Retinal Thickness and Volume Measured With Enhanced Depth Imaging Optical Coherence Tomography

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• PURPOSE: To evaluate the retinal thickness and volume measured with the enhanced depth imaging (EDI) method compared with those measured with the conventional method using spectral-domain optical coherence tomography (OCT).

• DESIGN: Retrospective, observational, case-control study.

• METHODS: Clinical records of 20 healthy subjects and those of 35 patients with chorioretinopathy (central serous chorioretinopathy, polypoidal choroidal vasculopathy, Vogt-Koyanagi-Harada disease, and reticular pseudodrusen) were analyzed retrospectively. All subjects underwent spectral-domain OCT using both the conventional and the EDI OCT raster scan protocols. The raster scan was composed of 31 B-scans that were 9.0 mm in length and 240 μm apart. Retinal thickness and volume of 9 Early Treatment Diabetic Retinopathy Study subfields were investigated. Intraclass correlation coefficients, Bland-Altman plots, and Wilcoxon signed-rank test results were used for the analysis.

• RESULTS: Sixty-five eyes of 35 patients with chorioretinal diseases and 40 eyes of 20 normal healthy subjects were evaluated. The automatically measured retinal thickness and volume of 9 Early Treatment Diabetic Retinopathy Study subfields with conventional and EDI raster scan showed an intraclass correlation coefficient of 0.861 to 0.995 and 0.873 to 0.995, respectively. The 95% limits of agreement between the 2 protocols in the measurement of central subfield were −14.52 to 12.88 μm in retinal thickness and −0.014 to 0.013 mm^3 in retinal volume. The differences of segmentation error rate between the 2 protocols were statistically insignificant ($P > .05$), except in eyes with reticular pseudodrusen in the subgroup analysis ($P = .006$). No significant differences were observed in measured values between healthy eyes and unaffected fellow eyes.

• CONCLUSIONS: The EDI OCT raster scan showed high agreement with conventional OCT in the measurement of retinal thickness and volume and could be used to evaluate both the retina and choroid in normal eyes and in eyes with some forms of chorioretinal disorder. (Am J Ophthalmol 2013;156:557–566. © 2013 by Elsevier Inc. All rights reserved.)

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THE ADVANCEMENT OF TECHNOLOGIES IN THE FIELD of OCT has enabled reproducible, automatic, quantitative measurement of retinal thickness or volume, even in pathologic eyes.[1,2] Recently, the enhanced depth imaging (EDI) method of spectral-domain optical coherence tomography (SD OCT), which places zero delay line to the choroid to obtain high-resolution images of the choroid, has enabled the quantitative measurement of choroidal thickness or volume, in addition to obtaining cross-sectional images of choroid.[3–8] Several SD OCT instruments now provide the conventional method for retinal evaluation and the EDI method for choroidal evaluation.

Previous studies using EDI OCT revealed that many ocular disorders feature thickness change of the retina as well as changes in the choroid. These disorders include hyperopia,[9] myopia,[10] central serous chorioretinopathy (CSC),[11] polypoidal choroidal vasculopathy (PCV),[12] age-related macular degeneration,[4,12] reticular pseudodrusen (RPD),[13] age-related choroidal sclerosis,[4] inherited retinal dystrophy,[14] inflammatory eye diseases,[15] diabetes,[16] and glaucoma.[17] In most of these disorders, both the conventional OCT and EDI OCT can be used to evaluate the retina and the choroid, respectively. Furthermore, the raster scan for the assessment of topographic variation of the thickness and volume could be more useful than a cross-sectional scan. However, it is time consuming and sometimes uncomfortable for the patient to undergo both OCT scans. We noted that the EDI OCT provides an image of both the retina and the choroid, whereas conventional OCT cannot. In addition, EDI OCT automatically provides a map of retinal thickness and volume in the raster scan mode, just as conventional OCT does. If the measured values provided by EDI OCT show similar results as those provided by conventional OCT, only the EDI OCT raster scan can be used to evaluate both the retina and choroid in eyes with chorioretinal disorders. Furthermore, the choroidal autosegmentation software for the EDI OCT probably will be available in the near future.[18] Hence, EDI OCT raster scanning will be a more efficient method of examination in clinical practice.

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However, a PubMed search revealed a scarcity of data comparing the retinal thickness or volume measured by these 2 OCT raster scan protocols. Thus, it is not clear whether automatically measured values of retinal thickness or volume by EDI OCT are acceptably similar to those measured by conventional OCT. In this study, we evaluated the agreement of the retinal thickness and volume in the maps provided with EDI OCT raster scanning and conventional OCT raster scanning.

METHODS

THIS STUDY WAS APPROVED BY THE INSTITUTIONAL REVIEW board of Samsung Medical Center, Seoul, South Korea, and adhered to the tenets of the Declaration of Helsinki. We performed a retrospective chart review of patients who visited the retina clinic of Samsung Medical Center between April 12 and May 5, 2012. Clinical records of consecutive patients who were diagnosed as having CSC, PCV, Vogt-Koyanagi-Harada (VKH) disease, or RPD and underwent SD OCT with both the conventional and EDI raster scan protocol were used in this study. Imaging data of 20 healthy subjects, randomly selected from the database of Korean Twin Study (an institutional review board-approved, prospective study carried out at Samsung Medical Center) performed between April 2012 and November 2012, were reviewed retrospectively. The healthy subjects were twins or a family member. Among twins, only 1 of the pair was selected to avoid any possible duplication effect by monozygotic twins. The exclusion criteria for the study included the presence of any vitreoretinal interface abnormalities, such as epiretinal membrane; severe retinal structural changes, such as almost full-thickness retinal atrophy and disciform scar; refractive errors exceeding ± 4 diopters; and having poor-quality images precluding retinal boundary segmentation.

All subjects underwent complete ophthalmic examination, including slit-lamp examination, corrected distance visual acuity assessment, intraocular pressure measurements, funduscopy using wide-angle noncontact lens, fundus color photography, and SD OCT with both the conventional and the EDI raster scan protocol. In addition, patients with chorioretinal diseases underwent near-infrared photography, red-free photography, and autofluorescence imaging. Fluorescein angiography and indocyanine green angiography were performed in some of the patients. Fundus color photographs were obtained with a model IX50 camera (Topcon, Paramus, New Jersey, USA). Near-infrared photography, red-free photography, autofluorescence imaging, fluorescein angiography, indocyanine green angiography, and SD OCT were performed using Spectralis HRA+OCT, version 1.7.0.0 (Heidelberg Engineering, Heidelberg, Germany).

Central serous chorioretinopathy was diagnosed if patients had circumscribed subretinal fluid involving the macula associated with leakages from the retinal pigment epithelium (RPE) during fluorescein angiography, or if patients had a similar history documented in the past medical records. Acute CSC, chronic or recurrent CSC, and resolved CSC were included. The diagnosis of PCV primarily was based on the indocyanine green angiography findings and abnormal branching vascular networks with polypoidal aneurysmal dilatations. The diagnosis of VKH disease was based on the revised criteria of VKH disease established by the International Nomenclature Committee.[19] Patients with any phase (early and late) of ocular manifestations were included. The diagnosis of RPD was based on the appropriate findings described elsewhere.[20]

Both eyes were studied in all subjects who had bilateral retinal lesions. However, in subjects who had unilateral retinal lesions, the fellow eye with no retinal lesion was classified as the unaffected eye (UAE). Overall, 65 eyes of 35 patients with chorioretinal diseases were evaluated. The 35 patients consisted 14 with CSC, 8 with PCV, 4 with VKH disease, and 9 with RPD. Study eyes at baseline consisted of 16 eyes of 14 patients with CSC, 9 eyes of 8 patients with PCV, 8 eyes of 4 patients with VKH disease, and 18 eyes of 9 patients with RPD. However, 2 eyes of 2 RPD patients were excluded because of an epiretinal membrane (1 eye) and almost full-thickness retinal atrophy with disciform scar (1 eye). Sixteen of 19 unaffected fellow eyes of study patients were evaluated as the UAE group, which included 12 fellow eyes of CSC patients and 4 fellow eyes of PCV patients. Three unaffected fellow eyes of 3 PCV patients were excluded because of inadequate OCT examination (1 eye) and poor OCT image quality (2 eyes).

• **OPTICAL COHERENCE TOMOGRAPHY EXAMINATIONS AND EVALUATIONS:** The raster scan was performed on each eye centered at the fovea using 2 scan protocols: a conventional protocol and an EDI protocol.[3] The raster scan was composed of 31 B-scans covering an area of 30 degrees × 25 degrees. Each B-scan consisted of 768 A lines, 9.0 mm in length and spaced 240 μm apart from each other. The automatic real-time mode using an eye-tracker system was activated, and 25 frames were averaged for 1 B-scan image. Both protocol scans were performed on the same day with a single examination session in random order. During the OCT examination, subjects continuously were encouraged to fixate on the internal fixation target.

The retinal thickness and volume was measured using the built-in software of the Spectralis with the autosegmentation algorithm, which calculates the retinal thickness as the distance between the vitreoretinal interface and the outer border of RPE. Topographic maps with numerical values were produced by the calculation of software in 9 subfields of the Early Treatment Diabetic Retinopathy Study grid.[21]

The autosegmentation lines in 31 B-scan images were assessed by 2 independent masked physicians (S.Y.P. and S.M.K.). The number of B-scans with segmentation error was evaluated in each raster scan session. If there was