Determination of optic cup depth by confocal scanning laser tomography

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PURPOSE. *To assess whether confocal scanning laser tomography of the optic disc and clinical ophthalmoscopy using stereoscopic optic disc photographs, agree in the evaluation of the deepest part of the optic cup.*

PATIENTS AND METHODS. *The study included 33 eyes of patients with focal normal-pressure glaucoma. Using 15° color stereoscopic optic disc photographs and dividing the optic disc into an upper and a lower half, two trained observers independently established the location of the deepest part of the cup. By selection, the two observers had made congruent judgements for all eyes in the study. All patients also underwent confocal scanning laser tomography of the optic disc using the Heidelberg Retina Tomograph (HRT). The location of the deepest "mean cup depth" was noted.*

RESULTS. *The deepest optic cup region based on stereoscopic evaluation of photographs and on scanning laser tomography did not correlate significantly with each other (p=0.18; chi-square test, linear-by-linear association). According to the scanning laser tomography data, the maximal optic cup depths were not correlated with the corresponding locations of maximal visual field defect (p=0.80). Using the stereo photographic data, the locations of maximal optic cup depth and maximal visual field defect were correlated (p=0.006).*

CONCLUSIONS. *In some glaucomatous eyes, confocal scanning laser tomographic assessment of the location of the deepest optic cup region does not agree with clinical judgement and, in contrast to clinical examination, does not correlate with the location of the maximal visual field defect. (Eur J Ophthalmol 2003; 13: 42-8)*

KEY WORDS. *Confocal scanning laser tomography, Glaucoma, Neuroretinal rim, Optic disc*

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INTRODUCTION

A hallmark of glaucomatous optic neuropathy is loss of the neuroretinal rim. In doubtful cases, morphologic features of less importance such as parapapillary atrophy or increasing depth and focal deepenings of the optic cup, may facilitate the diagnosis or the evaluation in glaucoma follow-up. Focal deepenings of the optic cup are most evident in eyes with acquired pits of the optic disc and notching of the neuro retinal rim in normal-tension glaucoma, as already described by Radius, Gayer, Geear and Javitt (1-4). Even when clear-cut notches of the rim were lacking, subtle deepenings of the cup may be spatially correlated with loss of neuroretinal rim and visual field in normal-tension glaucoma (5).

Clinically, deepening of the optic cup is usually assessed by stereoscopic biomicroscopy using ophthalmoscopic lenses and a slit lamp, by indirect or direct ophthalmoscopy, or by examining stereoscopic

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optic disc photographs. Confocal scanning laser tomography provides a three-dimensional semiautomatic quantitative evaluation of the optic nerve head with special advantages in quantitative three-dimensional analysis of the optic cup (6). The purpose of the present study was to assess the utility of scanning laser tomography for investigating such subtle irregularities of the cup bottom as a sign of glaucomatous optic atrophy. Therefore we compared optic cup measurements, obtained by confocal scanning laser tomography, with clinical assessment of the optic cup depth.

Patients with focal normal-tension glaucoma show mainly local changes of the optic disc including focal deepenings of the optic cup (3, 10-12). In recent hospital-based cross-sectional studies patients with normal-tension glaucoma had relatively large optic discs and, consequently, large optic cups whose depth can easily be assessed (7-9). For the present investigation we selected patients with normal-tension glaucoma.

PATIENTS AND METHODS

The study included 33 eyes of 27 patients with focal normal-tension glaucoma. Mean (± SD) age was 58.9 ± 7.8 years (range 39-74 years), mean refractive error was -0.14 ± 2.71 diopters (range -8.0 to +4.75 diopters). Criteria for the diagnosis of normal-tension glaucoma were, an open anterior chamber angle, glaucomatous visual field loss, and localized loss of retinal nerve fiber layer. Maximal intraocular pressure readings had to be 21 mm Hg or less in at least two 24-hour pressure profiles obtained by slit lamp applanation tonometry and containing measurements at 5 p.m., 9 p.m., midnight, 7 a.m. and noon. Ophthalmoscopy, medical history, and neuroradiologic, neurologic and medical examinations did not reveal any reason for optic nerve damage other than glaucoma, such as intrasellar or suprasellar tumors, retinal vessel occlusions, optic disc drusen, or nonarteritic anterior ischemic optic neuropathy.

A glaucomatous visual field defect was defined as an Octopus G1 field with (a) at least three adjacent test points having a deviation of 5 dB or more and one test point with a deviation more than 10 dB lower, (b) at least two adjacent test points with a deviation of 10 dB or more, (c) at least three adjacent test points with a deviation of 5 dB or more, abutting the horizontal nasal meridian, and (d) a mean visual field defect of more than 2 dB. The rate of false positive and false negative answers had to be less than 10%. Perimetry done within one week of optic disc imaging. The mean visual field defect was computed for the upper and lower hemifields and the one with the larger mean defect was identified. If the two hemifields differed in mean defect by less than 1.5 dB, the field loss was considered evenly distributed.

By selection, all eyes included in the study had an optic cup sufficiently large to evaluate the depth of the optic cup bottom. Additional selection criterion was that the two examiners (WMB and JBJ) agreed independently on the location of the deepest part of the optic cup as evaluated on stereoscopic optic disc photographs. Highly myopic eyes with a myopic refractive error exceeding -8 diopters were excluded on account of the different appearance of the optic disc (13).

For all eyes, sequential 15° color stereo optic disc transparencies were taken using a Zeiss telecentric fundus camera (30° fundus camera, equipped with a 15° converter; Zeiss, Oberkochen, Germany). With the photographs in a stereo viewer, the location of the deepest part of the optic cup was established or the two disc halves were judged to be equally deep. The stereo photographs were evaluated independently by two observers in a masked fashion, without knowledge of the clinical data or the confocal scanning laser tomographic images.

For each eye, three 10° confocal scanning laser tomographic images were obtained using the Heidelberg Retina Tomograph HRT I (Heidelberg Engineering, Heidelberg, Germany). Optic disc photography and scanning laser tomography were done within one week. The mean topography of the three images was analyzed by the HRT software, version 2.01. The mean ± SD for the three topographic images from each eye was 28.32 ± 9.60 µm. The vertical tilt of the scan plane had to be less than 3.0°. According to the clinical standard protocol, to obtain scanning laser tomographic images of the optic nerve head, scan depth was adjusted to ensure that at least three scans were behind the plane of the bottom of the optic cup. The border of the disc was outlined manually. According to the software version 2.01, the reference plane for delineation of the optic cup from the neuroretinal rim was the level 50 micrometers beneath the contour line in the temporal segment, 4-10° below the horizontal axis of the disc.

In HRT images, falsely deep pixel values occur frequently at vessel borders, e.g. at the bottom of the cup. Therefore any determination of the disc half containing the pixel with the maximal cup depth is doomed to be confounded by these artifacts. Using the HRT images, the disc half with the deepest cup depth was determined by two methods in the current study. The mean cup depth (mean of the depths for the area below the reference plane) was computed for the upper and lower disc halves. The half with the greatest mean cup depth was taken as the half with the deeper cup. If the mean cup depth of the upper and lower halves of the disc differed by less than 0.01 mm, the cup depth was considered the same in both halves.

As a second method, one examiner visually examined the HRT topography maps, which presented the mean depth measurements in 16 x 16 fields of 16 x 16 pixel quadrants. Quadrants containing large vessels were excluded by eye, as vessels influence the configuration of the cup bottom with falsely deep pixel values at their borders. The disc half containing the pixel quadrant with the greatest mean depths was determined. If this quadrant was located in a field along the horizontal disc axis, the cup depth was considered the same in both disc halves. The HRT images were evaluated by an investigator masked to the results of the examination of the clinical photographs and without the disc photographs at hand.

The locations of the deepest cup depth were compared in a 3 x 3 matrix with linear-by-linear association of the chi-square test. To obtain data for linear correlation analysis, the differences in the HRT variables “mean cup depth” and “neuroretinal rim area” were computed for the two disc halves. Linear correlations were tested by Pearson’s correlation coefficient. Since multiple comparisons were done, statistical significance was defined as a probability of error of less than 0.01. Statistical analysis was done using SPSS for Windows (Statistical Package for Social Sciences, Chicago, IL).

RESULTS

Stereoscopic analysis of the optic disc photographs showed asymmetry in the depth of the optic cup in the upper and lower halves of the disc in 29 of the 33 eyes (Tabs. I, II). Seven eyes had a notch in the neuroretinal rim with an acquired pit of the optic nerve head as an extreme of focal optic cup deepening. Using scanning laser tomography, asymmetry in the optic cup depth in the two halves was detected in 30

TABLE I - ASYMMETRY OF THE DEPTH OF THE CUP IN THE UPPER AND LOWER HALVES OF THE DISC: STEREO OPTIC DISC PHOTOGRAPH EVALUATION VERSUS “MEAN CUP DEPTH” FOR THE TWO HALVES OBTAINED BY SCANNING LASER TOMOGRAPHY (HRT). THE ASSOCIATION BETWEEN THE TWO METHODS WAS NOT SIGNIFICANT (CHI-SQUARE TEST, LINEAR-BY-LINEAR ASSOCIATION: VALUE=1.78; df=1; p=0.18)

		Visual evaluation of stereo optic disc photographs		
		Cup depth same in lower and upper halves	**Cup deeper in upper half of disc**	**Cup deeper in lower half of disc**
Evaluation of HRT images (“mean cup depth” of the two disc halves)	Cup depth same in lower and upper halves	0	2	1
	Cup deeper in upper half	2	13	10
	Cup deeper in lower disc half	2	2	1

of the 33 eyes on the basis of mean cup depth, and in 18 of the 33 eyes by evaluation of the pixel quadrants by eye. The locations of the deepest part of the optic cup, determined stereoscopically, and by the two scanning laser tomography techniques, were not significantly related (chi-square test, linear-by-linear association; for the mean cup depth: value=1.78, df=1, p=0.18; for evaluation of the pixel quadrants by eye: value=0.44, df=1, p=0.51; Tabs. I, II).

The association between the location of the deepest part of the optic cup as determined on stereo optic disc photographs and the location of the largest visual field loss in the corresponding upper or lower hemifield was significant (chi-square test, linear-by-linear association: value=7.50, df=1, p=0.006). The associations between the location of the deepest part of the optic cup as determined by the two scanning laser tomography techniques and of the largest visual field loss in the corresponding upper or lower hemifield were not significant (chi-square test, linear-by-linear association; for the mean cup depth: value=0.06, df=1, p=0.80; for evaluation of the pixel quadrants by eye: value=2.50, df=1, p=0.11).

Differences in “mean optic cup depth” between the upper and lower disc halves, obtained by HRT, were not significantly correlated with corresponding differences in mean visual field defect of the two hemifields. In contrast, the differences in neuroretinal rim area of the two disc halves as evaluated by the HRT were significantly correlated with the differences in mean visual field defects (Tab. III).

Considering only the seven eyes with acquired pits of the optic nerve head, the locations of the deepest part of the optic cup, determined stereoscopically on the optic disc photographs and of the deepest part of the optic cup, determined by the two scanning laser tomography techniques, agreed in four of the seven eyes.

DISCUSSION

Confocal scanning laser ophthalmoscopy of the optic nerve head examines the topography of the optic disc by analyzing 32 tomographic images acquired in successive confocal planes. Two- and three-dimensional variables are obtained such as the area of the optic disc and optic cup, the volumes above and below the reference plane, and a shape of the cup. The three-dimensional variables, such as cup volume, partially depend on the (correct) assessment of the bottom of the optic cup. In the present study, scanning laser tomography measurements of the optic cup depth did not significantly correlate with the clinical assessment of the depth made independently by two examiners on color stereoscopic optic disc photographs. The results of the clinical examination of the stereoscopic optic disc photographs, in contrast with the

TABLE II - ASYMMETRY OF THE DEPTH OF THE CUP IN THE UPPER AND LOWER HALVES OF THE DISC: STEREO OPTIC DISC PHOTOGRAPH EVALUATION VERSUS EVALUATION OF TOPOGRAPHY MAPS PROVIDED BY SCANNING LASER TOMOGRAPHY (HRT). THE ASSOCIATION BETWEEN THE TWO METHODS WAS NOT SIGNIFICANT (CHI-SQUARE TEST, LINEAR-BY-LINEAR ASSOCIATION: VALUE=0.44; df=1, p=0.51)

		Visual evaluation of stereo optic disc photographs		
		Cup depth same in lower and upper halves	**Cup deeper in upper half of disc**	**Cup deeper in lower half of disc**
	Cup depth same in lower and upper halves	1	12	2
Visual evaluation of HRT images (topography maps)	Cup deeper in upper half	2	5	10
	Cup deeper in lower disc half	1	0	0

scanning laser tomography examination, were significantly correlated with the location of maximal visual field loss as external standard. One wonders what are the reasons for this difference between the clinical assessment and the confocal scanning laser tomograph examination of the optic cup depth.

The cup as defined by scanning laser tomography includes the region of the disc lying below a reference plane. Clearly, this differs from the cup defined by an observer, in that deep parts of the neuroretinal rim are included. This may have confounded one method of assessing the scanning laser tomographic images which compared the mean cup depth of the upper and lower disc halves and may explain the enormous differences between this method and the second method which allowed the evaluation of pixel quadrants by eye. Another factor may be a discrepancy between the anatomical surface of the cup and the surface determined from reflectivity profiles. Confocal scanning laser tomography assesses the location of maximal reflectivity of light as it hits or partially enters tissue after passing through the vitreous cavity. In view of the high light reflectivity of scleral tissue in the deep layer of the optic cup, it is possible that the confocal scanning laser tomograph considers this tissue as the bottom of the cup instead of the glial tissue on top of the *lamina cribrosa*. Then too, the plane of the cup bottom may not be parallel to the scanning plane of the scanning laser tomograph. This tilt would falsify the location of the deepest part of the optic cup. For that reason, we excluded eyes with a tilt of the scanning laser tomograph plane in relation to the plane of the retinal surface of more than 3 degrees. Despite this quality procedure, however, the deepest part of the cup was rarely detected in the lower disc half by scanning laser tomography (Tabs. I. II).

The shape of the bottom of the optic cup is modified by retinal vessels running across it. In addition, at the border of blood vessels the laser beam is reflected orthogonally and does not reach the detection unit of the device, thus leading to false deep pixel values at vessel borders. Similar artifacts may appear at the edges of very steep cups. To compensate for a possible artifact induced by blood vessels on the optic cup bottom, one method of assessing the deepest part of the cup in the present study used topography maps provided by the scanning laser tomograph. Those parts of the optic cup image which contained large vessels were excluded from analysis. Even so, this did not reduce the discrepancy between the scanning laser tomographic images and the stereo disc photos in assessments of the deepest optic cup region.

We must recall that the routine examination technique for scanning laser tomography was not modified for the purpose of this study. The scan depth was set to cover the whole disc so that only some of the 32 tomographic images represented the bottom of the optic cup. Scanning laser tomography techniques especially modified with a narrower scan depth focused on the level of the optic cup bottom might have given a better representation of the optic cup. Furthermore, only one scanning laser tomography system was evaluated. Other systems have not been tested for their ability to represent the cup bottom.

The main limitation of the study is the absence of a reference standard so the evaluation of stereo disc photographs is necessarily subjective. Variable stereo angles of sequential pairs of photos and morphological cues such as diminished neuroretinal rim, hinting at adjacent focal cup deepenings, may have confounded the subjective evaluation of stereo pho-

TABLE III - LINEAR CORRELATIONS BETWEEN SCANNING LASER TOMOGRAPHY VARIABLES AND PERIMETRIC DATA

	Pearson correlation coefficient r	**p**
Difference in “mean cup depth” of the two disc halves and in mean visual field defect of the two hemifields	0.13	0.46
Difference in rim area of the two disc halves and in mean visual field defect of the two hemifields	0.44	0.01

tographs. Seven eyes in the series had a clear-cut notch of the neuroretinal rim extending to the disc margin which may have influenced the decision in favor of one particular disc half. That was why we only included eyes with similar judgements by two experienced observers. In a pilot study, 55 of 106 optic discs were judged concordantly by the two observers (which is more than chance because there are three possible three values: the upper disc half is deeper, the lower half is deeper, or the two halves are the same).

Clinical examination of the stereoscopic optic disc photographs, in contrast to the scanning laser tomography results, significantly correlated with the location of maximal visual field loss as external standard. The present study thus failed to establish scanning laser tomography as a “gold standard” for the detection of focal cup deepenings.

In conclusion, this study brought to light differences in determining the location of the deepest region of the optic cup between routine confocal laser scanning laser tomography and clinical examination of the optic disc on stereoscopic photographs. Since the reasons are still not clear, this result suggests caution in interpreting routine scanning laser tomography data on the depth of the optic cup. Scanning laser tomography, however, offers numerous clinical and practical advantages, such as the high reproducibility of its measurements, its ability to detect morphologic changes of the optic disc in follow-up examinations, the fast availability of its results, and that, being a semiautomatic technique, it can at least partially be delegated to technicians (14-19).

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