA Standard automated perimetry (SAP) and stereophotographs of the optic disc and parapapillary retina were obtained (TRC-SS, Topcon Instruments Corp. of America, Paramus, NJ). All subjects had good quality stereophotographs of the optic disc and reliable (false positives, fixation losses and false negatives ≤33% with no observable testing artifacts) SAP testing.

Masked stereophotograph assessment was used to determine the location and the extent of localized RNFL defects. Each stereophotograph was graded by two experienced graders using a stereoscopic viewer (Asahi Pentax StereoViewer II; Asahi Optical Co, Tokyo, Japan) and a standard fluorescent light box. First, each stereophotograph was graded as glaucomatous or normal based on the presence or absence of neuroretinal rim thinning, RNFL thinning (focal or diffuse), or excavation and/or undermining of the cup characteristic of glaucoma. Second, the location of the RNFL defects, if present, was noted. A localized RNFL defect was considered as such only when both graders agreed on its presence and exact location by clock hour.

The patients selected for this study had both eyes considered glaucomatous and at least one eye with one or more localized RNFL defects identified by both graders.

2.1 Instrumentation

One RTVue 3D Disc scan, one RTVue NHM4 scan, one Cirrus Optic Disk Cube 200×200 scan and one Spectralis scan centered on the optic disc (15x15 scan angle, 768 A-scans x 73 B-scans) were obtained by an experienced technician on both undilated eyes of all patients within a single session.
2.1.1 RTVue—RTVue (software version 2.0.4.0; Model RT 100) uses a scanning laser diode to emit a scan beam with a wavelength of 840±10 nm to provide images of ocular microstructures.

In this study the 3D Disc and NHM4 RTVue protocols were used. The 3D Disc protocol is a 4 × 4 mm raster scan centered on the optic disc and composed of 101 B-scans each composed of 512 A-scans. The resulting scan provides a three dimensional image of the optic disc and surrounding area. For the current study, the en-face image generated by this scanning protocol was used to draw the contour line describing the disc margin that is required in order to generate optic disc parameters from the NHM4 protocol (below). The contour line was initially drawn on the en-face image by hand. The position of the contour line was then assessed and if necessary corrected by examining the interface between its position and the position of the retinal pigment epithelium (RPE) tips in approximately 8 locations.

The NHM4 protocol is composed of 12 radial scans of 3.4 mm length (452 A-scans each) and 6 concentric ring scans ranging from 2.5 to 4.0 mm diameter (587 or 775 A-scans each) all centered on the optic disc (using the previously drawn contour line to ensure scan registration). This scan configuration provides 9,510 A-scans in 0.39 seconds. Areas between A-scans are interpolated. A polar RNFL thickness map, and various parameters that describe the optic disc are provided. RNFL thickness measurements were obtained for the 3.45 mm radius ring only and measurements were described as average RNFL and RNFL in the inferior, temporal, superior, and nasal quadrants. The RNFL thickness parameters are measured by assessing a total of 2,325 data points between the anterior and posterior RNFL borders. The optic cup is automatically defined by RTVue software as the intersection points of the nerve head inner boundary and a parallel line that is 150 μm above the line connecting each RPE tip.

The RTVue software provides a printout with sections. The top “Nerve Head/RNFL Analysis” section provides a map of rim and RNFL thickness values with red and yellow colors indicating thicker measurements and green and blue colors indicating thinner measurements. In addition, in a circular band framing the thickness map, RNFL thickness values and colored coded comparison to the normative database are displayed for each of 16 sectors of equal size (22.5°), 8 sectors of the superior hemiretina, (clockwise, starting from the temporal sector, Temporal Upper (TU) 1 and 2, Superior Temporal (ST) 2 and 1, Superior Nasal (SN) 1 and 2, Nasal Upper (NU) 2 and 1) and 8 sectors of the inferior hemiretina (clockwise, starting from the nasal sector, Nasal Lower (NL) 1 and 2, Inferior Nasal (IN) 2 and 1, Inferior Temporal (IT) 1 and 2, Temporal Lower (TL) 2 and 1). The middle section contains summary “RNFL Parameters”, “Nerve Head Parameters Volume” and “Nerve Head Parameters OD OS”. The lower section contains the “TSNIT Analysis” and inter-eye “Symmetry Analysis”.

For all 3 measurements, RNFL thickness and nerve head measurements are compared to an age-matched normative database for sectoral and average RNFL thickness. Parameter values that fall within the normal range are labeled as Within Normal (p > 5%, indicated by a green color), while parameter values that fall outside the normal range for the age are automatically flagged as Borderline (p < 5% and ≥1%, indicated by a yellow color) or Outside Normal (p < 1%, indicated by a red color).

For RTVue, criteria for determining scan quality were: signal strength indicator (SSI) ≥30 (out of a maximum of 100 as suggested by the manufacturer), a clear fundus image allowing optic disc and the scan circle visibility prior to and during image acquisition, color saturation even and dense throughout all retinal layers with red color visible in the RPE, and RNFL.
visible with no interruptions and a continuous scan pattern without missing or blank areas (i.e., no algorithm failures). Absence of scan failures or en-face OCT image distortions due to blinking or eye movements was required.

2.1.2 Cirrus HD-OCT—Cirrus (software version 3.0; Carl Zeiss Meditec, Dublin, CA, USA) uses a scanning laser diode to emit a scan beam with a wavelength of 840 nm to provide images of ocular microstructures. The instrument acquires OCT data with better resolution (5 microns compared to approximately 10 microns axial resolution in tissue) and about 70 times faster (27,000 vs 400 A-scans per second) than time domain-OCT technology (Stratus OCT, Carl Zeiss Meditec, Dublin, CA). For Cirrus, the Optic Disk Cube 200×200 protocol was used for acquisition and analysis. This protocol generates a cube of data through a 6 mm square grid by acquiring a series of 200 horizontal scan lines each composed of 200 A-scans. For analysis, Cirrus algorithms identify the center of the optic disc and automatically place a calculation circle of 3.46 mm diameter around it. The anterior and posterior margins of the RNFL are delineated and, after extracting from the data cube 256 A-scan samples along the path of the calculation circle, the system calculates the RNFL thickness at each point on the circle.

Cirrus software provides a printout consisting of 4 sections. The top section “RNFL Thickness Map” displays the RNFL thickness pattern around the disc, with red and yellow colors indicating thicker RNFL measurements and green and blue indicating thinner RNFL measurements. In addition, RNFL thickness measurements are generated for average, quadrant (superior, inferior, nasal and temporal) and by clock hour. RNFL thickness measurements also are compared to an age-matched normative database for sectoral and average RNFL thickness. Parameter values that fall within the normal range are labeled as Within Normal Limits (p > 5%, indicated by a green color), while parameter values that fall outside the normal range for the age are automatically flagged as Borderline (p < 5% and ≥ 1%, indicated by a yellow color) or Outside Normal Limits (p < 1%, indicated by a red color).

The second section, the “RNFL Thickness Deviation” map compares superpixel RNFL thickness measurements to the normal thickness range for each superpixel, overlaid on the OCT fundus image. Yellow and red colors are shown for superpixels whose RNFL thickness values are borderline or fall outside the normative database range for the age, respectively. The printout also includes the “RNFL TSNIT Normative Data” and “Extracted RNFL Tomogram” plot for each eye.

For Cirrus, criteria for determining scan quality were: signal strength ≥6 for Cirrus (out of a maximum of 10 as suggested by the manufacturers), a clear fundus image allowing optic disc and the scan circle visibility prior to and during image acquisition, color saturation even and dense throughout all retinal layers with red color visible in the RPE, and RNFL visible with no interruptions and a continuous scan pattern without missing or blank areas (i.e., no algorithm failures). Absence of scan failures or en-face OCT image distortions due to blinking or eye movements was required.

2.1.3 Spectralis OCT—Spectralis OCT (software version 3.1; Model Spectralis HRA +OCT) is a dual beam SD-OCT and confocal laser scanning ophthalmoscope (CSLO) that uses a scanning laser diode to emit a scan beam with a wavelength of 870 nm and an infrared reference image simultaneously to provide images of ocular microstructures. Spectralis OCT incorporates a real time eye tracking system that couples CSLO and SD-OCT scanners to adjust for eye movements and to ensure that the same location of the retina is scanned over time. This method allows B-scans to be re-sampled to improve the signal to
noise ratio, although re-sampling can considerably increase the time it takes to complete any scanning protocol.

We obtained 15 × 15 degrees scan angle (4.4 × 4.4 mm) images centered on the optic disc, each composed of 768 A-scans × 73 B-scans, with 61 microns distance between B-scans and with each B-scan re-sampled 9 times. This protocol allowed the total acquisition time to last approximately one minute. The result is a data cube whose characteristics are comparable to the RTVue 3D Disc and the Cirrus Optic Disk Cube 200×200. Because at this time, software for RNFL thickness evaluation is not available, for the purpose of this study, we report retinal thickness for the Spectralis. To obtain retinal thickness measurements in the peripapillary region, on the en-face OCT image a circle grid composed of three circles of 1, 2.22 and 3.45 mm diameter were centered on the optic disc by an experienced operator. The circle grid allows calculation of the retinal thickness at each diameter for the superior, inferior, temporal and nasal sectors. A retinal thickness map also is generated with red and yellow colors indicating thicker retinal measurements and green and blue indicating thinner retinal measurements. Because the map is centered on the optic disc, the portion of the map in white should represent the area of the cup (Figure 1–2–3–4D).

All Spectralis OCT scans were obtained by the same operator who ensured that the scan quality, indicated by a horizontal bar turning red in the presence of poor signal strength, was always under acceptable limits during scan acquisition. At the time of imaging, the operator did not verify the absence of scan failures or en-face OCT image distortions due to blinking or eye movements because Spectralis OCT eye tracker can theoretically compensate for blinking or eye movements.

2.2 Data Preparation

Raw voxel measurements of volumetric OCT scans acquired using Cirrus, RTVue and Spectralis were exported using their respective analysis software. Cirrus voxel measurement exports from each scan are stored in a single .IMG file. For RTVue, voxel measurement exports from each scan are stored in a .OCT file and detailed scan information (such as, coordinates of A- and B-scans in the .OCT file, number of A- and B-scans, and resolution along an A-Scan, between A-Scans and between B-Scans) are available in a .txt file. Using the Spectralis software module (ver. 3.2a), voxel measurements from each scan and the scan information required to correctly arrange the voxel measurements as a 3D cube were both exported in a single .vol file. The raw exports from Spectralis and RTVue were read using MATLAB (The Mathworks, Inc., Natick, MI) and generic data files were created for each scan using VTK libraries (The Visualization Toolkit, Kitware Inc., Clifton Park, New York). A VTK wrapper was used to access VTK libraries from the MATLAB environment.

To optimize volumetric visualization in OSA ISP, the floating point type raw measurements from Spectralis and RTVue were normalized to a range of values between 0 and 255 and converted to unsigned char data types. Raw exports from Cirrus are in unsigned char precision and therefore no additional data normalization was applied. Generic binary volumetric data files (.VTI) were created from the normalized volumetric measurements using the \texttt{vtkStructuredPointsWriter} class available in VTK. Volumetric measures from Spectralis were normalized as,

\[
\text{Spectralis normalized voxel (i)} = 255 \cdot \sqrt{\text{voxel (i)}}
\]

and volumetric measures from RTVue were normalized as,
3. Results

Table 1 summarizes the results obtained from RTVue, Cirrus and Spectralis internal analysis methods, including RTVue and Cirrus average RNFL thickness, Spectralis average total retinal thickness at 3.45 mm diameter and sectors within normal limits, borderline or outside normal limits for RTVue and Cirrus for the locations corresponding to the localized RNFL defects identified on stereophotographs. Each case also is discussed below. The SD-OCT sectoral or clock hour RNFL thickness measurement corresponding to the defect location or closest to the defect location was reported for both RTVue and Cirrus.

3.1 Case 1

Case 1 is a 70 year old Hispanic female who was diagnosed with primary open angle glaucoma 15 years earlier and medically treated to lower the intraocular pressure (IOP). On the day of study, best corrected visual acuity (VA) was 20/25 OD, 20/40 OS and IOP was 11 mmHg in both eyes.

Figure 1(A–D) shows the optic disc stereophotographs and visual field results (A) along with RTVue (B), Cirrus SD-OCT (C) and Spectralis (D) results. All tests were performed within a one month period. Based on masked stereophotographs assessment, both eyes were classified as glaucomatous. In addition, both graders agreed on the presence of an inferior notch with a localized RNFL defect at 5–6 clock hours in OS. This RNFL defect was associated with a corresponding repeatable superior visual field defect (Fig. 1(A)). Both RTVue and Cirrus confirmed the presence of the inferior defect in OS, as shown in the RNFL thickness maps and in the corresponding sectors and clock hours outside normal limits (Fig. 1(B) and 1(C)). The ratios between RNFL thickness measurements at these sectors (i.e., IT1 for RTVue and 5 clock hour for Cirrus) and at the corresponding sectors in OS were 0.51 and 0.48 for RTVue and Cirrus, respectively, indicating similar degree of inter-eye asymmetry. In addition, both RTVue and Cirrus also showed the presence of supero-temporal RNFL thinning OS not seen on stereophotographs. The thinning was indicated by the ST2 sector and the superior quadrant outside normal limits on RTVue and Cirrus, respectively. Spectralis total retinal thickness map also showed clear evidence of thinning at 5–6 clock hours in OS with marked inter-eye asymmetry between the maps of the two eyes (Fig. 1(D)). Superior retinal thinning OS was also evident.

3.2 Case 2

Case 2 is a 73 year old white female who had been treated for glaucoma for 20 years. On the day of study, best corrected VA was 20/30 OD, 20/25 OS and IOP was 9 mmHg and 8 mmHg in OD and OS, respectively.

Figure 2(A–D) shows the optic disc stereophotographs and visual field results (A) along with RTVue (B), Cirrus SD-OCT (C) and Spectralis (D) results. As for case 1, all tests were performed within a one month period. Based on masked stereophotographs assessment, both eyes were classified as glaucomatous. Both discs showed an enlarged cup with superior and inferior rim thinning. The presence of several localized RNFL defects (OD at 5, 7 and 11–12 o’clock, and OS at 1–2 and 5–6 o’clock) was also confirmed in both eyes by both graders (Fig. 2(A)). In addition, a localized defect at 10–11 clock hours in OS was noted by the first grader but not confirmed by the second grader. In the right eye, Cirrus and RTVue identified...
the 7 and 11–12 o’clock RNFL as outside normal limits or borderline, but not the 5 o’clock
defect. In the left eye, both Cirrus and RTVue identified the 5–6 o’clock RNFL defect.
Cirrus normative database identified the 1–2 o’clock as borderline, but inspection of
the RNFL thickness deviation map shows a clearly defined wedge-shaped RNFL defect (Fig.
2(B)). This area was found to be within normal limits on the RTVue (Fig. 2(C)). Spectralis
total retinal thickness map showed several areas of thinning in both eyes, in particular
supero and infero-temporal in OD and infero-temporal in OS (Fig. 2(D)). In addition, a
wedge-shaped RNFL defect is visible at 1–2 o’clock OS.

3.3 Case 3

Case 3 is a 68 year old Asian female diagnosed and treated with normal tension glaucoma
associated with a possible component of segmental optic nerve hypoplasia. On the day of
study, best corrected VA was 20/30 OD, 20/25 OS and IOP was 16 mmHg and 13 mmHg in
OD and OS, respectively.

Figure 3(A–D) shows the last available optic disc stereophotographs (2006) and results from
the visual field (A) along with RTVue (B), Cirrus SD-OCT (C) and Spectralis (D) results, all
taken the same day. Optic discs revealed significant cupping with inferior peripapillary
atrophy and no rim visible in the inferior temporal region in both eyes. Based on masked
stereophotographs assessment, both eyes were classified as glaucomatous. In addition, both
graders agreed on the presence of diffuse inferior RNFL loss in both eyes that was
associated with a repeatable bilateral superior hemifield defect (Fig. 3(A)).

Both RTVue and Cirrus were consistent with the presence of inferior RNFL thinning while
the superior RNFL thickness remained within normal limits based on the internal normative
database for each instrument (Fig. 3(B) and 3(C)). The ratios between the inferior and
superior sectoral RNFL thickness were 0.41 and 0.55 in OD and OS, respectively for Cirrus,
while they were 0.67 and 0.77 in OD and OS, respectively for the corresponding regions of
RTVue (ST+SN for the superior sector, IT+IN for the inferior sector), indicating marked
intra-eye asymmetry. Spectralis also identified a similar pattern of inferior tissue loss in both
eyes with relevant intra-eye asymmetry between the superior and inferior hemiretinas, as
shown by the total retinal thickness map (Fig. 3(D)).

3.4 Case 4

Case 4 is a 71 year old white female who was diagnosed with glaucoma approximately 20
years ago and medically treated. On the day of study, best corrected VA was 20/25 OD,
20/25 OS and IOP was 20 mmHg and 23 mmHg in OD and OS, respectively.

Figure 4(A–D) shows the optic disc stereophotographs and results from the visual field (A)
along with RTVue (B), Cirrus SD-OCT (C) and Spectralis (D) results. All tests were
performed within a one year period. Based on masked stereophotographs assessment, both
eyes were classified as glaucomatous. The stereophotographs showed an enlarged cup in
both eyes, with superior rim thinning in OD and no visible RNFL defects. However, OS
showed the presence of an inferior notch with localized RNFL defect at 5–7 clock hours
(Fig. 4(A)).

While RTVue confirmed the presence of a localized RNFL defect in OS with sector IT1
outside normal limits and a borderline ST2 sector with no apparent abnormality detected in
OD (Fig. 4(B)), Cirrus showed both the superior and the inferior sectors in OS to be outside
normal limits with a border-line superior sector in OD also (Fig. 4(C)). The inter-eye
asymmetry calculated as the ratio between the inferior sectoral RNFL thickness in OS and
the inferior sectoral RNFL thickness in OD was 0.66 and 0.54 for RTVue and Cirrus,
respectively.
Spectralis also showed retinal thinning inferiorly OS, and marked inter-eye asymmetry in the total retinal thickness map in the inferior sector (Fig. 4(D)).

4. Discussion

The results from the cases presented above showed that SD-OCT instruments are capable of detecting localized glaucomatous structural damage in agreement with masked stereophotographs assessment, as previously shown for previous OCT devices [24]. For example, RTVue and Cirrus provide RNFL thickness assessment with an internal normative database. Spectralis currently lacks software for RNFL thickness measurement and comparison to normative database, but includes a real-time eye tracking system that adjusts for eye movements. Software is improving rapidly so that current differences with respect to each instrument's automated analyses and the availability of normative databases may not be relevant in the very near future.

Although each instrument is based on SD-OCT technology, RTVue, Cirrus and Spectralis utilize largely different acquisition modalities, detection algorithms and analysis software. However, when the RNFL and retinal thickness maps of the three instruments were qualitatively compared, all three devices demonstrated similar ability to detect localized stereophotographic RNFL defects. These findings suggest that visual inspection of the retinal thickness maps obtained with SD-OCT can detect the presence of localized RNFL defects seen on stereophotographs. In addition, as evidenced by Case 1, SD-OCT may also identify RNFL thinning not otherwise detected by stereophotograph assessment.

Although limited to 4 cases, this study offers a unique evaluation of the results from three commercially available SD-OCT instruments, the RTVue, the Cirrus and the Spectralis OCT, in eyes with localized RNFL defects as evidenced by masked stereophotographs assessment. These instruments, designed to obtain in vivo, high resolution images of retinal microstructures, differ in acquisition protocols, software detection algorithms and may provide different RNFL thickness estimates. Nevertheless, this study showed that SD-OCT technology may help clinicians identify the presence of localized glaucomatous structural damage. Future more extensive studies will determine how this new technology can further benefit glaucoma diagnosis and management.

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Fig. 1.
Results from photographs, visual fields (pattern standard deviation map) and SD-OCT devices for Case 1. A. The photographs show an inferior notch with a localized RNFL defect at 5–6 clock hours in OS (indicated by the white arrows) associated with a corresponding repeatable superior visual field defect. B. RTVue “Nerve Head/RNFL Analysis” map divided into 16 sectors. Values outside Normal limits based on the internal normative database are shown in red (to explore RTVue 3-D scans, see View 1 for OD and View 2 for OS). C. Cirrus “RNFL Thickness Map and “RNFL Thickness Deviation” map highlight in red clock hours and peripapillary RNFL Outside Normal Limits compared to on the internal normative database (to explore Cirrus 3-D scans, see View 3 for OD and View 4 for OS). D. Spectralis OCT retinal thickness map with retinal thickness measurements (microns, in black) and volume (mm$^3$, in red) for the 2.2 and 3.45 mm diameters at the superior, inferior, temporal and nasal quadrants (to explore Spectralis 3-D scans, see View 5 for OD and View 6 for OS). All three instruments identify the wedge-shaped RNFL defect at 5 to 6 o'clock.
Fig. 2.
Results from photographs, visual fields (pattern standard deviation map) and SD-OCT devices for Case 2. A. The photographs show an enlarged cup with superior and inferior rim thinning with the presence of several localized RNFL defects (OD at 5, 7 and 11–12 o'clock, and OS at 1–2 and 5–6 o'clock), as indicated by the white arrows. B. RTVue “Nerve Head/RNFL Analysis” map identifies sectors Outside Normal in red based on the internal normative (to explore RTVue 3-D scans, see View 7 for OD and View 8 for OS). C. Cirrus “RNFL Thickness Map” and “RNFL Thickness Deviation” map highlight in red clock hours and peripapillary retina areas Outside Normal Limits based on the internal normative database (to explore Cirrus 3-D scans, View 9 for OD and View 10 for OS). D. Spectralis OCT retinal thickness map with retinal thickness measurements (microns, in black) and volume (mm³, in red) for the 2.2 and 3.45 mm diameters at the superior, inferior, temporal and nasal quadrants (to explore Spectralis 3-D scans, see View 11 for OD and View 12 for OS). All 3 instruments identify RNFL defects in the superior and inferior hemifields.
Fig. 3.
Results from photographs, visual fields (pattern standard deviation map) and SD-OCT devices for Case 3. A. The photographs show diffuse inferior RNFL loss in both eyes, as indicated by the white arrows, associated with a repeatable bilateral superior hemifield defect. B. RTVue “Nerve Head/RNFL Analysis” map identifies in red sectors Outside Normal based on the internal normative database (to explore RTVue 3-D scans, see View 13 for OD and View 14 for OS). C. Cirrus “RNFL Thickness Map” and “RNFL Thickness Deviation” map highlight in red clock hours and peripapillary retina areas Outside Normal Limits based on the internal normative database (to explore Cirrus 3-D scans, see View 15 for OD and View 16 for OS). D. Spectralis OCT retinal thickness map with retinal thickness measurements (microns, in black) and volume (mm³, in red) for the 2.2 and 3.45 mm diameters at the superior, inferior, temporal and nasal quadrants (to explore Spectralis 3-D scans, see View 17 for OD and View 18). All 3 instruments identify RNFL loss in the inferior region.
Results from photographs, visual fields (pattern standard deviation map) and SD-OCT devices for Case 4. A. The photographs show an enlarged cup in both eyes, with an inferior notch in OS with localized RNFL defect at 5–7 clock hours, indicated by the white arrows. B. RTVue “Nerve Head/RNFL Analysis” map identifies in red sectors Outside Normal based on the internal normative database (to explore RTVue 3-D scans, see View 19 for OD and View 20 for OS). C. “RNFL Thickness Map” and “RNFL Thickness Deviation” map highlight in red clock hours and peripapillary retina areas Outside Normal Limits based on the internal normative database (to explore Cirrus 3-D scans, see View 21 for OD and View 22 for OS). D. Spectralis OCT retinal thickness map with retinal thickness measurements (microns, in black) and volume (mm³, in red) for the 2.2 and 3.45 mm diameters at the superior, inferior, temporal and nasal quadrants (to explore Spectralis 3-D scans, see View 23 for OD and View 24 for OS). All 3 instruments show RNFL loss in the left eye.
Table 1

RTVue, Cirrus and Spectralis OCT average thickness measurements and RTVue and Cirrus sectoral results at RNFL defect locations (clock hours) identified based on masked stereophotographs evaluation. Measurements are derived from the internal standard analysis methods provided by each instrument.

| Case 1          | RTVue average RNFL thickness (microns) | Cirrus average RNFL thickness (microns) | Spectralis OCT total retinal thickness 3.46 mm circle scan (microns) | RNFL defect location (clock hours) based on masked stereophotographs evaluation | RTVue RNFL thickness (microns) at RNFL defect location | RTVue normative database results at RNFL defect location | Cirrus RNFL thickness (microns) at RNFL defect location | Cirrus normative database results at RNFL defect location |
|-----------------|----------------------------------------|----------------------------------------|-------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| OD              | 101.83                                 | 88                                     | 327.3                                           | None                                                            | -                                               | -                                               | -                                               | -                                               |
| OS              | 80.37                                  | 68                                     | 288.3                                           | 5–6 clock hours                                                | 83                                              | ONL                                            | 58                                              | ONL                                            |

| Case 2          | RTVue average RNFL thickness (microns) | Cirrus average RNFL thickness (microns) | Spectralis OCT total retinal thickness 3.46 mm circle scan (microns) | RNFL defect location (clock hours) based on masked stereophotographs evaluation | RTVue RNFL thickness (microns) at RNFL defect location | RTVue normative database results at RNFL defect location | Cirrus RNFL thickness (microns) at RNFL defect location | Cirrus normative database results at RNFL defect location |
|-----------------|----------------------------------------|----------------------------------------|-------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| OD              | 77.01                                  | 63                                     | 289.3                                           | 5 clock hour                                                    | 88                                              | WNL                                            | 70                                              | WNL                                            |
|                 |                                        |                                        | 7 clock hour                                     | 90                                                              | ONL                                            | 47                                              | ONL                                            |                                                  |
|                 |                                        |                                        | 11–12 clock hour                                  | 86                                                              | BL                                             | 49                                              | BL                                             |                                                  |
| OS              | 79.41                                  | 69                                     | 296.5                                           | 1–2 clock hour                                                  | 100                                             | WNL                                            | 81                                              | BL                                             |
|                 |                                        |                                        | 5–6 clock hour                                    | 84                                                              | ONL                                            | 58                                              | ONL                                            |                                                  |

| Case 3          | RTVue average RNFL thickness (microns) | Cirrus average RNFL thickness (microns) | Spectralis OCT total retinal thickness 3.46 mm circle scan (microns) | RNFL defect location (clock hours) based on masked stereophotographs evaluation | RTVue RNFL thickness (microns) at RNFL defect location | RTVue normative database results at RNFL defect location | Cirrus RNFL thickness (microns) at RNFL defect location | Cirrus normative database results at RNFL defect location |
|-----------------|----------------------------------------|----------------------------------------|-------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| OD              | 87.99                                  | 78                                     | 309                                             | 3 to 9 clock hours                                              | 70.05                                           | ONL                                            | 50                                              | ONL                                            |
| OS              | 85.07                                  | 68                                     | 295.8                                           | 3 to 9 clock hours                                              | 76.32                                           | BL                                             | 54                                              | ONL                                            |

| Case 4          | RTVue average RNFL thickness (microns) | Cirrus average RNFL thickness (microns) | Spectralis OCT total retinal thickness 3.46 mm circle scan (microns) | RNFL defect location (clock hours) based on masked stereophotographs evaluation | RTVue RNFL thickness (microns) at RNFL defect location | RTVue normative database results at RNFL defect location | Cirrus RNFL thickness (microns) at RNFL defect location | Cirrus normative database results at RNFL defect location |
|-----------------|----------------------------------------|----------------------------------------|-------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| OD              | 95.87                                  | 89                                     | 340                                             | None                                                            | -                                               | -                                               | -                                               | -                                               |
| OS              | 75.86                                  | 64                                     | 296.3                                           | 5–7 clock hours                                                 | 93                                              | ONL                                            | 53                                              | ONL                                            |