Artifacts in Spectral-Domain Optical Coherence Tomography Measurements in Glaucoma

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IMPORTANCE  Spectral-domain optical coherence tomography (SD-OCT) has an integral role in the diagnosis and treatment of glaucoma. Understanding the types of artifacts commonly seen in the imaging of patients being evaluated for glaucoma will help physicians better implement these data in the care of patients.

OBJECTIVES  To determine the frequency and distribution of SD-OCT imaging artifacts in patients being evaluated for glaucoma and to provide examples of common artifacts.

DESIGN, SETTING, AND PARTICIPANTS  A retrospective cross-sectional study design was used to examine SD-OCT images (using Spectralis SD-OCT) of 277 consecutive patients who had a diagnosis of glaucoma of any stage or had suspected glaucoma. Retinal nerve fiber layer (RNFL) and macular thickness scans were included. For each scan, the final printout and the source images that generated the final printout were examined. If present, artifacts were classified as evident on the final printout or not and were categorized as to the primary source of the artifact (eg, ocular pathologic features or technician errors). Examples of common artifacts are provided.

MAIN OUTCOMES AND MEASURES  The presence of imaging artifacts.

RESULTS  In 277 consecutive patients, 131 macular thickness scans were obtained, and 277 RNFL scans were obtained. Of the macular thickness scans, 37 (28.2%; 95% CI, 20.8%-36.1%) had imaging artifacts. Six of these artifacts were not obvious on the final printout. Of the RNFL scans, 55 (19.9%; 95% CI, 15.2%-24.6%) contained artifacts. Seven of these artifacts were not evident on the final printout. The most common cause of artifacts for macular thickness and RNFL scans was ocular pathologic features, primarily the presence of an epiretinal membrane.

CONCLUSIONS AND RELEVANCE  It is likely that SD-OCT–related imaging artifacts occur in 15.2% to 36.1% of scans obtained in patients being evaluated for glaucoma. Some of these artifacts may not be evident on the final printout. Physicians should be alert to the possibility of artifacts, particularly in patients with ocular pathologic features such as an epiretinal membrane.
Artifacts in SD-OCT Measurements in Glaucoma

In the last decade, the use of imaging technology for glaucoma increased dramatically. Physicians have come to rely on data from these imaging devices to help them differentiate healthy patients from those with glaucoma. Future studies may demonstrate the usefulness of imaging devices as an objective measure of detecting progression. Spectral-domain optical coherence tomography (SD-OCT) is one such commonly used modality. Physicians depend on the classification provided by the machine for measuring the retinal nerve fiber layer (RNFL) and macular thickness or for defining the optic nerve head as normal or abnormal. They also rely on accurate and reproducible measurements of the retinal thickness or its sublayers such as the RNFL or ganglion cell layer to follow disease progression.

Recognition of artifacts is critical to interpret the data accurately. Many artifacts can occur in the measurement of the retina in disease states such as uveitis, epiretinal membranes (ERMs), diabetic retinopathy, or macular degeneration. In such patients, studies with various SD-OCT instruments have reported the following high rates of artifacts: 8% to 72% (Cirrus; Carl Zeiss Meditec), 25% to 61% (Spectralis; Heidelberg Engineering), 89% (RTVue; Optovue Inc), and 90% (Topcon 3D; Topcon Corporation). However, many artifacts occur even in the absence of such obvious retinal pathologic features (6%-44% for Cirrus, 38% for RTVue, and 53% for Topcon 3D). We aimed to systematically examine the frequency and distribution of SD-OCT artifacts during glaucoma evaluation using Spectralis SD-OCT and to provide examples of common artifacts.

Methods

The Duke University Institutional Review Board approved this study. A waiver of consent was obtained. We conducted a retrospective cross-sectional study to evaluate the prevalence of common errors and artifacts that can occur using SD-OCT measurements obtained from a single instrument in patients being evaluated for glaucoma.

We examined SD-OCT images of 277 consecutive patients on the glaucoma service at Duke Eye Center in 2012. Repeat scans acquired at subsequent visits were not included. Study eyes were classified as suspected glaucoma or as glaucoma of any stage (mild, moderate, or severe). Images were acquired by 8 technicians experienced in the use of SD-OCT imaging for glaucoma. During the measurement, a quality bar visualizes the signal-to-noise ratio. The quality scores range from 0 (poor) to 40 (excellent). These technicians had been trained to save only those scans with a quality rating exceeding 25 (following the manufacturer’s specifications).

We evaluated only right eyes unless the right eye was not imaged, in which case we examined the left eye. For each patient, we examined whatever glaucoma-related imaging was performed (a macular thickness scan, a peripapillary RNFL scan, or both). Cross-sectional optic nerve head scanning was not typically performed for our patients with glaucoma. The RNFL scan consists of measurements along a 12° peripapillary circle, with the result displayed on the final printout as (1) the straightened image of the raw scan with the boundaries of the RNFL delineated, (2) a scanning laser ophthalmoscope image of the optic nerve and the location of the measurement circle, and (3) the mean RNFL thickness of each sector (6 sectors) and a global mean. The macular SD-OCT scans for patients with glaucoma consist of 61 horizontal B-scans covering a 10 × 10-mm area centered on the fovea used to create a composite macular thickness map. The mean retinal thicknesses of small 3 × 3° areas were displayed as a grid overlaying the central 8 × 8-mm measured area.

For each image, 2 experienced examiners inspected the final printout and the source images. The source images included the raw image for the RNFL before it was straightened (normalized by the software) and the raw images (each single B-scan) of each of 61 lines for the macular measurements in which the boundaries of the retinal thickness were identified by the software.

If present, artifacts were classified as evident on the final printout or not, as well as whether they were within the area of the measurement (eg, within the 8 × 8-mm macular area) or outside of this area. The causes of the artifacts were categorized as due to ocular pathologic features, technician errors, or software errors in identifying the correct boundaries of the RNFL or the retinal thickness. Ocular pathologic features were identified from the SD-OCT images and not from the patient’s medical record. Technician errors included placement of the circle eccentrically or truncation of the SD-OCT images due to incorrect placement of the image in the acquisition window. Software errors in the identification of boundaries included cut-edge artifacts and boundary misidentification (when the software-identified boundary differed from the actual surface by >5% of the total thickness of the area measured). The presence of at least 1 error in any one B-scan was considered sufficient to classify the examination as affected by artifact.

Results

The SD-OCT images of 277 consecutive patients were examined. Among these patients, 131 macular thickness scan sets were obtained, and 277 RNFL scans were obtained. Sixteen scans were of left eyes. Of 131 macular thickness scan sets, 37 (28.2%; 95% CI, 20.8%-36.1%) had 43 imaging artifacts identified, which were in the central 8 × 8-mm area (where the mean thickness was measured and displayed). Of 37 macular thickness scans involving the central area measured, 31 (83.8%; 95% CI, 71.9%-95.7%) had artifacts that were obvious on the final printout. Of 6 scans with artifacts that were not obvious on the final printout, 3 were due to ocular pathologic features and 3 due to software errors.

Of 277 RNFL scans, 55 (19.9%; 95% CI, 15.2%-24.6%) had 63 imaging artifacts identified, of which 48 scans (87.3%; 95% CI, 78.4%-96.1%) had obvious artifacts on the final printout. Of 77 scans in which the artifacts were not obvious on the final printout, 3 were due to truncation of images by the technician, 2 due to ocular pathologic features, and 2 due to software errors.
The most common cause of artifacts for the RNFL and macular thickness images was ocular pathologic features. The primary ocular pathologic feature accounting for artifacts was the presence of an ERM. The categories of image artifacts are listed in eTable 1 (in the Supplement) for the macular thickness and RNFL scans. eTable 2 (in the Supplement) lists the frequency of various ocular pathologic features associated with artifacts in the macular thickness and RNFL scans.

Discussion

Most studies in the literature that report on SD-OCT for glaucoma diagnosis have used single operators and typically reject images with artifacts, including those with inadequate signal strength or improper placement of the measurement circle, as well as motion artifacts that appear as discontinuous blood vessels in en face images. Therefore, many studies are unable to provide an estimate of the type and frequency of artifacts that occur during SD-OCT imaging for glaucoma evaluation.

In the scans obtained herein among patients being evaluated for glaucoma, artifacts in measurement of the RNFL or macular thickness by SD-OCT likely occur in 15.2% to 36.1% of scans. Most should be easily identifiable on the final printout in the macular thickness scans (83.8%) and RNFL scans (87.3%). Therefore, increasing the awareness of obvious artifacts on the final printout can assist the physician in avoiding erroneous clinical interpretation. However, artifacts that are not obvious on the final printout remain a major concern and may lead to significant errors in clinical evaluation. While typically a physician does not examine the raw images for each scan because of impracticality, caution should be exercised in making clinical decisions based on the imaging technology alone. Access to the electronic imaging data in the examination lane can enable the physician to review the raw images, minimizing the effect of such artifacts.

It was not surprising that ocular pathologic features were the most common cause of artifacts for the RNFL and macular thickness images. However, it was unexpected that ERMs represent the most frequent artifacts in macular thickness scans and especially in RNFL scans. Some of these ERMs were difficult to identify on the final printout. That ERMs occur commonly in the peripapillary region has been previously unknown. Studies\(^6\,7\) have indicated a loss of peripapillary RNFL thickness following vitrectomy for ERM peeling. Those results may have been due to the fact that an erroneously thickened RNFL on SD-OCT decreased in thickness following removal of the ERM. Such artifacts are more easily visible with SD-OCT machines that show the details of the vitreous–internal limiting membrane interface compared with those machines in which such details are not clear. Therefore, greater imaging detail facilitates the identification of more artifacts. The software algorithm identifies the upper boundary of the ERM as that of the upper edge of the RNFL or as the internal limiting mem-

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**Figure 1. The Epiretinal Membrane in the Superotemporal Quadrant Prevents Collapse of a Degenerated and Thinned Retinal Nerve Fiber Layer (RNFL) (Arrowhead)**

![Image of a superotemporal quadrant with an arrowhead pointing at an epiretinal membrane preventing RNFL collapse](Image)

The spectral-domain optical coherence tomography software algorithm has misidentified the boundary of the epiretinal membrane as the upper edge of the RNFL, leading to an erroneously elevated measure of the RNFL in that region.

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<table>
<thead>
<tr>
<th>Peripapillary RNFL thickness classification</th>
<th>Thickness, μm</th>
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<tbody>
<tr>
<td><strong>T</strong>&lt;sup&gt;50&lt;/sup&gt; (71)</td>
<td>150 (130)</td>
</tr>
<tr>
<td><strong>G</strong>&lt;sup&gt;76&lt;/sup&gt; (95)</td>
<td>132 (102)</td>
</tr>
<tr>
<td><strong>N</strong>&lt;sup&gt;58&lt;/sup&gt; (72)</td>
<td>130</td>
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</tbody>
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**Legend:**

- **T:** temporal
- **G:** global mean thickness
- **N:** nasal
- **I:** inferonasal
- **S:** superonasal
- **N:** inferotemporal
- **T:** temporal
- **S:** superotemporal
- **M:** temporal
- **S:** superotemporal

**Warning:** classification results valid for eyes of patients of white race/ethnicity only.
brane of the retina, leading to erroneous measurements of the RNFL (Figure 1) or macular thickness. Scalloped edges of a macular thickness map (eFigure 1 in the Supplement) can indicate the presence of an ERM as the cause of an artificially thick macula. In 23.1% (6 of 26) of the RNFL scans with ERM artifacts, it was possible to easily identify the ERM in the macular thickness scans. The presence of an ERM in a macular thickness scan should alert the physician to the possibility of an ERM in the RNFL scans.

Another common ocular cause of artifact is the natural evolution of a posterior vitreous detachment, which results in traction on the inner limiting membrane. In a few RNFL scans, areas of vitreous adhesion resulted in erroneously thickened RNFL measurements that subsequently decreased over time, with release of the vitreous traction masquerading as progression of RNFL thinning (Figure 2). Unless details of the vitreous interface with the internal limiting membrane are visible, a potential area of artifact could easily be overlooked. In macular thickness scans, prominent posterior hyaloid surface and vitreomacular traction create abnormal hyperreflective bands inward of the normal internal limiting membrane (eFigure 2 in the Supplement). The software algorithm may identify the abnormal bands as the retinal boundary, resulting in an overestimation of the retinal thickness, as was found in another study.3 These artifacts were easily identified on the final printout because of the well-demarcated linear nature of increased macular thickness.

The upper scan demonstrates a retinal nerve fiber layer (RNFL) in the nasal region (black arrowhead) that is thicker than normal. The lower scan 18 months later demonstrates thinning of the RNFL (pink area in the bottom right measurement graph). A closer examination of the scans reveals released vitreous adherence from the retina. The edge of the vitreous is now clearly identifiable following release of vitreous–internal limiting membrane adhesions (red arrowhead). G indicates global mean thickness; ILM, internal limiting membrane; INF, inferior; NAS, nasal; NI, inferonasal; NS, superonasal; SUP, superior; T, temporal; TI, inferotemporal; TMP, temporal; and TS, superotemporal.
Figure 3. Operator-Dependent Artifacts Included Truncation of the Acquired Spectral-Domain Optical Coherence Tomography (SD-OCT) Image (ie, All Edges of the Image Were Not Within the Acquisition Window)

A. The retinal nerve fiber layer (RNFL) was outside of the acquisition window in a portion of this scan.

B. The corresponding final printout, showing a severely thin RNFL in the temporal and superotemporal quadrants. In the final printout, the SD-OCT scan is centered, making the truncated portion less obvious.

C. The same patient's RNFL scan repeated, with the entire RNFL in the acquisition window.

D. The final printout, showing a normal RNFL in all quadrants. G indicates global mean thickness; ILM, internal limiting membrane; INF, inferior; NAS, nasal; NI, inferonasal; NS, superonasal; SUP, superior; T, temporal; TI, inferotemporal; TMP, temporal; and TS, superotemporal.

Warning: classification results valid for eyes of patients of white race/ethnicity only.
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Operator-dependent artifacts included truncation of the acquired SD-OCT image (ie, all edges of the image were not within the acquisition window). Truncation of the image in RNFL measurements was unable to be identified on the final printout and was seen only when the raw images were examined. This artifact resulted in erroneous mean measurements in the sector and in the global mean RNFL thickness values. A clue to identifying such artifacts was the presence of RNFL values near zero because even in end-stage glaucoma the RNFL thickness remains approximately 30 μm due to a floor effect of the glial cell thickness (Figure 3). However, such truncation artifacts in macular thickness scans were easily identifiable on the final printouts owing to irregular-shaped areas of near-zero macular thickness.

Incorrect RNFL circle placement is another operator-dependent artifact that is easily identifiable on the final printout. Although most of these artifacts have been reported to be mild,9 moderate to severe displacement of the circle may result in erroneous RNFL values.9 In some SD-OCT instruments (eg, Cirrus), the points along a peripapillary concentric circle are identified by the software, eliminating this type of artifact.

Myopic eyes with longer axial length are associated with a higher percentage of abnormal diagnostic classifications because the RNFL normative databases are typically adjusted only by age and not by axial length or refractive error.10,11 Furthermore, myopic eyes are associated with many other artifacts such as difficulty in acquiring a good image owing to excessively long axial length or myopic retinal schisis affecting peripapillary RNFL thickness (Figure 4).

The SD-OCT software–related artifacts included the misidentification of the retinal boundaries. This is commonly seen in eyes with high myopia, eyes with prominent posterior hyaloid, or eyes with significant media opacities because of poor image quality. These artifacts were easily identified on the final printout. Previous studies12,13 of the application of SD-OCT to retinal pathologic features have disclosed multiple sources of error that dramatically decrease the accuracy of these macular thickness measurements. The most obvious source of error may be imprecise retinal layer segmentation, which can result from poor signal quality of the SD-OCT image or outright failure of the segmentation algorithm in otherwise high-quality images.12,14,15 Poor signal strength has been demonstrated as a major source of artifacts in other studies16,17 as well, precluding the ability to detect change in the RNFL over time.

In this study, we used a single machine to evaluate our patients. Depending on the software features and inbuilt protocols of measurements, different machines may have greater or lesser artifacts. The SD-OCT machine used herein has inbuilt software to control for head tilt and eye tracking. In the absence of software to control for head tilt, significant artifacts may ensue with as little as 8° of head tilt.18 In the absence of an eye tracking system, another artifact type related to patient eye movement is likely to occur when some cross-sectional retina images are shifted superiorly or inferiorly compared with adjacent images that are without corresponding shifts of the retina segmentation lines. These artifacts result in characteristic motion waves in the inner limiting membrane and retinal pigment epithelium layer maps that may be mistaken for true retinal pathologic features or significant software algorithm errors.7 Some tips shared by experienced technicians herein include the following: reducing the ambient light in the room in the case of an undilated pupil, ensuring that the forehead of the patient is in constant contact with the headband during imaging, reminding the patient to blink just before scan acquisition and using artificial tears if blinking did not help, and needing to adjust the dial on the console pad and the focus knob on the camera to obtain the best images.

Clinical interpretation errors include failure to recognize nonglaucomatous patterns of loss such as those seen in optic neuritis, retinal dystrophies, ischemic optic neuropathy, and hemiretinal vein occlusion or in toxic or nutritional causes of optic atrophy.19 Another clinical interpretation artifact is failure to recognize that the measurements of RNFL or macular thickness are presented as a mean value in a sector or a quadrant, resulting in focal and localized losses of RNFL or macular thickness being classified as normal. In the presence of multifocal intraocular lenses, the SD-OCT line-scanning ophthalmoscope images can show unique wavy horizontal artifacts. Gaps between the wavy horizontal artifacts are wider in the center of the image and narrower in the periphery, matching the diffractive rings on the surface of such intraocular lenses.20

![Figure 4. An Example of a Retinal Nerve Fiber Layer (RNFL) Scan of a Patient With High Myopia](image-url)
Conclusions

Ophthalmic imaging is an important adjunct to clinical diagnosis, but the results from imaging devices must be assessed critically relative to the artifacts of imaging and the limitations of the technology and its normative databases. Physicians should avoid making therapeutic decisions based on thickness measurements without first assessing scans for artifacts. Manually correcting segmentation errors is time-consuming, but doing so may promote more accurate RNFL or macular thickness measurements and better clinical care. Ultimately, SD-OCT imaging for glaucoma remains a rapidly developing field, and continued improvements in software and segmentation algorithms may provide increasingly reliable retinal images and quantitative thickness data.