Saudi Journal of Ophthalmology (2014) 28, 81–87

Retinal and Choroidal Imaging Update

Artifacts in optical coherence tomography

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Abstract

Optical coherence tomography (OCT) is now an integral part of management for numerous retinal diseases for diagnosis, treatment planning and follow up. OCT interpretation must involve the understanding of the associated artifacts. These artifacts can mislead physicians to wrong diagnosis or inappropriate management. This review article discusses the various types of artifacts in OCT scans obtained from various devices in various retinal diseases. This article would help to improve the understanding about the various artifacts and their clinical importance.

Keywords: Optical coherence tomography, Time domain optical coherence tomography, Spectral domain optical coherence tomography, Cirrus, TOPCON, Spectralis, Artifacts

http://dx.doi.org/10.1016/j.sjopt.2014.02.010

Introduction

Optical coherence tomography (OCT) is a non-invasive imaging modality useful for identification of lesions in the macula, optic disk and the anterior segment.[1] It provides a high resolution, in vivo optical biopsy of the tissue being scanned, using the principle of optical interferometry.[2,3] OCT can be in the form of Time Domain OCT (TD OCT) or Fourier domain OCT. In TD OCT a mechanically moving scanning reference arm sequentially measures the echo time delay.[1] Fourier domain OCT has a stationary reference arm which obtains an interference spectrum which then undergoes Fourier transformation allowing simultaneous measurements of all echo time delays thereby reducing the image acquisition time. Fourier domain OCT is again subdivided into Spectral Domain OCT (SD OCT) which uses a spectrometer and a line scan camera for image acquisition as opposed to a swept source OCT which has a rapidly tunable laser source for the same purpose.[4]

Information gathered from OCT can be qualitative or quantitative in nature. Qualitative data can be in the form of identification of retinal pathologies like vitreo macular traction, macular holes, cystoid macular edema and choroidal neovascular membrane.[1] Quantitative data such as foveal thickness are used to make treatment decisions like in conditions such as age related macular degeneration, diabetic macular edema and retinal vein occlusions.[5–8] Likewise retreatment decisions are also based to some extent on the foveal thicknesses obtained by an OCT scan.

Interpretation of these data and their implications in clinical situations must be tempered by the fact that images thus obtained are subject to artifacts.[3] These artifacts can mislead physicians to wrong diagnosis or inappropriate management. The first step for an examiner to address the issue of artifacts is to be aware of the presence of artifacts.[9] Knowledge about the possible artifacts in an OCT image will aid in better interpretation of the disease condition. Here we describe various types of artifacts and their clinical significance.

Available online 6 March 2014

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Peer review under responsibility of Saudi Ophthalmological Society, King Saud University

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Ray et al. were the first group to report and classify artifacts in TD OCT.[3] They had identified six types of OCT artifacts namely[1]: misidentification of the inner retinal layer,[2] misidentification of the outer retinal layer,[3] out of register artifact,[4] degraded image scan,[5] cut edge artifact and[6] off center artifact. These artifacts while originally reported in TD OCT can also be noted in SD OCT. There are certain other artifacts like mirror artifacts, which are noted exclusively in SD OCT on account of the technique involved in acquiring the image.[4] The artifacts can be a result of software errors (misidentification of retinal layers, mirror artifact, cut edge artifact), operator related error (degraded image scan, out of register artifact, off center artifact) or patient related factors (motion artifact, off center artifact, degraded image scan, mirror artifact) (Fig. 1). It is apparent from the above classification that the causes of some artifacts are not mutually exclusive.

Misidentification of inner retinal layer

All devices used the internal limiting membrane for the placement of the inner retinal layer. Misidentification of internal limiting membrane occurs due to software breakdown, mostly in eyes with epiretinal membrane (ERM), vitreomacular traction (VMT) or macular hole. Ray et al. found that on univariate analysis, inner layer misidentification was more common in eyes with neovascular age related macular degeneration (AMD), macular holes and eyes which have undergone photodynamic therapy (PDT).[3] However, on multivariate analysis, they found that the neovascular AMD was the only condition associated with inner layer misidentification. The authors also found inner layer misidentification in eyes with vitreo-retinal traction but the number was too small to analyze statistically.

Comparison over different OCT machines (STRATUS (Carl Zeiss Meditec, Dublin, CA), CIRRUS (Carl Zeiss Meditec, Dublin, CA), RTVue (Optovue, Inc., Fremont, CA), TOPCON (Topcon Medical Systems, Paramus, NJ)) showed that inner layer misidentification was a common feature with all machines showing artifact in more than 50% of cases.[1] Inner layer misidentification was most commonly noted in eyes with epiretinal membrane (ERM) followed by diabetic macular edema (DME) and macular hole in STRATUS OCT (Carl Zeiss Meditec, Dublin, CA). Vitreomacular traction (VMT) followed by ERM and cystoid macular edema (CME) were the most common conditions with CIRRUS machine (Carl Zeiss Meditec, Dublin, CA). VMT, ERM and macular hole were the most common conditions associated with inner layer misidentification with TOPCON (Topcon Medical Systems, Paramus, NJ) and RTVue (Optovue, Inc., Fremont, CA) SD OCT machines.[1] Inner layer misidentification involving the central 1 mm sub field was noted in 6.7% of CIRRUS (Carl Zeiss Meditec, Dublin, CA) SD OCT machine line scans and 1.3% of SPECTRALIS SD OCT machine (Heidelberg Engineering, Vista, CA).[10] AMD and uveitis were the two conditions where the central sub field inner layer misidentification was more common with the CIRRUS SD OCT machine (Carl Zeiss Meditec, Dublin, CA).

In a study comparing the various OCT machines (STRATUS (Carl Zeiss Meditec, Dublin, CA), CIRRUS (Carl Zeiss Meditec, Dublin, CA), TOPCON (Topcon Medical Systems, Paramus, NJ), RTVue (Optovue, Inc., Fremont, CA), SPECTRALIS (Heidelberg Engineering, Vista, CA) and COPERNICUS (Optopol Tech. SA, Zawiercie, Poland)), the maximum number of errors in the inner layer misidentification was noted in the COPERNICUS (Optopol Tech. SA, Zawiercie, Poland) SD OCT machine suggesting that an error in software may have a greater contribution in the artifact rather than the nature of the machine i.e. TD OCT or SD OCT.[11]

Misidentification of outer retinal layers

Different instruments use different reference points for outer retinal layers. The STRATUS uses the inner segment–outer segment junction (IS–OS junction) while the CIRRUS (Carl Zeiss Meditec, Dublin, CA) and RTVue (Optovue, Inc.,

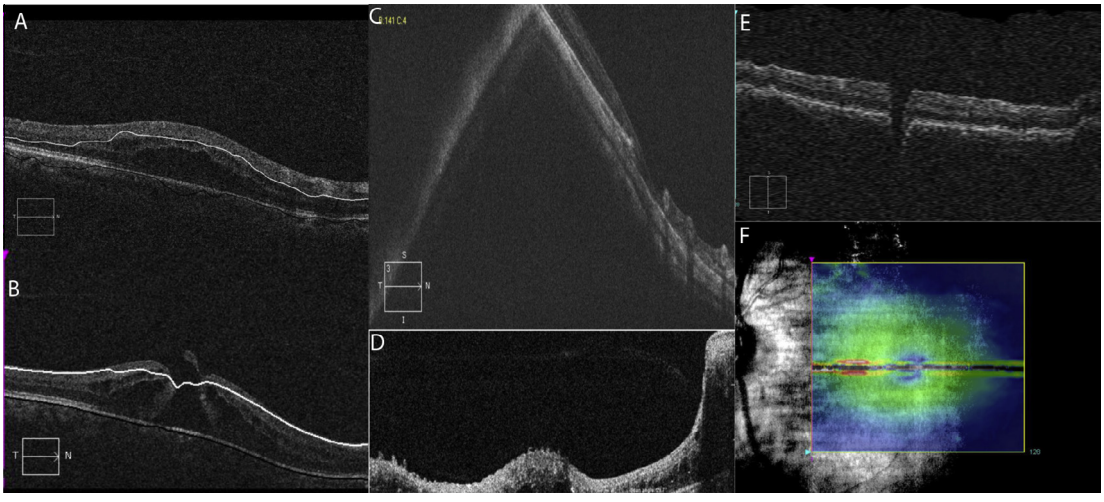

Figure 1. Common artifacts on Spectral Domain Optical Coherence Tomography. (A) Misidentification of inner and outer retinal layers: Image shows the incorrect automated segmentation; outer and inner boundaries are misidentified leading to an artifact. (B) Misidentification of inner layer: image shows the incorrect automated segmentation for inner boundary; outer boundary is correctly identified along the retinal pigment epithelium. (C) Mirror artifact: Image appears to be folded onto itself in a high myopic eye; called as mirror artifact. (D) Out of register artifact: Information from the outer retinal layers is not available from the OCT scan as it is shifted inferiorly; called as out of register artifact. (E) Blink artifact: OCT B scan appears discontinued with loss of retinal data in between due to blink during scan acquisition, which appears as dark line on rendered en-face image (F).

Fremont, CA) use the retinal pigment epithelium (RPE) as the outer retinal layer and the TOPCON 3D-OCT 1000 (Topcon Medical Systems, Paramus, NJ) uses the tip of the outer segment photoreceptor.[1] This artifact commonly occurs in outer retinal diseases such as central serous retinopathy (CSR), AMD, CME and geographic atrophy. Eyes with neovascular AMD and those which had undergone PDT had a greater chance of outer layer misidentification in a study by Ray et al.[3] Interestingly, eyes with posterior vitreous detachment (PVD) had a greater chance of outer layer misidentification in the same study.[3] CSR followed by CME and neovascular AMD seemed to be the most common condition associated with outer layer misidentification.[1] In a related study, AMD followed by uveitis and diabetic retinopathy seemed to be the most common cause of outer layer misidentification.[10] The COPERNICUS (Optopol Tech. SA, Zawiercie, Poland) and RTVue (Optovue, Inc., Fremont, CA) SD OCT machines had the highest error frequencies in identification of the outer retinal layers in subjects with neovascular AMD.[11]

Implications of misidentification of inner and outer retinal layers

Inner layer misidentification usually happens in eyes with vitreo–macular interface disorders for which the management involves mainly surgery. Quantitative assessment may not be essential for management of such disorders. Therefore, inner retinal misidentification is less important than outer retinal misidentification. Outer retinal misidentification occurs mostly in neovascular AMD, CSR, and CME, in which quantitative assessment becomes important for management of such cases. Leung et al. and Forooghian et al. found significantly different macular thickness measurements between time domain and spectral domain systems, with both groups finding higher thickness measurements in SD OCT as compared to TD OCT.[12,13] Similar finding was also noted by Mylonas et al.[14] Improper delineation of retinal layers result in improper assessment of foveal thickness. As stated previously, quantitative data (foveal thickness) help in treatment as well as follow up decisions. Sadda et al. found error in thickness measurement in 92% of all scans.[2] However, the quantum of severe errors, which was arrived at using a grading system stood at 13%. In eyes with neo-vascular AMD undergoing treatment with anti VEGF therapy, an error of 74% has been reported when measuring foveal thickness.[15] This error was reduced to 60% on repeat scan suggesting that repeat scans reduce but do not completely eliminate the error. This is a matter of concern as retreatment decisions are made based on foveal thickness.[5]

It has been suggested that when such artifacts are identified a manual measurement of the thickness can help us circumvent the problem.[9,15] Ho et al. had suggested that a difference of 11 microns between the software generated thickness and manual measurement need to be considered clinically significant.[1] The difference between the two measurements was the greatest for STRATUS TD OCT machine while it was the least for CIRRUS SD OCT machine (Carl Zeiss Meditec, Dublin, CA). They also reported a poor range of agreement for TD OCT (from 309 μm to 396 μm), and concluded that thickness measurements obtained from time domain systems could not be directly compared to SD OCT.

Ho et al.[1] found that STRATUS OCT (TD OCT) created significantly higher rates of clinically significant errors compared to any of the Fourier domain OCT. However, TD OCT did not perform the poorest out of the entire artifact types analyzed. In fact to their surprise, STRATUS OCT scans had the lowest percentage of outer retina misidentification.

They suggested that while SD OCT technology may be superior in terms of decreasing the overall number of clinically significant segmentation errors, differences in technology may not be the only factor in the determination of segmentation breakdown rates. They stated that other factors such as the quality of the segmentation software written for the OCT device may, in fact, play a very important role in determining the incidences of segmentation errors present for a device.

Mirror artifact/inverted artifact

These are noted only in Fourier domain OCT machines, which reconstruct the image around the region of zero time delay. The machine is unable to distinguish between negative and positive time delays and hence produce images around the zero time delay line, which are usually mirror images. The sensitivity also gets reduced as the image is formed away from the zero time delay line causing development of greater amount of interference.[4] Subjects with higher myopic spherical equivalent, less visual acuity and a longer axial length had a greater chance of mirror artifacts. This can also occur in eyes with raised lesion such as choroidal tumor, retinal detachment or retinoschisis. The mirror artifacts were noted in 9.3% of all scans and were noted in the periphery of the scan in view of the greater curvature of the globe leading to the peripheral area of the scanned retina traversing the zero time delay zone.[4] Han et al. found inverted artifacts more commonly in CIRRUS SD-OCT (Carl Zeiss Meditec, Dublin, CA) as compared to SPECTRALIS (Heidelberg Engineering, Vista, CA).[10] As the mirror artifact is usually due to an increase in the height of lesion (macular traction) or increased depth of lesion, it would be ideal to have an additional scan keeping the non-macular area of interest in the center of the scan to gather further information from the pathology thereby reducing the chance of a mirror artifact

Out of register artifact

Out of register artifact is defined as a condition where the scan is shifted superiorly or inferiorly such that some of the retinal layers are not fully imaged.[3] The prevalence of this artifact ranges from 2.4% to 13% across different TD OCT and SD OCT machines.[1,3] This is generally an artifact, which is operator dependent and caused due to misalignment of the scan.[1,9] It can be rectified by bringing the scan to the center of the frame.

Degraded image

Degraded images are due to poor image acquisition and have been noted in 11% of cases in a study by Ray et al.[3] These images were generally associated with non-retinal diagnosis. In the presence of a degraded image, the software is unable to delineate the inner and outer retinal layers properly resulting in errors of foveal thickness measurement. As

the OCT uses a near infrared beam to acquire images, the presence of media opacity like cataract may not be a cause for a degraded image.[9] This artifact is probably due to poor image acquisition and can be rectified by refocusing on the area of interest.

Cut edge artifact

This is an artifact where the edge of the scan is truncated.[3] Cut edge artifacts were noted in 2.3–6.35% of scans.[3,16] These artifacts result in abnormality in peripheral part of the scan and do not affect the central retinal thickness measurements. Cut edge artifacts are seen with similar frequency in normal and diseased eyes. These are operator induced artifacts due to poor scan acquisition and often occur during the first scan and can be overcome by disregarding the first scan.[9]

Off center artifact

This happens due to a fixation error, causing the displacement of the central foveal subfield of the early treatment diabetic retinopathy study (ETDRS)-like map by more than 0.25 mm from the true center based on topographic map and OCT B-scan data.[16] This happens mostly with subjects with poor vision, eccentric fixation or poor attention. This abnormal representation of the fovea was translated into inaccurate foveal thickness measurement. Similar error can happen with retinal nerve fiber layer measurement as well (Fig. 2). An error of 44.5% in foveal thickness was noted in eyes with a decentration of 0.5 mm and the quantum of deviation only increases with further decentration.[17] Univariate analysis showed an association of neovascular AMD with off center artifact.[3] This artifact can be rectified manually by the OCT operator by looking at the rendered fundus image of the OCT or repeating the scan using external fixation.[10] SPECTRALIS (Heidelberg Engineering, Vista, CA), RTVue100 (Optovue, Inc., Fremont, CA) and TOPCON 3D-OCT (Topcon Medical Systems, Paramus, NJ) have the facility to manually reposition the foveal center in slightly off center scans.

Motion artifact

These artifacts are noted due to ocular saccades, change of head position or due to respiratory movements.[18,19] They can occur due to poor tracking system, even with heart beat or respiration. They can be detected by noting the misalignment of the retinal blood vessels in the rendered fundus image. It has been reported as a double fovea artifact possibly due to a micro saccade.[20] Motion artifacts are common in TD-OCT but are difficult to detect as the rendered fundus image is taken after the OCT scan. Though the SD OCT scan acquisition time is lesser, they are not totally immune from motion artifacts. Motion artifacts are known to result in segmentation error especially abnormal retinal nerve fiber layer thickness measurement. Therefore artifacts showing more than one vessel shift need to be discarded and the scan is repeated. This artifact can be overcome by eye tracking system such as Heidelberg, however, eye tracking reduces only transverse motion, but not axial motion. Sometimes, repeating the scan may be required. Several techniques have been proposed to reduce the motion artifacts on SD-OCT and swept source OCT.[21,22]

Blink artifacts

These are noted when the patient blinks during the process of scan which are noted as areas of blanks in the rendered en-face image and macular thinning on macular map. B scan shows lost retinal data in between. The operator needs to repeat the image if such an artifact is noted.[9]

What is a clinically significant artifact?

- Any artifact resulting in automated segmentation errors of more than 10% of the actual (manually measured) ETDRS center subfield thickness (CST) is considered as clinically significant.[23,24]
- Any artifact resulting in an error is more than 50 μm. This is based on a study of reproducibility in STRATUS TD OCT that suggests 50 μm as a cutoff for retreatment of neovascular AMD patients.[15]
- Artifacts resulting in misdiagnosis of retinal thickening or thinning are noted as significant. Cutoffs are generated using published normative data for CIRRUS (Carl Zeiss Meditec, Dublin, CA) and SPECTRALIS (Heidelberg Engineering, Vista, CA) and by defining retinal thickening or thinning as the mean ± 2 standard deviations.[25]

Clinical significance of artifacts

OCT is useful in tracking disease progression and treatment response as well as to provide outcome measures for treatment success or failure in a variety of retinal pathologic features, including diabetic macular edema, uveitic cystoid macular edema, and neovascular AMD.[26,27]

In clinical trials, OCT plays a major role for quantitative measurement of retinal thickness. OCT retinal thickness measurements are important in defining inclusion and exclusion criteria in clinical studies (e.g., foveal thickness of more than 250 or 300 μm for studies of macular edema). OCT retinal thickness measurements are important in guiding treatment and re-treatment during clinical trials (e.g., retreat if there is more than 100 μm increase in retinal thickness in neovascular AMD).[26–29]

Presence of artifacts on OCT would affect the quantitative as well as qualitative assessment of retinal diseases during treatment planning and response in clinics as well as in clinical trials.

Evaluation of artifacts among various oct machines

To evaluate artifact errors, Giani et al.[11] obtained error frequency (EF-exam), which was calculated as the percentage of OCT examinations that included at least one B-scan with an artifactual error. To account for the different number of scan lines and variable B-scan density of each instrument, the absolute number of errors produced by each instrument was recorded, and the ratio of total number of errors per total number of B-scans for each machine was calculated (EF-scan).

They noted that the total EF-exam of all OCT instruments was 25.8%. In healthy subjects, the EF-exam for all instru-

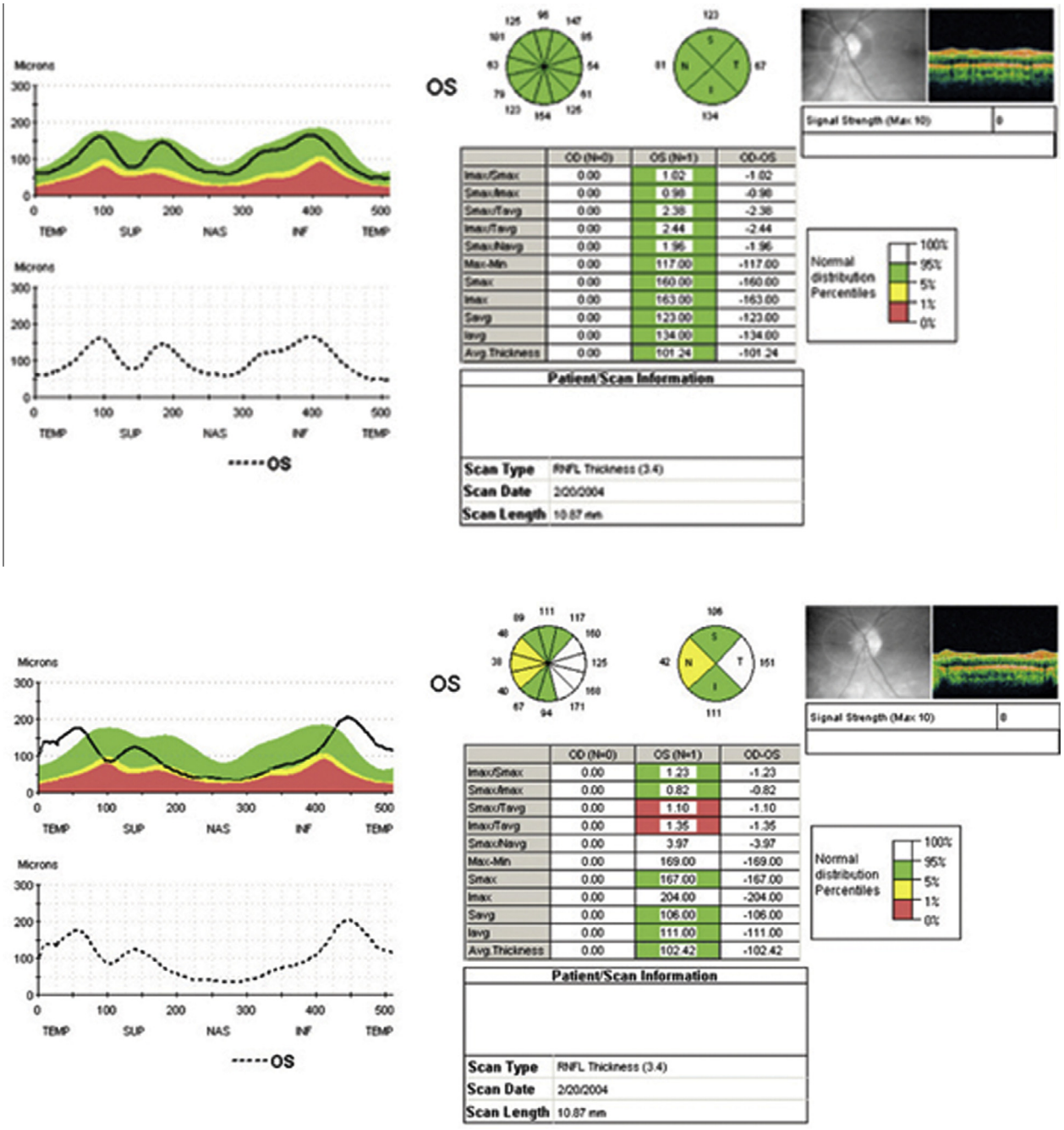

Figure 2. Off center centration. (A) Retinal nerve fiber layer (RNFL) scan with proper centration over the optic nerve head (upper right corner) showing normal RNFL thickness. (B) RNFL scan of the same eye with off center centration over the optic nerve head (upper right corner) showing (artificial) abnormalities of RNFL thickness.

ments was 6.9%, whereas in pathologic eyes, the EF-exam was 32.7%. The highest was for macular holes, 83.3%, followed by epiretinal membrane with cystoid macular edema, 66.6%, and neo-vascular AMD, 50.3%. The CIRRUS (Carl Zeiss Meditec, Dublin, CA) and 3D OCT-1000 (Topcon Medical Systems, Paramus, NJ) instruments had the lowest EF-exam values with 8.2% and 16.6%, respectively, whereas the other devices had higher EF-exam values, varying from 24.7% for the SPECTRALIS (Heidelberg Engineering, Vista, CA) to 49.5% for the COPERNICUS (Optopol Tech. SA, Zawiercie, Poland). The STRATUS (Carl Zeiss Meditec, Dublin, CA), the only TD-OCT in their study, had an EF-exam of 26.61%. The COPERNICUS (Optopol Tech. SA, Zawiercie, Poland) compiled the highest number of total errors compared with the other instruments and the authors attributed this result due to a more complex analysis for retinal segmentation used by this OCT machine as compared to others.

When the number of B-scans per study was taken into account, the STRATUS (Carl Zeiss Meditec, Dublin, CA) was the instrument with the highest EF-scan, even compared with the COPERNICUS (Optopol Tech. SA, Zawiercie, Poland). This observation was explained by the study group due to utilization of the radial line protocol (which included six scans) by the STRATUS (Carl Zeiss Meditec, Dublin, CA) machine and

thus the EF-exam could not accurately describe the clinical significance in comparison to EF-scan. They thus concluded that EF-scan determination may be more important when comparing the ability of different instruments to accurately create a retinal thickness map.

Artifacts based on pathology

Studies by various authors[2,3,12,30] have shown that the severity of retinal abnormalities is directly connected to the frequency of imaging errors. Giani et al.[11] proposed that this could occur because the software tries to identify the normal pattern of hyper- and hypo-reflective layers on each single A-scan. Pathologic conditions lead to haphazard remodeling of the retinal segmentation that is strictly dependent on the severity and the type of alteration. They observed, however, that the errors produced by different instruments were often similar in certain pathologic conditions. They inferred that it was likely because for all the devices, different layers were recognized using algorithms that identified gray value variations along the A-scan lines.

The authors concluded that CIRRUS (Carl Zeiss Meditec, Dublin, CA), SPECTRALIS (Heidelberg Engineering, Vista, CA), and TOPCON3D OCT-1000 (Topcon Medical Systems, Paramus, NJ) were the most reliable machines with excellent results, especially in normal retinae. They noted that all the SD-OCT systems used a raster line protocol, STRATUS (TD OCT) (Carl Zeiss Meditec, Dublin, CA) used a radial line protocol, thus this potentially led to a higher number of artifacts in pathologic conditions that directly affected the fovea. They found that the error occurrence was not deeply dependent on the noise quantity and they also inferred that the effectiveness of the automated delimitation of retinal boundaries was probably not dependent on the lateral resolution of the OCT machine as well.

Giani et al.[11] observed that in the epiretinal membrane group, errors were more frequent in the non-central macula and in delimiting the inner retinal boundary. In neovascular and nonneovascular AMD groups, however, the errors affecting the outer retinal boundary were more common. They also reported that in the macular hole group, the most common error was the imprecise recognition of hole shape, leading to overestimation of retinal thickness in the outer layers adjacent to the hole center. In severe myopia, they noted that the most common error was the translation of the retinal boundary adjacent to the choroid. The authors explained that this observation is occurring as a result of the significant reduction of retinal layer reflectivity and thickness typical of this condition. The signal from the choroid was increased because of the reduced attenuation of the retina and this resulted in shifting of the boundary positions by the software toward the choroidal hyper reflectivity.

Han et al.[10] reported that for both instruments, eyes with uveitis had the highest percentage of scans with centration errors. This result may be related to media opacity creating a difficult view for the OCT operator to center the scan properly in uveitic eyes. They also observed that in eyes with AMD, misidentifications of the outer retina were more common than misidentification of the inner retina for both CIRRUS (Carl Zeiss Meditec, Dublin, CA) and SPECTRALIS (Heidelberg Engineering, Vista, CA). They inferred that this is likely due to pathologic disruptions of the outer retina such as drusen and choroidal neovascularization, which creates challenges for proper appropriate outer segmentation line placement. Kim et al.[31] also reported a higher rate of segmentation error in AMD, more in CIRRUS HD-OCT (Carl Zeiss Meditec, Dublin, CA) compared to SPECTRALIS (Heidelberg Engineering, Vista, CA) OCT.

Table 1. OCT artifact and what to do?

OCT artifact	Remedial measure
Inner layer misidentification	Manual correction
Outer layer misidentification	Manual correction
Mirror artifact	Retake the scan in the area of interest
Degraded image	Repeat scan after proper positioning
Out of register scan	Repeat the scan after realigning the area of interest
Cut edge artifact	Ignore the first scan
Off center artifact	Retake the scan/manually plot the fovea
Motion artifact	Retake the scan
Blink artifact	Retake the scan

To conclude, artifacts occur in all makes of OCT machines and the first step to rectify these artifacts is by identifying them.[9] This can be done by looking at the topography map, which would enable us to identify off-center artifacts. Similarly, screening of individual scans helps us to identify improper delineation of inner and outer retinal layers and out of register artifacts. Looking at the rendered fundus image helps us to note motion and blink artifacts. The next step would be to take the appropriate remedial measures to achieve more realistic information from this imaging technique. (Table 1) At the end, not all the artifacts are important and affect the clinical management. The hope is that future advancement in OCT technology would further reduce artifacts to improve the image quality and clinical management.

Conflict of interest

The authors declare that there is no conflict of interest.

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