Reproducibility of the Measurements of the Optic Nerve Head Topographic Variables with a Confocal Scanning Laser Ophthalmoscope

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Purpose: To determine the optic nerve head topographic parameters with the least variability in repeat measurements.

Methods: We randomly selected and evaluated 1 eye each of 20 healthy subjects, a total of 20 eyes. We used the confocal scanning laser ophthalmoscope (CSLO) for optic nerve head analysis. The disc area and a total of 13 parameters were determined by Top SS. Each subject was examined five times, each time on a different day, during a 2-month period. We obtained a series of five $10 \times 10°$ images for each eye per visit. Three of the five images were randomly selected to create a mean image. Coefficients of variation of each of the 13 variables studied were calculated separately by using those five different optic nerve head topographic measurements.

Results: The subjects were 11 women and 9 men. The mean age of the subjects was 30.5 ± 6.9. The mean optic disc areas were 2.26 ± 0.39 mm^2 and 1.96 ± 0.37 mm^2 for the men and the women, respectively ($P > .05$). The mean coefficient of variation for measurement of the variables was found to range between 1.2% and 9.8%. The variables, cup shape, volume above, average depth, and volume below, were found to yield the best reproducible measurements.

Conclusion: The CSLO with its highly reproducible measurements (<10% error) offers a highly objective, safe, and effective method for clinical use in measurements of the topography of the optic nerve head. The subtle differences in the variables, cup shape, volume above, average depth, and volume below, may be of vital importance in the follow-up of those diseases requiring longitudinal monitoring of the optic nerve head, namely ocular hypertension and glaucoma. **Jpn J Ophthalmol 2003;47:173–177** © 2003 Japanese Ophthalmological Society

Key Words: Confocal scanning laser ophthalmoscope, optic nerve head topography variable, reproducibility.

Introduction

The efficacy of perimetry in glaucoma is somewhat limited by the subjective nature of the patient's response. As a result, long-term glaucoma management depends mainly on the clinician's assessment of the appearance of the optic disc and by the subjective nature of a patient's response during perimetry. Optic nerve head image analysis has become even more important as it is postulated that the structural changes in the optic nerve head in glaucoma can be detected long before the functional visual field loss.[1,2] It is essential that certain requirements are fulfilled before any computer image analysis system is introduced into the clinical setting. These include the assurance that the image acquired and the topographic measurements are accurate, reliable, and reproducible. Determination of the variability of the measurements is required to objectively estimate the magnitude of optic nerve head change over time.

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The confocal scanning laser ophthalmoscope has the potential to be a safe, rapid, and reproducible method of imaging ocular structures. [3]

In the present study, we aimed to investigate the variability of the optic nerve head topographic parameters in a normal population with a Top SS confocal scanning laser ophthalmoscope.

Materials and Methods

We randomly selected and evaluated 1 eye each in 20 healthy subjects (20 eyes) who visited the Department of Ophthalmology at Hacettepe University for ocular check-ups or prescription for glasses and contact lens. Informed consent was obtained from each study subject.

Excluded from this study were subjects with intraocular pressure readings >21 mm Hg, visual acuity <0.8, ametropia with >±0.50 diopters of cylindric or spheric refractive error, <4° contour tilt, degenerative fundus findings (age-related macular degeneration, high myopia), past history of ocular trauma, surgery, retinal photocoagulation, congenital optic disc anomaly, tilted discs, and systemic problems such as diabetes mellitus, hypertension, or malignancy.

We evaluated the best corrected visual acuity, refractive error, biomicroscopic findings, and intraocular pressure by Goldmann applanation tonometry. Fundus examination was conducted using slit-lamp biomicroscopy with a 78-D lens and keratometry for each subject.

We used the confocal scanning laser ophthalmoscope (Top SS, Topographic Scanning System, Version 3.1.03, Laser Diagnostic Technologies, San Diego, CA, USA) for optic nerve head analysis. The Top SS produces a three-dimensional image of the optic disc by multiple optical sectioning of the object, projecting a near infrared diode laser beam with a wavelength of 780 nm on the retina and the optic disc. A series of 32 consecutive image planes, 256 × 256 pixels each, are acquired automatically to obtain three-dimensional topography of the optic disc. With the software of the Top SS, it is possible to generate a mean topographic image from a set of discrete topographic images by determining the average height measurements at each pixel. All of our cases were noted to have pupil diameters >1.5 mm, so we were not required to dilate the pupils of the subjects.

The disc area and a total of 13 parameters, which can be determined by Top SS (Table 1), have been explained elsewhere previously.[3] Each subject was examined five times, each time on a different day, during a 2-month period. We obtained a series of five 10 × 10° images of each eye at each visit. Three out of the five images were randomly selected to create a mean image. Coefficients of variation of each of the 13 variables studied were calculated separately by using those five different optic nerve head topographic measurements.

Table 1. Sex-related Differences in Age, Keratometry Readings, Refractive Error, and the Disc Area

	Men (n = 9)	Women (n = 11)	
	Mean ± SD	Mean ± SD	P*
Age (y)	31.9 ± 6.81	29.4 ± 7.16	.43
Refractive error (D)	−0.22 ± 0.40	−0.06 ± 0.30	.34
Keratometry (D)	43.31 ± 1.44	42.80 ± 1.02	.31
Disc Area (mm^2)	2.26 ± 0.39	1.96 ± 0.37	.10

n: number of the subjects, SD: standard deviation, D: diopter.
*Statistical significance is set at $P < .05$ level.

We avoided 15 × 15° images as subtle details may be missed due to the larger field of view. The scan offset was set to 100 μ, as 50 μ and 150 μ settings were shown to cause artifacts or decreased sensitivity to detect surface changes, respectively.[9] The boundary of all the optic discs was drawn manually by the same experienced observer (YA). Keratometry readings and the refractive error (spherical equivalent) were entered on Top SS to correct for magnification errors. Top SS calculated the optic nerve head topographic variables automatically.

Reproducibility of the topographic variables was assessed by calculation of the coefficients of variation. Coefficients of variation were calculated as the ratio of the SD of the measurements to their mean multiplied by 100. The coefficients of variation were expressed in percentages. The independent sample *t*-test and the descriptive statistics were used for statistical analysis. Statistical significance was set as $P < .05$.

Results

Of the 20 eyes, half (10 eyes) were right and the other half were left. The mean age of the subjects was 30.5 ± 6.9 years (range, 19–41 years). The mean keratometric reading was 43.0 ± 1.2 diopter (range, 41.3–45.5). The mean optic disc area was 2.09 ± 0.40 mm^2 (range, 1.52–2.86 mm^2). There were no sex-related differences in age, keratometry readings, refractive error, or disc area (Table 1).

The mean optic nerve head topographic variables are shown in Table 2. The coefficients of variation of optic nerve head topographic measurements were found to range between 1.2% and 9.8% with an overall mean coefficient of variation of optic nerve

Table 2. Mean Values of the Optic Nerve Head Topographic Variables (n = 20)

Variables	Mean	SD	Minimum	Maximum
Cup shape	−1.40	1.20	−5.14	−0.16
Contour modulation	0.22	0.10	0.10	0.50
Effective area (mm^2)	0.67	0.39	0.13	1.49
Half depth area (mm^2)	0.30	0.25	0.04	0.82
Contour variation	0.33	0.14	0.12	0.62
Mean contour depth (mm)	0.04	0.16	−0.49	0.24
Volume above (mm^3)	0.29	0.08	0.17	0.46
Volume below (mm^3)	−0.23	0.20	−0.64	−0.02
Average depth (mm)	−0.19	−0.13	−0.43	−0.05
Maximum depth (mm)	−0.44	0.28	−1.03	−0.11
Cup-to-disk ratio	0.31	0.15	0.07	0.57
NRRA (mm^2)	1.50	0.42	0.90	2.40
Half depth volume (mm^3)	−0.05	0.05	−0.15	−0.001

SD: standard deviation.

head topographic measurements of 4.7% (Table 3). The best reproducible parameters were cup shape (1.2%), volume above (1.9%), average depth (2.3%), and volume below (2.6%).

Discussion

Because we acquired the same topography contour at independent imaging sessions when no anatomical change had occurred and obtained the same topographic measurements on repeated measurements of the same image with the confocal scanning laser ophthalmoscope, it seemed to indicate that the optic nerve head topographic measurements are reproducible. The differences in the optic nerve head topography among subjects resulting from differences in age, sex, race, side, refractive error, and disc area were published previously.[3,4] The sources of the variability with the use of the confocal scanning laser ophthalmoscope may be multifold: the misalignment between the patient and the laser scanner,[5] the cardiac cycle,[6] determination of the optic disc margin.[7] Roff et al suggested that the reproducibility of optic disc measurements are affected more by the variation in topography between images than by the change in contour line definition.[8] Ideally, we should point out the topographic data that predict the subsequent change in the visual field more objectively. The current study was undertaken to determine the optic nerve head topographic variables that yield the best reproducibility.

We used the confocal scanning laser ophthalmoscope, Top SS version 3.1.03 for the optic nerve head analysis of the subjects because its measurements of the optic nerve head topography were previously shown to be objective, quantitative and highly reproducible.[3,9] They are not time-consuming and they obviate the requirement for pupil dilatation.

Varma et al showed that there is no relation between refraction and optic nerve head topography.[4] In the present study, emmetropic subjects were purposely selected to rule out the probable refractive error related to differences in the reproducibility of the topographic measurements.

The coefficient of variation is frequently quoted in reproducibility studies. We found the coefficient of variation of the optic nerve head topographic parameters obtained from sequential images to range between 1.2% and 9.8% (Table 1). The best reproducible parameters were cup shape (1.2%), volume above (indicating neuroretinal rim volume) (1.9%), average depth (indicating cup depth) (2.3%), and volume be-

Table 3. Mean Coefficient of Variation of the Optic Nerve Head Topographic Variables (n = 20)

Variables	Mean CV*	SD	Minimum	Maximum
Cup shape	−1.24	0.32	0.63	1.71
Contour modulation	5.75	1.98	2.15	8.89
Effective area (mm^2)	4.95	1.51	1.86	7.46
Half depth area (mm^2)	5.64	1.45	1.99	8.58
Contour variation	7.08	1.40	4.72	9.64
Mean contour depth (mm)	8.01	3.81	2.72	22.57
Volume above (mm^3)	1.91	0.57	0.73	2.76
Volume below (mm^3)	2.58	0.83	1.21	4.10
Average depth (mm)	2.31	0.97	0.96	4.15
Maximum depth (mm)	3.33	1.18	1.02	5.00
Cup-to-disk ratio	3.72	0.88	1.59	5.60
NRRA (mm^2)	4.47	1.32	1.94	7.19
Half depth volume (mm^3)	9.84	3.34	5.25	15.65

SD: standard deviation.
*CV: coefficient of variation is considered to be the index for reproducibility.

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low (indicating cup volume) (2.6%). Rohrschneider et al, with three independent measurements of the optic disc using another confocal scanning laser ophthalmoscope, the Heidelberg Retina Tomograph (HRT; Heidelberg Engineering, Heidelberg, Germany) determined the mean coefficients of variation for measurements in normal subjects as 3.4% for cup area; 4.6% for cup volume; 3.3% for mean cup depth; and 4.0% for maximal cup depth.[10] Coefficients of variation ranging between 8% and 11% have been reported for optic nerve head cup volume in healthy human eyes.[5,11] Janknecht and Funk, using a plastic eye model of the human eye to simulate six optic nerve head papillae and several cone-shaped elevations with the HRT, reported a pooled relative error of 11% for the "volume below contour and the volume above contour" of the optic nerve head, reflecting the accuracy of their measurements.[12] Cup volume measurement tends to have the greatest variability among the parameters analysed by computed optic disc analysis.[13–15] Geyer et al[9] examined the optic discs of 16 glaucoma patients to determine the reproducibility of topography measurements with the Top SS at two independent sessions 30 minutes apart. They suggested that 3 (of 14) optic nerve head variables with the highest degree of reproducibility, namely, the cup depth, cup volume, and half depth area, were useful for long-term monitoring of the optic disc.

We found the three-dimensional variables, the volume and the depth measurements, to yield better reproducibility (lower coefficient of variation) than that of the two-dimensional cup-to-disc ratio and the area measurements. It seems that it is the measurement of the third dimension that yields highly reproducible results as it is a component of both the depth and the volume measurements. Orgül et al[5] claimed that the horizontal misalignment between the patients and the laser scanner is a major source of variability in the estimates of topometric variables with the HRT. This could partly account for the higher coefficient of variation for two-dimensional measurements. In contrast, Spencer et al, in their study using HRT, reported variability coefficients of $<2\%$ for a two-dimensional parameter, vertical optic disc diameters.[16]

Chauhan et al demonstrated the variability of the absolute height measurements to increase at the edge of the optic nerve cup as not being correlated with the degree of the optic nerve head excavation.[17] Cioffi et al found the variability of the depth measurements to be greatest where the neuroretinal rim sloped at the edge of the optic cup and lowest in the peripapillary area.[18]

Gundersen et al[19] in their study with a total of 296 eyes consisting of both a normal and a glaucomatous population, measured the optic nerve head topography in 24 sectors around the optic nerve head at nine different depths from the reference plane. They found that single sectors located close to the vertical meridian yielded better discrimination than global measurements. A potential limitation of our study was that our analysis was done in terms of the whole disc instead of the quadrants or sectors. So, there may have been regional difference in optic nerve head topography that would adversely affect the reproducibility of the variables.

In summary, confocal scanning laser ophthalmoscopes with their highly reproducible measurements offer a highly objective, safe, and effective method for clinical use in measurements of the topography of the optic nerve head. The subtle differences in the variables of "cup shape, volume below and the volume above" may be of vital importance in the follow-up of those diseases requiring longitudinal monitoring of the optic nerve head, namely, ocular hypertension and glaucoma. Moreover, the variable "cup shape," postulated in the previous literature[20] as being indicative of early glaucomatous visual field loss with a high degree of sensitivity and specificity, seems to be a promising parameter to be used in clinics widely in the evaluation of the optic nerve head topography of ocular hypertension and glaucoma patients.

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