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.
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 macula12 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. Zambarkajti 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 eyes13 and in eyes of diabetic patients with early macular edema.14 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 al19 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 with the use of cSLT. To our knowledge, this technique has not been applied to this disease previously.

METHODS

STUDY SUBJECTS

Twelve eyes of 11 patients with healed cytomegalovirus (CMV) retinitis with IRU that did not have CMV retinitis within 3000 µm of the fovea formed the study group. These patients had been referred to the University of California, San Diego, AIDS Ophthalmic Research Unit in La Jolla, Calif. All patients underwent complete vision assessment with Early Treatment Diabetic Retinopathy Study charts, anterior segment evaluation with slitlamp biomicroscopy, and fundus evaluation after pupillary dilatation with slitlamp biomicroscopy with the use of 78-diopter noncontact lens and indirect ophthalmoscopy. All patients also underwent fundus photography and fluorescein angiography in which stereo images recorded in the early phase. Midphase images and late-phase images (around 10 minutes postinjection) were also recorded. Fluorescein angiograms of each patient were read and graded by 2 of us (A.A. and W.R.F.). This group of patients with CMV retinitis with IRU was subdivided into 2 groups: group A, 8 eyes with healed CMV retinitis with IRU and CME; and group B, 4 eyes with healed CMV retinitis with IRU and clinically and angiographically normal macula.

CONTROL SUBJECTS

Eighteen age-matched subjects formed the control group (group C). None of them had IRU. All had corrected visual acuity of 20/20 or better. This group consisted of 15 eyes of patients who were human immunodeficiency virus positive but had no CMV retinitis and 3 eyes of patients who were negative for both human immunodeficiency virus and CMV retinitis. All patients underwent detailed anterior segment and fundus evaluation similar to the study group.

SURGICALLY TREATED GROUP

This group (group D) comprised 3 eyes that had undergone pars plana vitrectomy with removal of epiretinal membrane during the past 12 months. These subjects had undergone surgery for epiretinal membranes associated with macular edema and IRU. This group represents an intermediate group of subjects.

HRT IMAGE ACQUISITION TECHNIQUE

The HRT scans were done on the HRT with the use of software version 2.01. All HRT examinations were done with a dilated pupil (1% cyclopentolate hydrochloride and 2.5% phenylephrine hydrochloride eyedrops). Dilation was not necessary for HRT examination; however, the patients were examined during the course of their complete routine examination. The patients were comfortably positioned with the chin placed in the chin rest and asked to fixate on a target fixed on the wall (1 m away) with their other eye. We opted for a scan size of 20° × 20° and the scan depth was adjusted between 0.50 and 4.00 mm. The standard software of the HRT performs a check of illumination, axial scan range, and defocus compensation. If the examination variables do not adhere to the appropriate settings, the user is prompted to adjust the values accordingly. In addition, the stack of 32 images is aligned by the software with the use of vascular landmarks to cancel out eye movements. A scan depth of 1.5 to 2.0 mm was routinely used. For patient convenience, patients were scanned after 5 to 10 minutes on the same day, and this was considered to simulate a repeat examination. For each eye on a particular day, 3 fovea-centered 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 overlite 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-
tical comparison between the 4 groups (the 3000-µm circle.
ness, we were thus able to calculate the retinal volume within
After each measurement, the circle was erased and a new circle
with the study reference plane. This was performed 3 times.
the circle draw feature and the macular volume was calculated
local reference plane reading to arrive at our study refer-
surface was 160 µm. Thus, we added 110 µm to the HRT-
mal foveal thickness with 2 different instruments, we as-
reduction was recorded. On the basis of measurements of the nor-
ected into the imaging area were excluded, as this would
We ensured that all patients whose CMV retinitis ex-
importance. An important factor that contributes to this
pronounced reproducibility. In conducting this study, we ob-
were thus able to calculate the retinal volume within the
cein angiogram was used to determine a nonedematous area
measurement. The standard reference plane calculated by
HRT was recorded. Since HRT has been traditionally used for
blood column and the macular thickness was calculated with
This reading was recorded. On the basis of measurements of the normal
foveal thickness with 2 different instruments, we assumed that the retinal thickness from the RPE to the retinal surface was 160 µm. Thus, we added 110 µm to the HRT-calculated reference plane reading to arrive at our study reference plane. We assume that this reference plane is thus located in the RPE plane. A fovea-centered circle was drawn with the circle draw feature and the macular volume was calculated with the study reference plane. This was performed 3 times. After each measurement, the circle was erased and a new circle redrawn. 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.

RESULTS

There were 8 eyes in group A (healed CMV retinitis with IRU and angiographic CME), 4 eyes in group B (healed CMV retinitis, IRU without CME), 18 eyes in group C (control eyes without IRU and CME), and 3 eyes in group D (eyes with healed CMV retinitis, IRU, and CME that had undergone pars plana vitrectomy with peeling of the epiretinal membrane in the past year). As outlined in the ‘Methods’ section, each macular volume measurement was performed 3 times for each patient image. The average reproducibility for the repeat measurement was 0.008 mm³, ranging from 0.001 mm³ to 0.04 mm³.

The mean macular volume in eyes with healed CMV retinitis, IRU, and CME (group A) was significantly greater than that in the control eyes (group C), the eyes with CMV retinitis and IRU, but without angiographic CME (group B), and the surgically treated eyes (group D) (all P < .001) (Table). The macular volumes in eyes in groups B 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.

COMMENT

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

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<th>Characteristics of Patient Population</th>
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*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.
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,
Figure 2. Images of the left eye of a 43-year-old male patient from group B. A, Screen shot taken from the Heidelberg Retinal Tomograph. The left image is a gray-scale coded topographic height image. Darker shades represent higher elevations. The right image shows the monochromatic fundus photograph. The graph below shows the variation in height contour along the drawn circle. A 0.25-mm-radius circle is drawn in an extramacular area within the arcade. The machine’s standard reference plane (black arrowhead) here is at 0.040 mm. B, A 3.00-mm-diameter fovea-centered circle drawn with reference plane set at 0.150 mm. The height contour variation is shown below (black arrow) along with the location of the reference plane (black arrowhead). C, Screen shot of the stereometric evaluation. The image on the left shows the annotated topography image. The circle outlines the 3-mm measurement area. The results of the stereometric evaluation are shown on the right. The topographic retinal height variation is shown in the graph below (black arrow) along with the reference plane (black arrowhead). dz indicates the relative axial coordinate; \( z \), axial coordinate; \( H_{\text{Ref}} \), height of reference plane; \( \alpha_h \), tilt of reference plane in horizontal direction; and \( \alpha_v \), tilt of reference plane in vertical direction.

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