

Retinal and Choroidal Imaging With 870-nm Spectral-Domain OCT Compared With 1050-nm Spectral-Domain OCT, With and Without Enhanced Depth Imaging

Elizabeth A. Verner-Cole², John P. Campbell¹, Thomas S. Hwang¹, Michael L. Klein^{1,2}, Andreas K. Lauer¹, Dongseok Choi¹, and Steven T. Bailey¹ ✉

¹Casey Eye Institute (CEI), Oregon Health and Science University, Portland, OR, USA

²Devers Eye Institute, Legacy Health System, Portland, OR, USA

Correspondence: Steven T. Bailey, 3375 SW Terwilliger Boulevard, Portland, OR 97239, USA. e-mail: bailstev@ohsu.edu

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Purpose: The purpose of this study was to compare images of the retina and choroid obtained with Spectralis 1050-nm spectral-domain optical coherence tomography (SD-OCT) with and without enhanced depth imaging (EDI) to the commercially available 870-nm SD-OCT with and without EDI.

Methods: Full-length 30° line scans were obtained with both 870- and 1050-nm Spectralis OCT instruments, with and without EDI. Two trained retina physicians masked to wavelength and EDI status assessed the ability to visualize the vitreoretinal interface and full-thickness choroid, and subfoveal choroidal thickness (SFCT) was measured.

Results: Included in the study were 21 eyes. The vitreoretinal interface was visualized best with 870-nm OCT without EDI and was diminished with 1050-nm OCT. Graders preferred 1050 nm with EDI over 870 nm with EDI in qualitative comparisons of the choroid; 1050 nm without EDI was slightly preferred over 870 nm with EDI but was not statistically significant. SFCT measurements correlated well among the imaging modalities except for 870 nm without EDI.

Conclusions: SD-OCT with EDI at 870 nm provides good visualization of both the vitreoretinal interface and choroid, whereas 1050-nm SD-OCT with or without EDI provides more choroidal detail at the expense of visualization of the vitreoretinal interface.

Translational Relevance: Use of longer wavelength 1050-nm SD-OCT provides greater choroidal detail compared with 870-nm SD-OCT, but has reduced detail of the vitreoretinal interface. The significance of this trade-off for clinical management of retinal disease needs further evaluation.

Introduction

Optical coherence tomography (OCT) generates cross-sectional retinal imaging with micrometer-level axial resolution¹ and has become a critical tool in the evaluation and treatment of a variety of retinal diseases. Commercially available high speed spectral-domain OCT (SD-OCT) uses an 870-nm wavelength light source that provides excellent imaging of the vitreoretinal interface and retina,² but often lacks full-thickness visibility of the choroid due to depth and density of choroidal tissue and light attenuation by the retinal pigment epithelium (RPE).³ Enhanced

depth imaging (EDI), first described by Spaide et al.,⁴ is a technique that can be employed on the SD-OCT machine to provide deeper imaging beneath the RPE and into the choroid. Using EDI-OCT, Spaide and others have shown that the choroid undergoes both age-related changes as well as pathologic changes in various retinal disease processes that were not easily visible prior to use of OCT.⁵⁻⁷ Due to increased interest in choroidal imaging with OCT, other methods have been used to try to better visualize and measure the choroid, including use of swept-source OCT (ss-OCT)⁸ and longer wavelength OCT.⁹⁻¹¹ All of these methods, however, potentially cause loss of clear

Figure 1. The four study images in this eye with neovascular AMD show decreased ability to visualize vitreoretinal adhesion with addition of EDI and use of longer-wavelength OCT (1050 nm), labeled with *yellow arrows*. Vitreoretinal adhesion is clearest with 870-nm OCT without EDI. In addition, full-thickness choroid is increasingly more visible with longer wavelength and addition of EDI (*yellow bracket*).

visualization of the retinal surface, where other pathology such as vitreomacular traction or epiretinal membrane might be present and contributing to poor vision. To date, no studies have compared image quality of the vitreoretinal interface, sensory retina, and choroid to the readily available EDI-OCT technique demonstrated by Spaide et al.⁴

The purpose of this study was to compare commercially-available Heidelberg Spectralis (Heidelberg Engineering, Heidelberg, Germany) 870-nm SD-OCT imaging of the vitreous, retina, and choroid with a prototype longer wavelength 1050-nm Heidelberg Spectralis SD-OCT imaging, with and without EDI. Specifically, the aims were to determine whether 1050-nm SD-OCT imaging provided improved choroidal visualization when compared with standard 870-nm imaging (with and without EDI) across a spectrum of patients with and without macular disease, and whether that additional benefit was at the expense of visualization of the retina and vitreous.

Methods

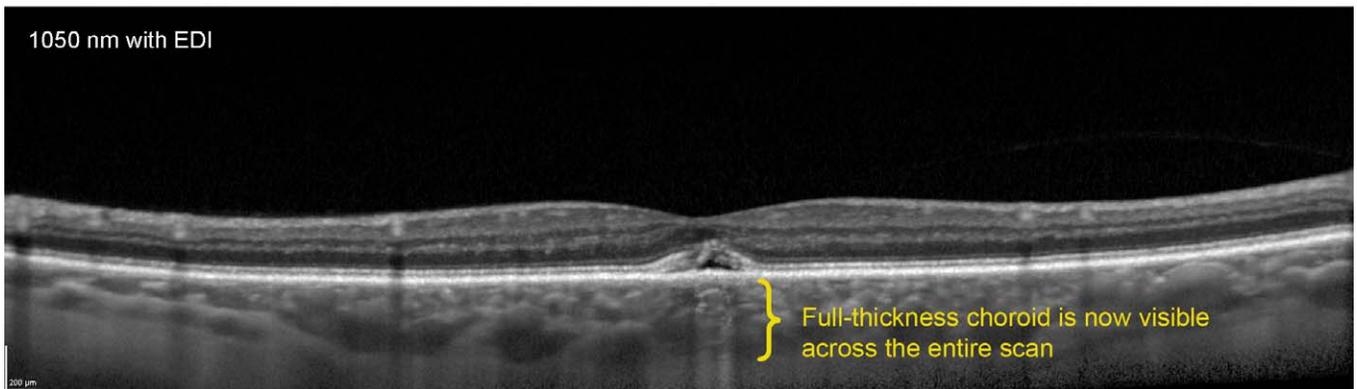
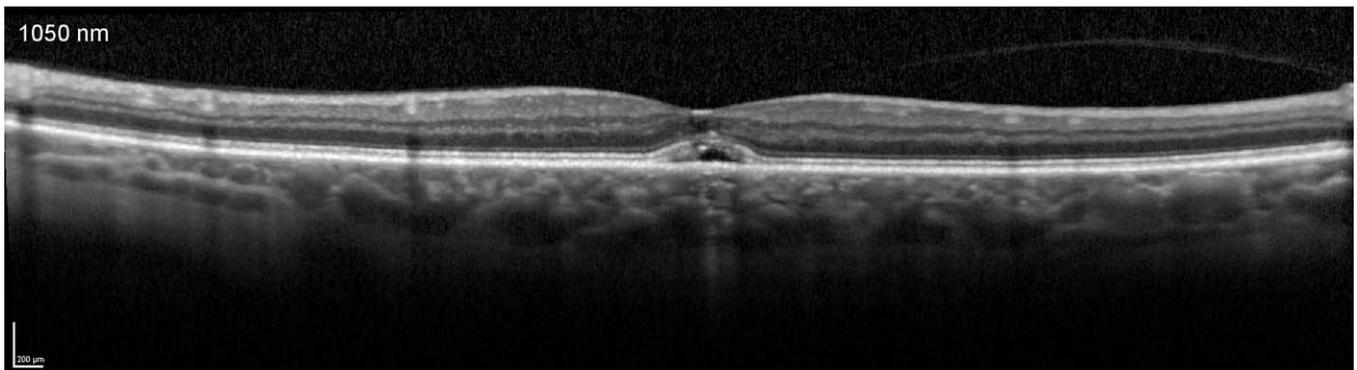
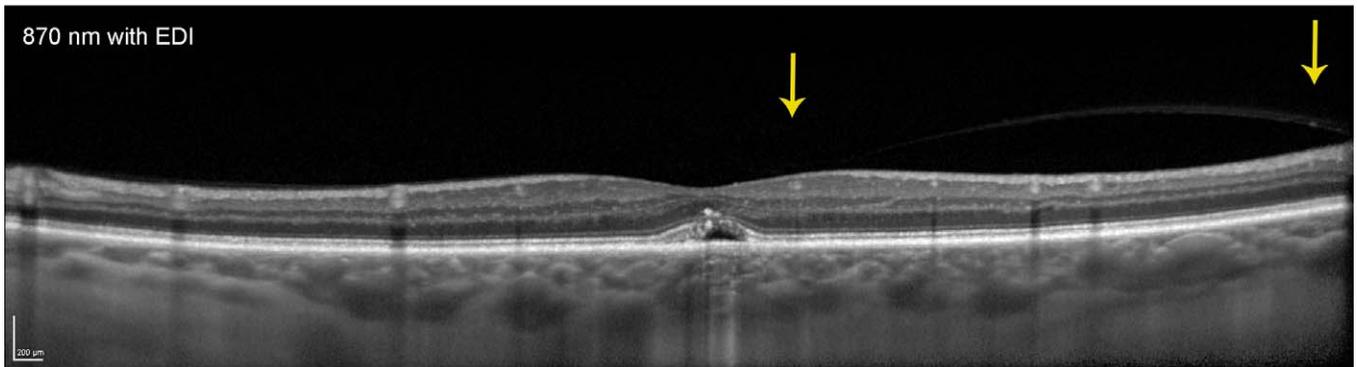
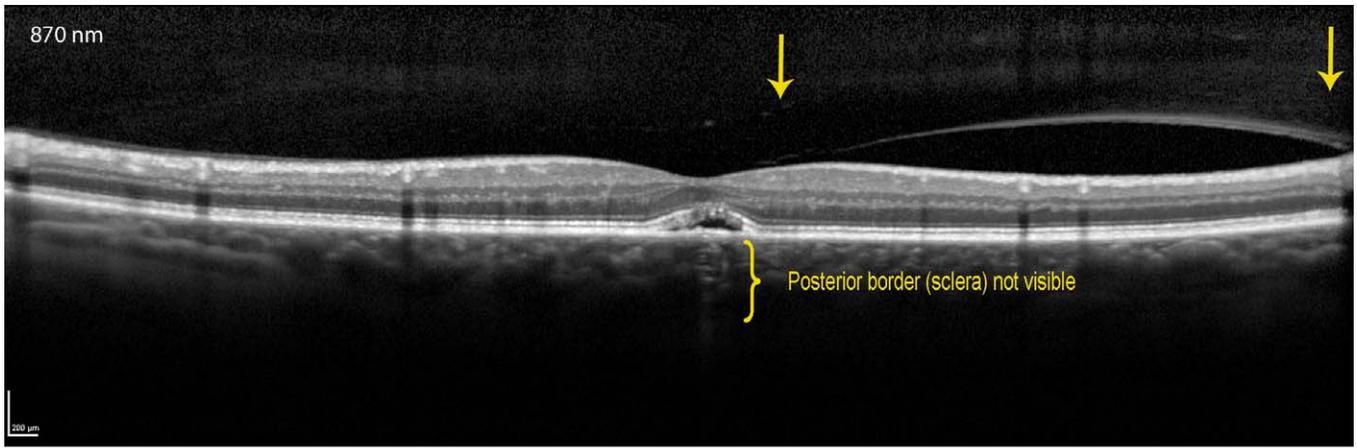
This was a prospective comparative study of 21 patients seen at the Devers Eye Institute Retina Service (Portland, OR) over a 1-month period. Informed consent was obtained from all study participants. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Legacy Health System (Portland, OR) institutional review board.

Full-length 30° horizontal and vertical line scans for each eye were obtained on a single visit and registered with 870- and 1050-nm instruments, with and without EDI (Spectralis: Heidelberg Engineering). The data acquisition speed was 40,000 A-scans/second for the 870-nm machine and 29,400 A-scans/sec for the 1050-nm machine, and oversampling of the OCT images remained constant among all scan techniques. Scans on the two machines were obtained within 5 minutes. The quality of each scan was determined using the signal strength reported for each image (in dB), and poor quality scans were excluded (<25 dB). An attempt was made to obtain the highest quality scan for each patient. One line scan was

studied per eye, either vertical or horizontal, depending on which scan had the highest quality images for all of the imaging modalities. Selected images were transferred to a PowerPoint (Microsoft, Redmond, WA) slide show allowing for random presentation to graders. Two trained retina physicians masked to patient, wavelength, and EDI status evaluated the images assessing the following: ability to visualize the vitreoretinal interface, ability to visualize full-thickness choroid, and qualitative comparison of images to one another.

The ability to see the vitreoretinal interface was assessed by reviewing individual images and grading them as simply “yes” or “no,” with yes indicating presence of any visible vitreoretinal adhesion. The ability to see full-thickness choroid (from Bruch’s membrane to inner sclera) was graded as 0% to 50% visible (meaning up to one-half the length of the OCT image included full-thickness visibility of the choroid), 51% to 90% visible, or 91% to 100% visible (full-thickness choroid was appreciated for nearly the entire length of the image).

Both graders qualitatively evaluated images using the 870 nm with EDI image as the “standard” to which the other imaging modalities were compared (since that was the commercially available wavelength at the time of the study that allowed for deeper choroidal imaging). Graders were shown a slide with two images: the 870 nm with EDI image at the top of the slide and an image from one of the other modalities (870 nm without EDI, 1050 nm with EDI, or 1050 nm without EDI) at the bottom of the slide. Graders were masked to all images, which were presented in a random fashion, and were asked to compare the quality of the image at the bottom of the slide to the image at the top of the slide with respect to the vitreoretinal interface, sensory retina (anterior to RPE), and choroid. Grading categories included superior, equivalent, or inferior when compared with the standard 870-nm SD-OCT with EDI. For each of these comparisons, a grade of superior (+1), equivalent (0), or inferior (−1) was given, and the scores from both graders were added to give a final score (i.e., if both graders felt a given image was superior to the 870 nm with EDI equivalent, it was given a score of +2; if one grader felt it was equivalent and the other



grader felt it was inferior to the 870-nm equivalent, then it was given a score of -1 .

Lastly, subfoveal choroidal thickness (SFCT) was measured manually by two graders using calipers within the Heidelberg software, measuring from the outer aspect of Bruch's membrane to the choroidal-scleral interface, defined as a hyperreflective layer at the posterior edge of the choroid. These measurements were averaged and then compared among the four image types. Additionally, interobserver reliability was assessed for each image type.

In order to analyze the degree of visible full-thickness choroid, the grades of 0% to 50%, 51% to 90%, and 91% to 100% were converted to -1 , 0 , and 1 , respectively. The averages between the two graders were computed, followed by performance of paired t -tests (870 vs. 870 nm with EDI, 1050 vs. 870 nm with EDI, 1050 with EDI vs. 870 nm with EDI) with confidence intervals (CIs). In order to analyze the qualitative comparisons between the different imaging modalities and the standard 870 nm OCT with EDI, the grades of superior, equivalent, and inferior were converted to a number grade as previously described. The mean, standard error, and 95% CI for each pair was calculated. Pearson's correlation coefficients were determined for the SFCT measurements for interobserver correlations, and average SFCT for each imaging modality between the two graders was calculated.

Results

Of the 18 patients who entered the study, 21 eyes of 13 patients ultimately underwent evaluation based on ability to obtain high quality SD-OCT images with all four imaging modalities. The mean age of the patients in our study was 74 years. Macular pathology among patients included nonneovascular age-related macular degeneration (AMD; 5 eyes), neovascular AMD (4 eyes), diabetic macular edema (2 eyes), macular edema secondary to vein occlusion (3 eyes), epiretinal membrane (4 eyes), and none/healthy (4 eyes). One eye had both neovascular AMD and epiretinal membrane present.

Assessment of the vitreoretinal interface revealed 5 of 21 eyes (24%) with vitreoretinal adhesion in at least one of the four images, and in all these cases it was present on 870-nm OCT imaging without EDI. With addition of EDI to the 870-nm images, the same vitreoretinal adhesion was still visible in four out of the five eyes (the fifth eye is depicted in Fig. 1). When 1050 nm with and without EDI imaging was used in

Table 1. Average Grade for Each Imaging Modality With Regard to Visibility of Full-Thickness Choroid, Including Differences in Grade and Associated P Values When Compared With the Standard of 870 nm With EDI.

Imaging Modality	Average Grade	Difference in Grade From Standard 870 nm With EDI	P value
870 nm	-0.21	-0.71	<0.01
870 nm with EDI	0.50	0	—
1050 nm	0.33	-0.17	0.07
1050 nm with EDI	0.67	0.17	0.05

Grading was on a spectrum of -1 to $+1$, with -1 representing 0% to 50% visible, 0 representing 51% to 90% visible, and $+1$ representing 91% to 100% visible.

these five eyes, the point of vitreoretinal adhesion either disappeared or there was disagreement between the two graders as to its visibility.

In assessing full-thickness choroid visibility, as expected there was a statistically significant difference in how much choroid was visible with 870-nm OCT compared with 870-nm OCT with EDI (difference in grade = -0.71 ; $P < 0.01$), as displayed in Table 1. There was also a slight statistically significant difference ($P = 0.05$) in improved full thickness choroid visibility with 1050 nm with EDI compared with 870 nm with EDI. There was no difference between 870 nm with EDI compared with 1050 nm without EDI ($P = 0.07$).

Qualitative comparisons of 870 nm with EDI to the other three imaging modalities with respect to visualization of the vitreoretinal interface, sensory retina, and choroid are shown in Figure 2. Images of the vitreoretinal interface obtained with 870 nm without EDI were considered superior to 870 nm with EDI, while images obtained with 1050 nm with EDI were graded as inferior. Use of 1050 nm without EDI was equivalent to 870 nm with EDI with respect to the vitreoretinal interface. None of the imaging modalities were superior or inferior to the standard with respect to visualization of the sensory retina. Results for visualization of the choroid were opposite those of the vitreoretinal interface, with 1050 nm with EDI superior and 870 nm without EDI inferior to the standard. No significant difference was noted comparing 1050-nm OCT with the standard 870 nm with EDI.

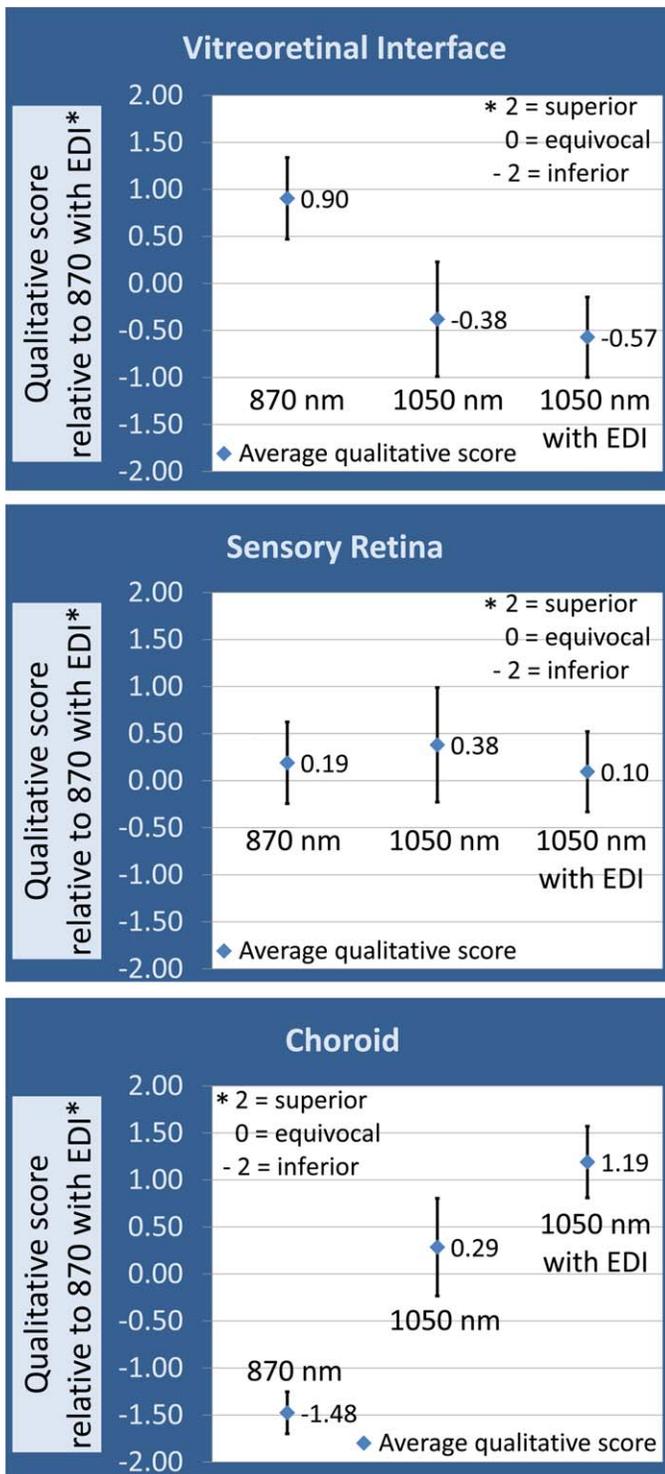


Figure 2. Qualitative comparison of 870 nm with EDI to the other three imaging modalities with respect to visualization of the vitreoretinal interface, sensory retina, and choroid. Each image was compared with its corresponding 870-nm EDI image and given a grade of superior (+1), equivalent (0), or inferior (−1). The scores were added for the two graders, who were masked to wavelength and EDI status. Shown are average scores for each wavelength (±EDI) with 95% CIs.

Average SFCT was measured as follows: 870 nm without EDI (179 μm ; 95% CI = 80–278 μm), 870 nm with EDI (214 μm ; 95% CI = 41–388 μm), 1050 nm without EDI (209 μm ; 95% CI = 51–367 μm), and 1050 nm with EDI (215 μm ; 95% CI = 42–387 μm). High interobserver correlation of SFCT measurements was seen with both EDI and longer wavelength but not with 870 nm without EDI (Table 2, bold data). When SFCT measurements were compared between the different imaging modalities, high correlation again was seen between all imaging modalities except 870-nm OCT.

Discussion

In this study, we compared the quality of images of the vitreoretinal interface, sensory retina, and choroid using standard and longer wavelength SD-OCT imaging, with and without EDI, on the Spectralis platform. We found superior imaging of the choroid with 1050-nm OCT with EDI when compared with 870-nm OCT with EDI in one-to-one qualitative comparisons. 1050 nm without EDI appeared to have equivalent choroidal image quality compared to 870 nm with EDI. Similar trends were seen when graders were asked to quantify how much full-thickness choroid was visible per image; 1050 nm with EDI demonstrated a slight statistically significant improvement over 870 nm with EDI, while 1050 nm without EDI was equivalent to 870 nm with EDI.

In this study, our graders found the vitreoretinal interface was best visualized with 870 nm without EDI and the longer wavelength OCT images had the poorest quality images of the vitreoretinal interface regardless of EDI status. As far as we are aware, this has not been described in current studies evaluating longer wavelength ss-OCT.^{8–13} Figure 1 demonstrates a case of neovascular AMD with vitreomacular adhesion not evident with the longer wavelength images. While no firm conclusions can be made regarding the clinical relevance of this specific finding, this case illustrates the potential loss of sensitivity to pathology at the retinal surface with use of these OCT modalities. This warrants further evaluation as OCT has greatly improved our understanding of how the vitreoretinal interface is related to pathology such as vitreomacular traction¹⁴ and AMD.^{15,16}

In a study comparing standard OCT to faster (100,000 A-scans/sec) longer wavelength ss-OCT imaging, Sayanagi et al.¹² imaged 79 eyes with polypoidal choroidal vasculopathy (PCV) and 63 eyes with AMD and found their prototype ss-OCT with

Table 2. Pearson's Correlation Coefficients for SFCT Measurements (Averaged Between the Two Graders) Compared Between Imaging Modalities.

Imaging Modality	870 nm	870 nm with EDI	1050 nm	1050 nm with EDI
870 nm	0.77	0.79	0.79	0.76
870 nm with EDI	0.79	0.91	0.97	0.99
1050 nm	0.79	0.97	0.90	0.96
1050 nm with EDI	0.76	0.99	0.96	0.94

Bold data represent interobserver correlation between the two graders for each modality.

longer wavelength improved visualization of the choroidal-scleral interface and improved definition of some pathologic findings compared with Spectralis SD-OCT without EDI. There are several differences, however, from our study in that our graders were masked, we compared the longer wavelength scans to 870 nm with EDI (while the majority of their lower wavelength scans were without EDI), and we studied vitreous at the vitreoretinal interface, not just presence of epiretinal membrane. Like their study, ours also found improved visualization of choroid with longer wavelength, however our study did not address presence or absence of specific pathologic features associated with the RPE and choroid. Similarly, Yasuno et al.¹³ found improved contrast of morphologies beneath the retinal pigment epithelium with their prototype ss-OCT (1060 nm; 28,000 depth scans/sec) compared with standard OCT without EDI. No comment was made regarding visibility of the vitreoretinal interface.

SFCT measurements were consistent between 870 nm with EDI and 1050 nm with and without EDI. Copete et al.¹⁷ found similar SFCT measurements with SD-OCT with EDI compared with faster ss-OCT at 1050 nm as did Ikuno et al.¹⁸ Differences in image quality of the vitreoretinal interface between the two systems was not evaluated. Despite the perceived superior quality of choroidal imaging with 1050-nm OCT in our study, it did not seem to improve the ability to measure SFCT compared with 870 nm with EDI. As expected, longer wavelength was superior to 870 nm without EDI. Our mean SFCT measurements with the longer wavelength and 870 nm with EDI was slightly over 200 μm , which is lower than expected for healthy eyes of similar age (250 μm for average age of 74 years).⁵ A likely reason for the lower mean is due to the fact that one-half the patients had AMD, which has been demonstrated to have variable choroidal thickness with OCT.¹⁹ Furthermore, refractive error and axial length were not reported as part of our

study. Overall, these data suggest that 870-nm SD-OCT with EDI may be sufficient in obtaining SFCT measurements, and 1050-nm SD-OCT may not provide additional benefit, at least in eyes without significant choroidal thickening.

There are several weaknesses to our study. The number of patients was small as we were only allowed a finite amount of time to acquire images due to the prototype OCT use in other studies. The relatively thin choroidal thickness in our study patients may have limited the ability to detect an advantage of longer wavelength OCT. The study population had a high degree of heterogeneity in terms of underlying disease, however this does simulate a typical clinical retinal practice. Lastly, this study did not address pathology associated with thickened choroid, such as central serous chorioretinopathy and Vogt-Koyanagi-Harada (VKH), in which the longer wavelength may prove even more useful. The strengths of this study include the prospective nature of the study, masking the graders to all images reviewed, and registration of images allowing for a high degree of line scan correspondence.

In this small study with the Spectralis SD-OCT platform, longer wavelength OCT improved choroidal visualization at the expense of visibility of the vitreoretinal interface. Improvement of choroidal visibility was marginal compared with 870 nm with EDI, and no difference in SFCT measurements was noted. Future longer wavelength and ss-OCT studies should include vitreoretinal interface visibility, and disease-specific studies (such as central serous chorioretinopathy or VKH) are needed to demonstrate clinical benefits of longer wavelength OCT.

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