Effect of Eccentric and Inconsistent Fixation on Retinal Optical Coherence Tomography Measures

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Objective: To assess the relative stabilities of optical coherence tomography (OCT)-based retinal volume and central foveal thickness measurements in the setting of eccentric or inconsistent fixation.

Methods: Ten healthy right eyes underwent multiple macular OCT centered at fixation. To model the effect of eccentric or inconsistent fixation, OCT was repeated with scan centers precisely shifted by 0.50, 1.00, and 1.50 mm in each of 4 directions. At each scan location, retinal volumes within a series of radii of the scan center, as well as central foveal thickness, were calculated. The main outcome measure was the percentage effect of decentered scanning on each OCT-based variable.

Results: Central foveal thickness was the variable most affected in this model of eccentric and inconsistent fixation. This variable demonstrated changes from baseline-centered scans of up to 69.4%. Retinal volumes within a radius of the scan center measuring 1.11 mm or greater were least affected by decentered scanning, demonstrating maximum changes from baseline-centered scans of only 15.7% (P<.001 vs foveal thickness).

Conclusion: Optical coherence tomography–based retinal volume quantification provides a more stable measure than foveal thickness in the setting of eccentric or inconsistent fixation as may occur in the setting of macular pathologic conditions.

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Many pathologic processes result in retinal edema, and quantification of this process is of great clinical importance. Optical coherence tomography (OCT) is capable of measuring retinal thickness to within approximately 10 to 14 µm, making it a valuable clinical tool.1-4 However, technologies that are highly precise under ideal conditions and during short periods may be subject to large long-term fluctuations because of operator and subject factors. These short- and long-term variabilities are somewhat analogous to the short- and long-term fluctuations associated with visual fields. Although it has been well established that OCT-based retinal thickness determinations are subject to small intrasession and short-term intersession variabilities, long-term variability may be a more important issue for patients undergoing successive OCT examinations.5-7 To date, factors affecting the long-term fluctuation of successive OCT test results have not been well explored.

One potentially important source of long-term variability in OCT-based measures is eccentric fixation and, in particular, fixation that varies between examinations. Indeed, some patients with diabetic macular edema exhibit eccentric fixation that shifts location over time.8,9 By using significantly more of the available OCT-generated information, retinal volume measures may be less susceptible to changes resulting from such inconsistent fixation. This may be of importance during long-term follow-up with successive measurements. However, it is unknown which retinal region generates volume measures that are least affected by changes in fixation and how this compares with commonly used foveal thickness measurements. Therefore, we simulated variable fixation using precisely decentered OCT and evaluated the effect on OCT-based retinal volume and foveal thickness measurements.

METHODS

The technological specifics of OCT have been described previously.1 In the present study, OCT was carried out using a commercially available system (StratusOCT 3.0 model 3000; Carl Zeiss Meditec, Dublin, Calif). Using an internal fixation target, a total of 160 scans were...
performed on the undilated right eyes of 10 healthy subjects. In each subject, 4 scans were first carried out centered at fixation. Next, to simulate altered and eccentric fixation, scans were carried out centered at 12 eccentric locations. These locations were located superior, nasal, inferior, and temporal to the point of fixation at distances of 0.50, 1.00, and 1.50 mm. The sample size was chosen to provide an estimated power of 90% to detect a difference of 10% in the effect of altered fixation among the variables investigated at $\alpha = 0.01$.

A fast macular thickness protocol was used throughout all studies on all subjects. This protocol provides A-scans at a total of 768 points equally spaced along six 6-mm-long radial lines intersecting at their midpoints. The StratusOCT software algorithm was used to define the internal limiting membrane and the retinal pigment epithelium. All 960 individual line scans were manually reviewed to verify that the algorithm had accurately identified these structures. Retinal thickness at each A-scan location was then determined as the distance between these landmarks. Central foveal thickness, termed *foveal thickness* in the software algorithm, was calculated as the mean thickness at the intersection of the 6 radial scan lines. Retinal sector volumes were calculated by multiplying the mean thickness by the surface area within the 9 Early Treatment of Diabetic Retinopathy Study sectors (*Figure 1*). Appropriate retinal sector volumes were summed to provide volume measurements within radii of 0.50, 1.11, 1.50, 1.73, and 3.00 mm of the scan center. The calculation of total retinal volume within radii of 1.11 mm and 1.50 mm required the export of data, as the software algorithm does not automatically provide these measures.

The direction of decetration did not significantly affect the magnitude of the error induced ($P > 0.05$ for all comparisons, Wilcoxon rank sum test). Therefore, to maximize generalizability, scans of equal decetration distance were grouped in subsequent analyses. Eccentric scanning resulted in significant changes in foveal thickness measurements regardless of the amount of eccentricity (*Table* and *Figure 2*). Retinal volume within the smallest radius, 0.50 mm, also exhibited a mean value that was significantly affected by all degrees of decetration. In contrast, retinal volume measures within larger radii were affected to a lesser extent. The mean retinal volume within a 1.73-mm radius was significantly affected only when decetration reached 1.50 mm, while the mean volumes within other radii were not significantly altered by decentered scanning.

To overcome the potential for comparisons of mean values to misinterpret changes of equal magnitude but of opposite direction, results were further assessed by comparing the percentage changes in values with decentered scanning. On this percentage basis, foveal thickness was again affected to a much larger extent than any of the retinal volume variables. Foveal thickness measures were in error by 44.5%, 69.4%, and 62.1% with 0.50, 1.00, and 1.50 mm of decetration, respectively. Although all retinal volume variables were more stable than foveal thickness, the volume within a 0.50-mm radius of the scan center was altered by decentered scanning to the greatest extent, with the change reaching up to 34.7%. This was significantly greater than the changes induced in retinal volumes within larger radii which reached a maximum value of 15.7% ($P < 0.01$ for all comparisons). The effect of decetration was not significantly different among the retinal volumes within radii measuring 1.11 to 3.00 mm.

### Table. Retinal Volume and Foveal Thickness Measures Under Centered and Decentered Optical Coherence Tomographic Conditions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Centered Scan</th>
<th>0.50</th>
<th>1.00</th>
<th>1.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinal volume, mm$^3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50-mm Radius</td>
<td>0.162 (0.154-0.169)</td>
<td>0.191 (0.183-0.198)$^\dagger$</td>
<td>0.217 (0.209-0.224)$^\dagger$</td>
<td>0.210 (0.203-0.218)$^\dagger$</td>
</tr>
<tr>
<td>1.11-mm Radius</td>
<td>1.00 (0.97-1.04)</td>
<td>1.01 (0.98-1.04)</td>
<td>1.02 (0.98-1.05)</td>
<td>1.00 (0.97-1.04)</td>
</tr>
<tr>
<td>1.50-mm Radius</td>
<td>1.73 (1.67-1.79)</td>
<td>1.68 (1.63-1.73)</td>
<td>1.60 (1.55-1.66)</td>
<td>1.56 (1.50-1.61)</td>
</tr>
<tr>
<td>1.73-mm Radius</td>
<td>2.51 (2.42-2.59)</td>
<td>2.47 (2.40-2.55)</td>
<td>2.39 (2.31-2.47)</td>
<td>2.31 (2.24-2.40)$^\ddagger$</td>
</tr>
<tr>
<td>3.00-mm Radius</td>
<td>6.95 (6.74-7.15)</td>
<td>6.92 (6.73-7.12)</td>
<td>6.90 (6.68-7.11)</td>
<td>6.79 (6.53-7.05)</td>
</tr>
<tr>
<td>Foveal thickness, µm</td>
<td>167 (158-176)</td>
<td>240 (230-250)$^\dagger$</td>
<td>280 (269-291)$^\dagger$</td>
<td>268 (258-278)$^\dagger$</td>
</tr>
</tbody>
</table>

*Data are given as mean (95% confidence intervals). The optical coherence tomography was performed using the Stratus OCT 3.0 model 3000 (Carl Zeiss Meditec, Dublin, Calif). $^\dagger P < 0.01$, decentered vs centered.

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Several studies using different criteria have investigated the repeatability of OCT-based retinal thickness measurements. For example, the coefficient of variation for single-point thickness determinations at the intersection of 6 radial lines through fixation is approximately 5%. However, this represents the intrasession variation among scans carried out at a single sitting in rapid succession. Because the intersession variability of single-point thickness measurements is larger, the mean thickness determinations within retinal regions have been suggested for clinical use. The intersession coefficient of variation for such mean thickness measurements within 500 µm of fixation is 5% in healthy eyes and 6% in eyes with diabetic macular edema.

These previous studies examined the technological limits of precision under ideal circumstances and during short intervals as opposed to the long-term follow-up periods encountered clinically. In contrast, our study examined the potential for errors in retinal volume and foveal thickness measurements in the setting of decentered scanning as may be encountered during clinical follow-up. To the best of our knowledge, this is the first study to quantify the effect of altered fixation by observing the location of the foveal pit on the retinal thickness map, macular pathology conditions often make the detection of the foveal pit impossible. Alternatively, the use of the landmarking function of commercial OCT systems, while preventing eccentric fixation, may help in efforts to consistently image the same section of retina during follow-up. In summary, pending the widespread availability of OCT registration and tracking systems, clinicians will need to be cognizant of the potentially important effect of scan centration on OCT-based measurements.

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REFERENCES


Ophthalmological Numismatics

Mauno Vannas (1891-1964) was professor of ophthalmology at the University of Helsinki, Helsinki, Finland. Vannas was a great opportunist and surgeon. The scissors he designed for use in intraocular surgery are popular and used to this day.

In 1971, a medal depicting Vannas was made in honor of his 70th birthday. It was designed by the artist Oskari Jauhiainen. The obverse depicts his bust facing left. The reverse depicts a stylized eye, the sun, and a von Graefe knife.

Courtesy of: Jay M. Galst, MD, 30 E 60th St, New York, NY 10022.