Effect of Optical Coherence Tomography Scan Decentration on Macular Center Subfield Thickness Measurements

Jeong W. Pak,¹ Ashwini Narkar,¹ Sapna Gangaputra,¹ Ronald Klein,² Barbara Klein,² Stacy Meuer,² Yijun Huang,^{1,3} and Ronald P. Danis^{1,3}

¹Fundus Photograph Reading Center, Department of Ophthalmology and Visual Sciences, University of Wisconsin–Madison, Madison, Wisconsin

²Ophthalmic Epidemiology Reading Center, Department of Ophthalmology and Visual Sciences, University of Wisconsin–Madison, Madison, Wisconsin

³McPherson Eye Research Institute, University of Wisconsin–Madison, Madison, Wisconsin

Correspondence: Yijun Huang, Fundus Photograph Reading Center, Department of Ophthalmology and Visual Sciences, University of Wisconsin–Madison, 8010 Excelsior Drive, Suite 100, Madison, WI 53717; yhuang@rc.ophth.wisc.edu.

Submitted: April 19, 2013

Accepted: June 3, 2013

Citation: Pak JW, Narkar A, Gangaputra S, et al. Effect of optical coherence tomography scan decentration on macular center subfield thickness measurements. *Invest Ophthalmol Vis Sci*. 2013;54:4512–4518. DOI: 10.1167/iovs.13-12265

PURPOSE. To investigate the effect of optical coherence tomography macular grid displacement on retinal thickness measurements.

METHODS. SD-OCT macular scans of 66 eyes with various retinal thicknesses were selected. Decentration of the 1-, 3-, 6-mm-diameter macular grid was simulated by manually adjusting the distance between center of the fovea (cFovea) and center of the grid (cGrid). Center subfield thickness (CSF) between the internal limiting membrane and the top of the retinal pigment epithelium was measured along the displacement distance where the grid was displaced in eight cardinal directions from the cFovea in steps of 100 μm within the central 1-mm subfield and then by 200 μm within the inner subfields. One-way/mixed-effects repeated-measures ANOVA models were used to determine changes of CSF (ΔCSF) as a function of displacement distance (for $\alpha = 0.05$, power = 0.80 and effect size = 0.1). The interactions between the displacement distance and direction, center point thickness (CPT), and foveal contour were also analyzed.

RESULTS. The CSF measurement showed statistically significant error when the displacement distance between cFovea and cGrid exceeded 200 μm . The direction of displacement did not affect the ΔCSF -distance relationship, while the CPT and foveal contour significantly affected the relationship, in that some subgroups showed slightly larger tolerance in the displacement distance up to 300 μm before reaching significant ΔCSF .

CONCLUSIONS. Small displacement distances of the macular grid from the cFovea affect CSF measurements throughout a broad range of thicknesses and retinal contour alterations from disease. Accurate registration of OCT scans or post hoc repositioning of the grid is essential to optimize CSF accuracy.

Keywords: SD OCT, retinal thickness, decentration, OCT artifacts

Optical coherence tomography (OCT)-measured retinal thickness of the central 1-mm zone of the fovea (center subfield thickness [CSF]) is an important outcome in clinical trials of diseases that affect the macula. CSF has been used in determining patient eligibility and for monitoring disease progression and treatment effects.^{1–10} The CSF is measured using OCT instruments with scanning patterns centered on the fovea: in time-domain OCT (TD-OCT), a radial pattern consisting of six intersecting scans is used; in spectral-domain OCT (SD-OCT) with faster scanning speed, usually a cube scan consisting of 128 or 200 horizontal raster lines is obtained. Retinal thickness is measured based on the segmented inner and outer boundaries of the retina, and averaged in each subfield of a 1-, 3-, 6-mm-diameter macular grid modified from the Early Treatment Diabetic Retinopathy Study (ETDRS) grid,¹¹ in which the averaged retinal thickness in the center subfield is reported as CSF.

The accuracy of the calculated CSF is dependent on the precise registration of the center of the macular grid (cGrid) to

the center of the anatomical fovea (cFovea). In practice, imprecise registration, or “decentration,” of the cFovea and cGrid locations may be introduced during data acquisition if the cGrid is not centered on the cFovea. Decentration occurs even among healthy subjects,^{12,13} and can become a large contributing factor for error, particularly when a patient has eccentric or unstable fixation. In TD-OCT, as the OCT data sampling sparsely covers the foveal region, rescanning may be necessary when the scanning pattern is displaced from the cFovea location. In SD-OCT, the foveal region is usually covered by the densely spaced cube scan, which allows post hoc examination of the serial B-scans and identification of the “true” cFovea location based on retinal morphological structure and recalculation of the CSF in corrected grid positioning.

In this study, we took advantage of the ability to position the cGrid location independently to the cFovea location in SD-OCT using custom image analysis software, and simulated decentration of the cGrid in a selected group of SD-OCT cube scans to study the absolute difference in CSF values (ΔCSF) as a function

FIGURE 1. Simulation of the decentration in spectral domain OCT cube scans by manually adjusting the distance between cFovea and cGrid. **(A)** Identification of cFovea on OCT scan. The location corresponding to the cFovea was determined by reviewing consecutive B-scans for evidence of the foveal depression and thinning of the nerve fiber layers. **(B)** cGrid was placed at the cFovea location and was artificially displaced from the cFovea in eight cardinal directions in steps of 100 μm within the center subfield and then in steps of 200 μm within the inner subfields. The CSF values were collected at cGrid of each displacement.

of the displacement distance. The data were further stratified by parameters such as direction of displacement, retinal thickness, and foveal morphologic shape. The purpose of the study was to determine the statistical and clinical relevance of the decentration effects on ΔCSF in normal and diseased eyes.

METHODS

This was a retrospective study using post hoc volumetric OCT macular scans (covering $6 \times 6\text{-mm}$ area with 512×128 sampling) obtained from two source datasets that both used Topcon 3D OCT 1000 (Topcon Corporation, Tokyo, Japan), the

Beaver Dam Eye Study,^{14,15} and a study evaluating differences between TD- and SD-OCT.¹⁶ Both studies were approved by the institutional review boards and compliant with the tenets of the Declaration of Helsinki and the Health Insurance Portability and Accountability Act.

We were interested in determining the minimum decentration at which ΔCSF becomes statistically significantly greater than zero. First, we examined the ΔCSF -distance relationship over the entire data samples, the overall ΔCSF , independent of the other contributing factors. Then, we examined the interactive effects between the distance and the following independent parameters. We hypothesized that the ΔCSF -distance relationship was influenced by these parameters:

TABLE 1. Sample Size Calculation and Distribution

Parameter	Calculated Minimum Sample Size	Group	Sample Distribution
Overall	35		66
CPT	11	0–100 μm	11
	11	101–200 μm	11
	11	201–300 μm	11
	11	301–400 μm	11
	11	401–500 μm	11
	11	>500 μm	11
Shape	15	Trough	29
	15	Flat	16
	15	Dome	21

Power = 0.8, effect size = 0.1, α = 0.05.

1. Direction of decentration: We examined the ΔCSF -distance relationship by ΔCSF along each of the eight cardinal directions from cFovea (Fig. 1) versus distance.
2. Center point thickness (CPT) measured at cFovea: Using the CPT, data were stratified into six groups of 100- μm steps of retinal thicknesses, ranging from less than 100 μm to greater than 500 μm of CPT (Table 1).
3. Foveal contour: We stratified the data into three foveal contours: flat, dome-shaped, and trough-shaped. The foveal contour was defined by the difference between the CPT and the perifoveal average thickness at 1100 μm away from cFovea: if the difference was none or minimal (± 50 μm) the contour was considered flat; if the center was thicker than the perifoveal region (> 50 μm) it was considered dome-shaped; and if the center was less than -50 μm from the perifoveal thickness, it was deemed trough-shaped (Fig. 2).

Statistical Models and Sample Size Calculation

We used a one-way repeated-measures ANOVA to examine the absolute ΔCSF -distance relationship overall and in each of the

eight cardinal directions, in which the distance step was the categorical variable and the ΔCSF was the continuous variable. For CPT and foveal contour parameters, we used a mixed model repeated-measures ANOVA.

We performed an a priori power analysis to determine the sample size for α = 0.05, power = 0.80, and effect size = 0.1 (calculated using G*Power, Version 3.1.3; program written by Franz Faul, Universität Kiel, Kiel, Germany). The requirements for the minimum sample sizes were calculated for each analysis (Table 1). Based on the minimum sample requirements, the data collection was designed to accommodate the CPT parameter that has the largest sample size requirement. OCT scans were selected randomly from the source datasets to fill the six CPT groups. A maximum of 11 images per group was selected, yielding the total number of 66 images of 66 subjects in the final dataset (Table 1). An additional selection criterion was image quality: only images with adequate signal quality to enable clear visualization of retinal layers and absence of artifacts were chosen.

Data Processing

The decentration analysis was performed in a custom OCT viewer (MATLAB R2011b; The MathWorks, Natick, MA). OCT scans were segmented by the segmentation algorithms incorporated in the Topcon 3D OCT 1000 software (Topcon Corporation), which are reported in the manufacturer's documentation to demarcate the internal limiting membrane (ILM) and the retinal pigment epithelium (RPE). The OCT raw data and the segmented lines were exported from the Topcon 3D OCT 1000 software (Topcon Corporation), converted into DICOM format, and read into the custom OCT viewer. A trained ocular disease evaluator (JWP) reviewed each scan for quality, and corrected any segmentation errors if present. The evaluator further reviewed all B scans to identify the A-scan location corresponding to the cFovea, as evidenced by the foveal depression and thinning of the nerve fiber layers. The ETDRS grid was adjusted to be centered at cFovea. The CPT and CSF values at cFovea were collected. Next, CSF was

FIGURE 2. Representative examples of foveal contour. (A) Normal fovea and (B) flat fovea were categorized to the difference of within ± 50 μm between the CPT and the average thickness at 1100 μm away from cFovea. (C) Dome-shaped fovea to the difference greater than $+50$ μm and (D) trough-shaped fovea to the difference less than -50 μm .

FIGURE 3. Overall Δ CSF-distance relationship for all 66 scans. The mean absolute Δ CSF was plotted as connected black dots, and the dotted lines indicate the 95% confidence interval. The displacement distance that exhibited statistically significant CSF measurement error is indicated by the asterisk.

measured as the center of the ETDRS grid was displaced in eight cardinal directions from the cFovea in steps of 100 μ m within the central 1-mm zone and then in steps of 200 μ m within the central 3-mm zone (Fig. 1). Δ CSF, the absolute difference of the CSF values between the cFovea location and the displaced cGrid locations, were calculated for each direction. In addition, overall Δ CSF was determined by averaging Δ CSFs among the locations of equal distance to cFovea from eight directions.

RESULTS

Data from 66 eyes were collected and analyzed. The sample distribution is summarized in Table 1; the requirements for minimum sample size were met for each grouping. There were 7 eyes with normal appearance and 59 eyes with various retinal lesions. Although lesion appearance was not investigated in this study, the following retinal abnormalities were observed in the dataset: epiretinal membrane (13 eyes), cysts (35), subretinal fluid (9), drusen (12), choroidal neovascularization (16), and geographic atrophy (8).

Overall Δ CSF Versus Distance

Figure 3 shows the relationship between overall Δ CSF and decentration distance. As the decentration distance increased, Δ CSF was also increased. At the displacement distance of 1100 μ m, the overall Δ CSF was as large as 73.41 μ m. One-way repeated-measures ANOVA shows when the displacement distance is greater than 200 μ m, the overall Δ CSF becomes statistically greater than zero ($P < 0.0001$).

Directionality

Figure 4A examined the decentration effect of the Δ CSF in the eight cardinal directions independently. Similar to the overall Δ CSF-distance relationship, Δ CSF increased as the decentration increased, and became statistically greater than zero when the displacement distance reached 200 μ m. However, the decentration effects were the same among the eight directions; the directional parameter did not influence the Δ CSF-distance relationship. Based on this finding, we used the overall Δ CSF for further analysis of decentration effect by CPT and foveal contour.

CPT

The data sample was stratified by CPT into six groups. In all groups, the Δ CSF became significantly greater than zero with large displacement distances. Among the groups, there were subtle differences. Eyes in the CPT groups of less than 100 μ m, 101 to 200 μ m, and 201 to 300 μ m demonstrated slightly more tolerance to displacement distance of 300 μ m, whereas eyes with CPT greater than 300 μ m showed significant effects of displacement with a threshold at 200 μ m (Fig. 4B; Table 2). Mixed model ANOVA indicated that an interactive relationship between CPT and Δ CSF-distance was statistically significant ($P < 0.0001$) (Table 3).

Foveal Contour

Similarly, we stratified the data sample by foveal contour (Fig. 4C). The eyes that were classified as the trough and flat shapes showed slightly more tolerance to decentration with a threshold at 300 μ m, whereas eyes with the dome shape

FIGURE 4. Interactive relationships between Δ CSF and three parameters. (A) Δ CSF-distance relationship stratified by direction. IN, inner nasal; T, temporal; the rest of the directions are in between. (B) Δ CSF-distance relationship stratified by CPT. Groups with CPT greater than 300 μ m showed the statistically significant decentration distance at 200 μ m (light gray area), and all groups showed significance at 300 μ m (dark gray area). (C) Δ CSF-distance relationship stratified by foveal contour. Flat and dome-shaped showed the statistically significant decentration distance at 200 μ m (light gray area) and all groups at 300 μ m (dark gray area).

showed a decentration threshold at 200 μ m (Table 3). The interactive relationship between foveal contour and Δ CSF-distance was analyzed to be statistically significant via mixed model ANOVA ($P < 0.0001$).

Magnitude of Decentration Error in CSF

The magnitude of CSF measurement error due to decentration is shown on Table 2. The overall Δ CSF for all 66 scans was 9.39 μ m at 200- μ m displacement from the true fovea to exhibit statistical significance. For all subgroups, Δ CSF ranged from 8.5 to 16.4 μ m. The minimum of the range, 8.5 μ m, approximates

the lowest CSF measurement error that is statistically significant.

DISCUSSION

Errors caused by decentering the OCT scan with respect to the anatomical fovea have been considered as one of the major sources of imaging artifacts in OCT data acquisition. In SD-OCT, the decentration error can be corrected after acquisition by the image acquirer, but this is time-consuming and not routinely performed in busy clinical practices. In this report,

TABLE 2. Δ CSF at the Threshold of Statistically Significant Decentration Distance

Parameter	Group	Displacement Distance, μm	Δ CSF at the Given Distance
Overall	Mean of all 66	200	9.39
Direction*	Superior-temporal	200	9.44
	Temporal	200	8.52
	Nasal	200	9.17
	Superior	200	8.68
	Superior-nasal	200	8.52
	Inferior	200	10.36
	Inferior-nasal	200	11.03
	Inferior-temporal	200	9.39
CPT	0–100	300	16.00
	101–200	300	16.40
	201–300	300	9.81
	301–400	200	10.84
	401–500	200	12.96
	>500	200	11.90
Foveal contour	Trough	300	14.59
	Flat	200	11.84
	Dome	200	11.11

* As there is no significant interaction within direction to distance, the statistically significant displacement distance for this parameter remained unchanged from that for the overall samples.

we investigated the following questions: what is the minimum displacement distance between anatomical fovea and grid center where the CSF measurement exhibits statistical difference, and how large is the variation in CSF given the allowable decentration? We used one-way and mixed-effect repeated measures ANOVA models to quantify the effects of decentration. Our data showed that the effect of decentration of the grid on the measurement of CSF becomes statistically significant beyond 200 μm from the true fovea (cFovea), where the average Δ CSF values were $9.39 \pm 6.05 \mu\text{m}$.

Our study was similar to findings in several other publications. Campbell et al.¹⁷ examined how the center subfield thickness measurement was affected by intentionally shifting the center fixation in TD-OCT scans in healthy subjects. Their findings indicated scan decentration of 0.5 mm resulted in statistically significant difference in foveal thickness measurements. Odell et al.¹⁸ demonstrated a correlative relationship between the decentration distance and the accumulative retinal error in both healthy and pathological subjects. Although in agreement with these findings, we used smaller decentration steps and statistical modeling, and determined the statistical threshold of decentration is approximately 200 μm . Furthermore, we categorized the normal and diseased retinas in subgroups based on direction of decentration, CPT value, and foveal contour. We confirmed that the magnitude of CSF measurement error was not affected by direction of decentration as reported by Campbell et al.¹⁷ Similar to the directionality parameter, we also found that the decentration effect was unaffected by retinal disease type, such as AMD and diabetic retinopathy (data not shown). However, the CPT and foveal contour parameters exhibited significant interactive effect on the Δ CSF-distance relationship. Nonetheless, all eyes showed statistically significant decentration error beyond 300 μm regardless of the subgrouping scheme.

Several publications addressed the error tolerance level that is considered to be *clinically* significant, which may vary with disease type and application of the OCT data. Han and Jaffe¹⁹

TABLE 3. Statistical Significance of Individual Parameters on Decentration

Parameter	Effect	P Value
Overall	Distance	<0.0001
Direction	Direction	<0.0001
	Distance	<0.0001
	Direction-distance interaction	0.9992*
	CPT	<0.0001
Foveal contour	Distance	<0.0001
	CPT-distance interaction	<0.0001†
	Foveal contour	<0.0001
	Distance	<0.0001
	Foveal contour-distance interaction	<0.0001†

Δ CSF-distance relationship was statistically significant for all the parameters analyzed.

* Although all directions affect decentration statistically significantly, there is no significant interaction between direction and the Δ CSF-distance relationship.

† CPT and foveal contour are statistically significant not only on displacement distance but also on the interaction of these parameters with Δ CSF-distance.

defined clinically significant artifacts as greater than 50 μm of the automated and corrected CSF or change of more than 10% of the true CSF. Ho et al.²⁰ defined decentration as eccentric fixation greater than 0.25 mm from the true fovea and clinically significant change as greater than 11 μm . We determined in this report that at the threshold of *statistically* significant decentration, the minimum measurement error of CSF is approximately 8.5 μm , regardless of retinal thickness or foveal contour. This information is useful in the discussion of the clinical tolerance of error because it defines the statistical threshold at which the methodology used for determining CSF begins to fail and add measureable variability to thickness measurements.

Additionally, our findings augment several repeatability and reproducibility studies of OCT devices in patients with retinal diseases.^{18,20–24} It is suspected that the repeatability and reproducibility variance is chiefly due to decentration error and/or segmentation error generated during image acquisition.^{17,22,25–29} The statistically significant threshold for decentration error in our result is approximately 8.5 μm of the CSF change in both healthy and various retinal pathological eyes, supporting that decentration error indeed accounts for a large portion of CSF measurement variability. Subsequently, correcting the decentration errors using new software features like Cirrus' FoveaFinder (Carl Zeiss Meditec, Inc., Dublin, CA) and Heidelberg's TruTrack Active Eye Tracking (Heidelberg Engineering Inc., Heidelberg, Germany) will reduce the decentration errors and thus improve the measurement reproducibility.

Acknowledgments

Supported by an unrestricted fund provided by Research to Prevent Blindness Foundation to the Department of Ophthalmology, University of Wisconsin-Madison. Additional support was provided by National Institutes of Health Grant EY06594, and Senior Scientific Investigator Awards from Research to Prevent Blindness (BK, RK). The authors alone are responsible for the content and writing of the paper.

Disclosure: **J.W. Pak**, None; **A. Narkar**, None; **S. Gangaputra**, None; **R. Klein**, None; **B. Klein**, None; **S. Meuer**, None; **Y. Huang**, Eyekor, LLC (I); **R.P. Danis**, Eyekor, LLC (I), Topcon Corporation (C)

References

- Do DV, Schmidt-Erfurth U, Gonzalez VH, et al. The DA VINCI Study: phase 2 primary results of VEGF Trap-Eye in patients with diabetic macular edema. *Ophthalmology*. 2011;118:1819-1826.
- Mitchell P, Bandello F, Schmidt-Erfurth U, et al. for the RESTORE study group. The RESTORE study: ranibizumab monotherapy or combined with laser versus laser monotherapy for diabetic macular edema. *Ophthalmology*. 2011;118:615-625.
- Elman MJ, Bressler NM, Qin H, et al. for the Diabetic Retinopathy Clinical Research Network. Expanded 2-year follow-up of ranibizumab plus prompt or deferred laser or triamcinolone plus prompt laser for diabetic macular edema. *Ophthalmology*. 2011;118:609-614.
- Pearson PA, Comstock TL, Ip M, et al. Fluocinolone acetonide intravitreal implant for diabetic macular edema: a 3-year multicenter, randomized, controlled clinical trial. *Ophthalmology*. 2011;118:1580-1587.
- Campochiaro PA, Brown DM, Awh CC, et al. Sustained benefits from ranibizumab for macular edema following central retinal vein occlusion: twelve-month outcomes of a phase III study. *Ophthalmology*. 2011;118:2041-2049.
- Ip MS, Oden NL, Scott IU, et al. for the SCORE Study Investigator Group. SCORE Study report 3: study design and baseline characteristics. *Ophthalmology*. 2009;116:1770-1777.
- Haller JA, Bandello F, Belfort R Jr, et al. for the OZURDEX GENEVA Study Group. Randomized, sham-controlled trial of dexamethasone intravitreal implant in patients with macular edema due to retinal vein occlusion. *Ophthalmology*. 2010;117:1134-1146.
- Heier JS, Boyer D, Nguyen QD, et al. The 1-year results of CLEAR-IT 2, a phase 2 study of vascular endothelial growth factor trap-eye dosed as-needed after 12-week fixed dosing. *Ophthalmology*. 2011;118:1098-1106.
- Martin DF, Maguire MG, Ying GS, Grunwald JE, Fine SL, Jaffe GJ for the CATT Research Group. Ranibizumab and bevacizumab for neovascular age-related macular degeneration. *N Engl J Med*. 2011;364:1897-1908.
- Lalwani GA, Rosenfeld PJ, Fung AE, et al. A variable-dosing regimen with intravitreal ranibizumab for neovascular age-related macular degeneration: year 2 of the PrONT0 Study. *Am J Ophthalmol*. 2009;148:43-58.
- Davis MD, Bressler SB, Aiello LP, et al. Comparison of time-domain OCT and fundus photographic assessments of retinal thickening in eyes with diabetic macular edema. *Invest Ophthalmol Vis Sci*. 2008;49:1745-1752.
- Cremasco F, Massa G, Gonçalves Vidotti V, Pedroso de Carvalho Lupinacci Á, Costa VP. Intrasection, intersession, and interexaminer variabilities of retinal nerve fiber layer measurements with spectral-domain OCT. *Eur J Ophthalmol*. 2011;21:264-270.
- Giani A, Deiro AP, Staurengi G. Repeatability and reproducibility of retinal thickness measurements with spectral-domain optical coherence tomography using different scan parameters. *Retina*. 2012;32:1007-1012.
- Klein R, Klein BE, Linton KL, De Mets DL. The Beaver Dam Eye Study: visual acuity. *Ophthalmology*. 1991;98:1310-1315.
- Klein R, Klein BE, Linton KL. Prevalence of age-related maculopathy. The Beaver Dam Eye Study. *Ophthalmology*. 1992;99:933-943.
- Domalpally A, Gangaputra S, Peng Q, Danis RP. Repeatability of retinal thickness measurements between spectral-domain and time-domain optical coherence tomography images in macular disease. *Ophthalmic Surg Lasers Imaging*. 2010;41:S34-S41.
- Campbell RJ, Coupland SG, Buhrmann RR, Kertes PJ. Effect of eccentric and inconsistent fixation on retinal optical coherence tomography measures. *Arch Ophthalmol*. 2007;125:624-627.
- Odell D, Dubis AM, Lever JF, Stepien KE, Carroll J. Assessing errors inherent in OCT-derived macular thickness maps. *J Ophthalmol*. 2011;2011:692574.
- Han IC, Jaffe GJ. Evaluation of artifacts associated with macular spectral-domain optical coherence tomography. *Ophthalmology*. 2010;117:1177-1189.
- Ho J, Sull AC, Vuong LN, et al. Assessment of artifacts and reproducibility across spectral- and time-domain optical coherence tomography devices. *Ophthalmology*. 2009;116:1960-1970.
- Danis RP, Fisher MR, Lambert E, Goulding A, Wu D, Lee L-Y. Results and repeatability of retinal thickness measurements from certification submissions. *Arch Ophthalmol*. 2008;126:45-50.
- Eriksson U, Alm A, Larsson E. Is quantitative spectral-domain superior to time-domain optical coherence tomography (OCT) in eyes with age-related macular degeneration? *Acta Ophthalmol*. 2012;90:620-627.
- Lammer J, Scholda C, Prunte C, Benesch T, Schmidt-Erfurth U, Bolz M. Retinal thickness and volume measurements in diabetic macular edema: a comparison of four optical coherence tomography systems. *Retina*. 2011;31:48-55.
- Patel PJ, Chen FK, Ikeji F, et al. Repeatability of Stratus optical coherence tomography measures in neovascular age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2008;49:1084-1088.
- Krebs I, Hagen S, Brannath W, et al. Repeatability and reproducibility of retinal thickness measurements by optical coherence tomography in age-related macular degeneration. *Ophthalmology*. 2010;117:1577-1584.
- Krebs I, Smretschne E, Moussa S, Brannath W, Womastek I, Binder S. Quality and reproducibility of retinal thickness measurements in two spectral-domain optical coherence tomography machines. *Invest Ophthalmol Vis Sci*. 2011;52:6925-6933.
- Wolf-Schnurrbusch UEK, Ceklic L, Brinkmann CK, et al. Macular thickness measurements in healthy eyes using six different optical coherence tomography instruments. *Invest Ophthalmol Vis Sci*. 2009;50:3432-3437.
- Giani A, Cigada M, Esmaili DD, et al. Artifacts in automatic retinal segmentation using different optical coherence tomography instruments. *Retina*. 2010;4:607-616.
- Parravano M, Oddone F, Boccassini B, et al. Reproducibility of macular thickness measurements using Cirrus SD-OCT in neovascular age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2010;51:4788-4791.