Published in final edited form as:

Optom Vis Sci. 2012 December ; 89(12): e109–e111. doi:10.1097/OPX.0b013e3182771797.

Novel Analytical Methods for StratusOCT: Alignment of the Scan Circle

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Abstract

Measurement of retinal nerve fiber layer (RNFL) thickness using optical coherence-tomography (OCT) is commonly used in the detection and management of glaucoma. The StratusOCT (Carl Zeiss Meditec, Inc., Dublin, CA) is widely used but image acquisition is subject to artifacts, such as those caused by normal fixational eye movements, and this leads to unreliable measurements. Novel analytical methods have been developed to estimate the amount of misalignment of the circular scanning protocol used by the StratusOCT. A computer program with a graphical user interface implementing these methods has been written by some of the authors. A case example is presented in this report that shows the effect that vertical displacements of the OCT scan have on measured RNFL thickness. The example is used to demonstrate how the software can be used for estimating the positional alignment of the scan circle. This software can potentially improve identification of unreliable RNFL thickness measurements and is freely available from the authors.

Keywords

glaucoma; imaging; optical coherence tomography; OCT; Stratus; Spectralis; retinal nerve fiber layer; RNFL thickness; OCT scan alignment

Detecting glaucoma and monitoring its progression requires a clinician to integrate information from a variety of instruments measuring characteristics including retinal morphology, intra-ocular pressure, and visual function. One such instrument is the StratusOCT (Carl Zeiss Meditec, Inc., Dublin, CA), which estimates the retinal nerve fiber layer (RNFL) thickness from circular optical coherence-tomography (OCT) scans. In general, any instrument that extracts information from retinal scans is subject to artifacts^{2,3,4} that affect its outcome, some of which may not be accounted for. Different scan alignments by operators before image acquisition and normal fixational eye movements, for instance, affect the actual position of the OCT scan path, and this affects estimates of RNFL thickness^{2,3,4}. Figure 1 in Kim et al⁴ is an illustration of these two artifacts in the acquisition of the OCT scan.

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None of the authors have a conflict of interest.

SUPPLEMENTAL DIGITAL CONTENT

An online video that demonstrates the scan alignment software is available at [LWW insert link].

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Novel analytical methods¹ have been developed to infer the actual location of circular OCT scans and to record the difference between the estimated scan location and a reference location. These methods have been implemented in MatLab (The MathWorks, Inc., Natick, MA) along with an interactive graphical user interface. The software has a tool for users to delineate vessels in a retinal image (eight is the minimum number of vessels recommended to be drawn in the retinal image¹). It reads in raw scanned images obtained with the Stratus OCT device, identifies the vessels in the OCT-scan image, and aligns the vessels delineated in the retinal image with those identified in the OCT-scan image (see Figure 1; an online video available at [LWW insert link] demonstrates how to use the software). The software (< 5 megabytes) is freely available from the authors as either a stand-alone executable file (for Windows or Macintosh) or as a package of MatLab source code. A regular computer is enough to execute the program¹.

The scan alignment software is used here to illustrate, with a representative case example, the effect that mainly vertical displacements have in measured RNFL thickness. Blood vessels were traced in retinal images taken with the Spectralis (Heidelberg Engineering, Heidelberg, Germany) for patients with glaucoma enrolled in an ongoing longitudinal study in Bloomington, Indiana. The OCT scans had a diameter of 12° of visual angle, which corresponds to 3.45 mm for the model eye used by StratusOCT.

Figure 2 shows two OCT scans from two visits about eight months apart and their corresponding RNFL profiles. Not all the vessels identified in the OCT images were matched with the vessels in the retinal image (left panel). Nevertheless, these were the best scan position estimates found by the program given the intrinsically noisy OCT scan and the inherent subjectivity in the determination of the vessel profile from the retinal image. In this example, the displacement between estimated OCT scan centers was 200 µm vertically and only 40 µm horizontally, with minor rotations in both scans, of -0.5° and -3.4° (denoted by the blue and black lines connecting the center of the circle with its circumference, which are practically horizontal in Figure 2). Overall thickness in the superior-temporal sector was greater for the scan circle shifted downwards (black) than for the scan circle shifted upwards (blue) by almost 20 µm. The difference in overall thickness in the inferior-temporal sector was much smaller, only 2 µm.

For delineation of retinal vessels, the OCT alignment software can be adapted to use retinal images obtained with any device, including fundus cameras. In the original study¹, scanning laser polarimetry (SLP; GDx VCC; Carl Zeiss Meditec, Inc., Dublin, CA) retinal images were used, whereas Spectralis retinal images were used here. Optics and other factors affect readings differently, and some devices cannot be compared directly. For instance, Patel et al⁶ found a ratio in ocular magnification of 0.98 between Spectralis and Cirrus HD OCT (Carl Zeiss Meditec, Dublin, CA). Similar methods could be applied to obtain the ocular-magnification ratio between the StratusOCT and other devices, and the value of scan diameter, whose default is 3.45 mm, could be manually updated in the scan alignment software (see Figure 1). The current program uses an optimization algorithm to estimate automatically three parameters: position in the x-axis, position in the y-axis, and scan rotation. Further work to improve the algorithm could include an automatic method for the estimation of scan diameter that gives reliable and reasonable results.

In addition to optical magnification and normal fixational eye movements, other factors can affect the validity of the results given by the scan software alignment. Involuntary saccades may occur where eye fixation changes substantially within the 0.6-second interval that takes to acquire an OCT scan. These involuntary saccades cause the scan paths to depart considerably from the intended circular scan⁵. Blinking is another factor that can introduce severe noise and artifacts in the images. Regardless of the reason, the vessels identified in a

poor OCT-scan image are very unlikely going to be well aligned with the vessels delineated by the user in the retinal image. The software provides two values that can be used to quantify the reliability of the alignment (see Fig 1). These are the proportion of aligned vessel, $pr(\text{align vessel})$, and the median absolute deviation, mad . A small value of the former indicates that many vessels were misaligned and a large value the later indicates that the misalignment was severe, that is, vessels in OCT-scan image were far away from those delineated in the retinal image. The value of these two indices accompanied by visual examination of the OCT-scan image can help distinguish poor OCT scans from good ones.

The scan alignment software usefully estimates the actual scan location, but it does not correct for it. Further work, including modelling changes in RNFL thickness with location, would be required to complement the current software with a means to translate these displacements into changes in thickness given e.g. the amount of vertical and horizontal shifts^{1,2,6}. Estimation of the actual scan location, as opposed to the putative one, can aid clinicians and researchers distinguish differences in thickness profile due to real morphological changes in the RNFL from those due to scan misalignments or other artifacts. This software may also aid in the comparison of OCT images taken with different instruments, provided that the same segmentation algorithm is used for all the OCT images⁶.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank Victor E. Malinovsky, OD, for useful comments and for critically reading the letter. Supported by National Eye Institute Grants R01-EY007716 (WHS) and T35-EY013937 (Indiana University School of Optometry)

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Figure 1.

Graphical user interface of MatLab implementation of the scan alignment method. The OCT image was obtained with a StratusOCT instrument. Red crosses superimposed on the OCT image represent the vessel locations, which are calculated automatically by the program. The retinal image shown was obtained using a Spectralis instrument. White paths on top of the retinal image represent the vessels and were delineated by one of the authors (BA). The black circle is the reference OCT scan circle with 12° of diameter as calculated by the program after manual delineation of the optic nerve head. The black horizontal line connects the center of the circle with the point where the scan theoretically started. The blue circle is the actual OCT scan circle as estimated by the alignment algorithm. The blue line connects the center of the circle with the point where the scan actually started. The green circle is part of the file obtained using the Spectralis instrument with the retinal image, not part of this analysis and, thus, can be ignored. The blue dots represent the aligned position of the OCT vessels in the retinal image (marked with red crosses in the OCT image). For further details on OCT scan alignment analytical methods see Zhu et al.¹

Figure 2.

Two StratusOCT scans and the corresponding recorded RNFL-thickness profiles. The left panel shows two estimated OCT scans (blue and black circles) for two OCT images. The vessels identified in the OCT scan are marked by the (blue and black) dots. The green circle is not part of the present analysis and can be ignored. The right panel shows the corresponding thickness profiles in which thickness in μm is plotted against angle in degrees (a TSNIT graph). The region delimited by the horizontal red lines corresponds to the superior-temporal sector of the optic nerve head and the region between the blue lines corresponds to the inferior-temporal sector