Volumetric Analysis of Macular Edema by Scanning Laser Tomography in Immune Recovery Uveitis

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Objectives: To evaluate the macular volume in eyes with immune recovery uveitis (IRU) and to describe a new method to quantify macular edema with the use of confocal scanning laser tomography (cSLT).

Methods: A prospective study was performed to assess the macular volume with cSLT in patients with and without IRU. None of the patients enrolled had cytomegalovirus retinitis within 3000 µm of the fovea. Eight eyes had healed cytomegalovirus retinitis with IRU and cystoid macular edema (group A); 4 eyes had healed cytomegalovirus retinitis with IRU and clinically normal maculas (group B); 18 eyes had no IRU (group C); and 3 eyes underwent pars plana vitrectomy and epiretinal membrane peeling for epiretinal membranes associated with cystoid macular edema and IRU (group D). Patients with IRU underwent standard clinical examinations and cSLT. On cSLT, volume above the reference plane was calculated within a fovea-centered circle of 3 mm in diameter. We devised a novel system for defining the reference plane. Measurements were performed 3 times in masked fashion and the mean was used for analyses.

Results: The mean macular volume was highest in group A (1.97 mm³). This was significantly higher (P<.001) than that in groups B (1.15 mm³), C (1.02 mm³), and D (0.86 mm³).

Conclusions: Macular edema in patients with IRU can be consistently and objectively quantitated by cSLT. The method of defining the reference plane used in our study is novel and can be used in other disorders causing macular edema.

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COMBINATION antiretroviral therapy leads to decreased plasma levels of human immunodeficiency virus RNA and increased CD4+T-lymphocyte counts, with impaired immune function in patients with human immunodeficiency virus infection.1 The ocular inflammation associated with immune recovery in patients taking potent antiretroviral combination therapy is known as immune recovery vitritis or immune recovery uveitis (IRU). Our group first described this entity in 5 patients with symptomatic vitritis, papillitis, and cystoid macular edema (CME) or epiretinal membrane formation.2 Presence of macular edema is traditionally assessed clinically by slitlamp biomicroscopy (with contact or noncontact lens), stereoscopic fundus photography, and fluorescein angiography. Fluorescein angiography has been the gold standard in diagnosing and monitoring macular edema. None of these techniques, however, can objectively quantify macular edema. This makes grading between different observers difficult, and subtle changes cannot be assessed. Nussenblatt et al3 used 4 standard photographs to estimate the degree of center thickening, but their technique did not provide objective measures.

Confocal scanning laser tomography (cSLT) was first described in 19874 and found its clinical use in the analysis of optic nerve head topography.5-7 We later adapted it for the assessment of the macula.8,9 In brief, this ophthalmoscope uses a red laser diode (670 nm) to illuminate the eye with a maximal corneal irradiance of 0.160 mW, which is well below the limits established by the American National Standards Institute and other international standards.10 Two galvanometric mirrors provide the horizontal and vertical scanning. The optics of the instrument allow spherical aberration compensation between −12 and +12 diopters. The system uses a 3-mm illumination beam diameter, and the full aperture of eye is used to collect light from the posterior pole. The instrument allows scanning with a field of

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10°, 15°, or 20°. A confocal pinhole located in front of the photodetector ensures that each image represents a thin optical section with a full-width and half-maximum thickness of approximately 300 µm. During an axial scan series, 32 consecutive, equidistant, overlapping optical slices are captured over a total depth of between 0.5 and 4 mm. The software calculates the location of the retinal surface with high reproducibility of better than 25 µm. Furthermore, it has been shown that the cSLT used in this study is telecentric and thus allows determination of true retinal sizes after correcting for refractive power and axial length. These findings have been confirmed in a study where optic nerve measurements with a cSLT were compared with direct measurements obtained during vitreoretinal surgery.

The Heidelberg Retinal Tomograph (HRT; Heidelberg Engineering, Carlsbad, Calif) has shown good reproducibility for point height and mean depth measurement at the macula and recently has been used to describe retinal reflectivity as a function of scan depth (z-profile) and hence to derive a topographic macular edema map. Zambarakji et al measured macular volume above an arbitrary reference plane drawn at the lowest point of the contour line with the use of the HRT in normal eyes and in eyes of diabetic patients with early macular edema. To be able to measure the macular volume above a reference plane, the reference plane needs to be stable and consistently identifiable.

Simplistically, one would consider that the retinal pigment epithelium (RPE) would form a good candidate for such a reference plane. The RPE, however, is not visible on cSLT. The “outer band” of the optical coherence tomography (OCT) image is believed to represent the RPE. The exact correlation of the colored bands and anatomic equivalents is still being studied.

However, OCT can yield high-resolution information on apparent optical thickness of retina at a specific point rather than the topographic edema distribution in the macula, which would be clinically desirable. Also, it may be difficult to measure the retinal thickness at a particular point in the retina with OCT consistently on follow-up examination over the same point.

Neubauer et al conducted a study of 21 normal eyes with 2 different instruments: the OCT and the retinal thickness analyzer (RTA). They measured a mean foveal thickness of 153 µm (OCT) and 181 µm (RTA). The coefficient of variation was 10% and 9% for the OCT and the RTA, respectively.

The aim of this study is to describe a new method of quantification of macular edema in patients with IRU and does not show eye movements in the image series. For each eye on a particular day, 3 fovea-centered axial scans were finally stored. Of these, the best-quality scan (ie, a scan that is clear, well illuminated, and centered on the fovea and does not show eye movements in the image series) was selected for analysis.

On the best scan, a circle of 0.25-mm radius was drawn by means of the circle draw feature of the standard software in the peripapillary retina within the arcade. It was ensured that the circle was drawn in a well and uniformly illuminated area that did not overlie any obvious retinal vessels and was well away from the clinically edematous area of retina. Fluorescein angiography was performed in all patients, and the fluores-
We assume that the retinal thickness from the RPE to the retinal surface at a predefined section of circle. This was performed 3 times. After each measurement, the circle was erased and a new circle was drawn. The study reference plane was, however, common to all 3 readings. On the basis of our assumption of retinal thickness, we were thus able to calculate the retinal volume within the 3000-µm circle.

**STATISTICAL ANALYSIS**

From the 3 readings of the volume above the reference plane, a mean value was calculated for each eye and was used for statistical comparison between the 4 groups (Table). Statistical significance was calculated with the 2-tailed, unpaired t test. *P < .05* was considered significant and *P < .01*, highly significant.

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Patients</th>
<th>Average ± SD Age, y</th>
<th>Mean ± SD Macular Volume, mm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>43.0 ± 11</td>
<td>1.973 ± 0.304†</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>39.5 ± 4</td>
<td>1.152 ± 0.178</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
<td>38.9 ± 9.1</td>
<td>1.015 ± 0.199</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>40.3 ± 7.1</td>
<td>0.860 ± 0.382</td>
</tr>
</tbody>
</table>

*Group A consisted of eyes with healed cytomegalovirus retinitis, immune recovery uveitis, and cystoid macular edema; group B, eyes with healed cytomegalovirus retinitis and immune recovery uveitis without angiographic cystoid macular edema; group C, control eyes; and group D, surgically treated eyes.

†*P < .001*. The macular volumes between groups B and C (*P = .22*) as well as between groups D and C (*P = .29*) were not statistically significant.

Although patients with CMV retinitis with immune recovery associated with combination antiretroviral therapy achieve effective control of CMV retinitis, they develop complications like cataract, macular edema, and epiretinal membrane because of their reconstituted immune system. Macular edema is an important cause of vision loss and can be sensitively detected by fluorescein angiography. The aim of the present study was to establish a reliable method of quantifying macular edema by using optical scanning laser technology with the HRT.

Small changes in retinal thickness are difficult to estimate with the traditional methods, including slitlamp biomicroscopy and stereofundus photography. In cases of IRU with angiographic macular edema, clinical examination missed the diagnosis of macular edema in more than half of the cases. In the present study, all eyes with angiographic macular edema showed swollen maculas when they were analyzed by our technique of macular volume measurement with cSLT. The mean macular volume in these eyes was 1.97 mm³. Our study documents that the macular volume in eyes with CME secondary to IRU is higher than in eyes without IRU, control eyes, or eyes with surgically treated IRU. The reliability of 3 independent macular volume readings is apparent from the observed minuscule variation of SD for individual sets of 3 readings. This means that, once the reference plane has been set, the volumes above that reference plane obtained by drawing fovea-centered circles are consistently reproducible. In conducting this study, we observed that defining the reference plane is of critical importance. An important factor that contributes to this is the quality of image and its illumination. The image should be neither too bright (ie, in photographic terminology, overexposed) nor too dark (ie, underexposed). We ensured that all patients whose CMV retinitis extended into the imaging area were excluded, as this would falsely reduce macular thickness from retinal atrophy secondary to CMV retinitis.

There are potential artifacts in evaluating macular edema by means of scanning laser tomography. In cases where the foveal tissue is extremely thinned because of CME, if the reflectivity of the tissue is below the threshold set for detection with the instrument, the central foveal thickness may be underestimated. Indeed, we found that this did occur in some cases. This, however, would tend to lead to an underestimation of macular volume in the cases with the most severe cystoid macular edema and would not affect the results of our study. Indeed, one could interpolate the inner retinal surface position from the perifoveal position; however, we chose not to manipulate the raw data. Such adjustments would only increase the statistical significance of our findings. Another potential problem in using this technology is determining the so-called baseline level of the retina. This were not statistically significantly different (*P = .22*); similarly, the macular volumes in groups D and C were not statistically significantly different (*P = .28*). Images from representative patients in groups A and B are shown in Figure 1 and Figure 2, respectively.
problem is inherent to any topographic measurement that uses reflecting optical instrumentation. Some researchers have chosen a method similar to ours, while others have chosen to ignore this consideration. Jaakkola and associates determined the reference area by selecting a region of the retina that was considered to remain flat during the follow-up. However, they did not correct for the difference in retinal thickness between the default value used in glaucoma analysis and our retinal thickness value. We chose to correct for this potential problem. To do this, we chose an area near the major vascular arcades that was clearly not involved by thickening or edema on fluorescein angiography. This was used as a positional baseline in the z-dimension (depth dimension).

The use of OCT has given good images of edematous macula. However, OCT as currently used performs only limited 3-dimensional mapping reconstruction. In addition, the OCT software does not always locate the anterior and posterior retina interface. This may lead to erroneous volumetric measurements. Furthermore, the instrument takes only 6 radial sections through the fovea and, from this, interpolates the entire macular area. The number of points of data in the retinal plane with OCT technology is 600 vs 65,536 with HRT in the retinal plane. For this reason, we chose to use the cSLT technology for this preliminary investigation. Future studies with enhanced OCT hardware and software may allow higher-resolution depth images of eyes with immune recovery macular edema to be obtained and analyzed. We also believe that simultaneous use of OCT and cSLT on the same patient needs to be considered. Two groups of researchers have been developing prototype instruments that allow an OCT image to be captured while a scanning laser ophthalmic image is recorded. However, neither instrument currently supports cSLT imaging. If such a device were available, OCT could help find the exact retinal thickness in an area of normal retina, define the RPE, and give a point thickness of the macula. These data may then be used for analysis with the cSLT.

Zeimer et al showed promising results with a new method for mapping retinal thickness at the posterior pole with the use of the RTA. The technique allows the analysis of the central 20° of the macula by way of 9 scans,
the macular region requires capturing 5 overlapping fields to cover a $20^\circ \times 20^\circ$ area in approximately 3 to 4 minutes (http://www.talia.com). The RTA records about 200 points per scan line and 16 scan lines in each 3 × 3-mm region, for a total of 3200 points. The HRT records 65 536 pixels per image plane in about the same area ($10^\circ \times 10^\circ$ field of view). The HRT takes 1.6 seconds for a scan, which consists of 32 independent scans obtained axially along the optical axis and aligned electronically by means of the vascular landmarks.

Light levels used in the scanning laser ophthalmoscope are safe and comfortable to the patient and are much lower (70 µW/cm²) than those used during indirect ophthalmoscopy (100 000 µW/cm²) or fluorescein angiography (400 000 µW/cm²). Hence, the cSLT, with its high light efficiency and the ability to reconstruct a 3-dimensional image from the 32 sections it records along the optical axis, is an ideal system for detecting and quantifying macular edema.

In the present study, we have not tried to correlate the visual status with the macular volume. This would require careful observation of macular volume over time, and we are collecting such data at present.

In summary, this study demonstrates a novel technique of quantifying macular edema in eyes with CMV retinitis with IRU and CME by means of the HRT. We believe that this technique will be applied to other conditions with macular edema and may help to monitor macular edema and the results of treatment in these eyes.

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