Correlations Between Digital Planimetry and Optical Coherence Tomography, Confocal Scanning Laser Ophthalmoscopy in Assessment of Optic Disc Parameters

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***Key words**: optic disc; digital planimetry; optical coherence tomography; confocal scanning laser ophthalmoscopy.*

***Summary.** Objective and Aim. In routine clinical practice, laser methods for the evaluation of optic disc parameters are expensive and not accessible for all ophthalmologists; therefore, there is a need for less expensive technique. The aim of this study was to assess correlations between the parameters of the optic disc measured by digital planimetry (DP), optical coherence tomography (OCT), and confocal scanning laser ophthalmoscopy (CSLO) in healthy and glaucoma patients with the normal biometric parameters of the eye.*

Material and Methods. This case-control study enrolled 40 patients with glaucoma and 32 healthy patients with the normal biometric parameters of the eye. All subjects underwent full ophthalmologic examination, digital color optic disc photography, OCT, and CSLO at the same visit. The optic disc was morphometrically analyzed by DP, OCT, and CSLO. Seven optic disc parameters were evaluated.

Results. In the glaucoma group, the optic disc and cup areas ($r=0.7–0.8$, $P<0.001$) and cup-to-optic disc and rim-to-optic disc area ratios ($r=0.7$, $P<0.001$) measured by DP were strongly correlated with those measured by OCT and CSLO, while the horizontal and vertical cup-to-optic disc diameter ratios were found to be moderately correlated ($r=0.6–0.7$, $P<0.001$). In healthy patients, the optic disc and cup areas were strongly correlated ($r=0.7–8.0$, $P<0.001$). Significant differences in all optic disc parameters, except for the optic disc area, measured by DP, OCT, and CSLO were found between glaucoma and healthy patients.

Conclusions. Strong correlations between the parameters of the optic disc measured by DP, OCT, and CSLO were found. There were significant differences in the parameters between healthy and glaucoma eyes measured using DP; therefore, this technique may be used for diagnosis, management, and screening of glaucoma.

Introduction

Ophthalmoscopy – an assessment of the eye fundus – is a fundamental method used in ophthalmology and starts with the evaluation of the optic disc (1). Lesions of the optic disc may lead to irreversible changes in the clinical functionality of the eye: impaired vision, dyschromatopsia, contrast sensitivity disorders, and visual field defects (1, 2). Assessment of optic disc morphology is essential in the diagnosis and management of many ophthalmic disorders (3). Thus, an objective and early detection of optic disc pathology particularly in glaucoma cases is relevant for sustaining of visual functions (2).

There are several methods for optic disc parameterization: histomorphometry of histological preparations, biomicroscopy using magnifying lenses (+60D, +78D, +90D, Superfield NC) and retina scale, laser methods, such as confocal scanning laser ophthalmoscopy (CSLO), optical coherence tomography (OCT), and planimetry, which allows the quantitative measurements of the optic disc by plotting disc photographs on paper and measuring them manually (3, 4).

Morphologic evaluation of histological sections has been used to assess both topographical features of the optic disc and nerve fiber characteristics (3). Recent histomorphometric studies of the optic nerve disc in humans and monkeys have used sophisticated sectioning and imaging techniques to generate three-dimensional reconstructions of the optic disc (3, 5). This method is more commonly used for the evaluation of optic disc morphology in scientific research rather than in clinical practice (3).

Slit lamp biomicroscopy using a high-power fundus lens is a standard technique for evaluating the optic disc. It is an easy, rapid, and inexpensive method. However, it is also subjective and shows

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only an acceptable level of intraobserver and interobserver variability (3, 4).

Laser methods are relatively new techniques that help quantify the topography of the optic disc. These high technology-based techniques are being more reproducible and more independent of the subjective evaluation by an examiner than the conventional techniques of disc examination. However, partly CSLO and OCT are semiautomated techniques and use different methods to determine the margins of the optic nerve disc and cup (3, 6). The basis for the computation of the optic disc stereometric parameters in CSLO is the margin of the optic disc, which must be defined manually by placing a contour line along the varying height of the retinal surface (7). The algorithm in OCT detects and measures all the features of optic disc anatomy based on the anatomic markers (disc reference points) on each side of the disc where the retinal pigment epithelium ends. It is possible to adjust interactively the placement of the disc reference points in the case of an imprecise indication of the boundary and thus to impact the measurements (8). However, laser methods are expensive and not accessible for all ophthalmologists.

Manual planimetry still is the gold standard in quantitative evaluation of optic nerve disc morphology and is conventionally performed by projecting on a screen or plotting on paper the outlines of the disc structures from slides or photographs (3). The optic disc slides or photographs are projected in a scale of 1–15. The outlines of the optic cup, optic disc, and peripapillary scleral ring are plotted on paper and analyzed morphometrically. The optic cup is defined based on the contour, not pallor. The border of the optic disc is marked at the inner side of the peripapillary scleral ring. To obtain values in mm or mm^2, the ocular and photographic magnification is corrected using the Littmann method (9). Several studies have reported good interobserver and intraobserver agreement for experienced observers using manual planimetry. However, this method is very time-consuming, and the evolution of computer technology has prompted the digitization of this process (3).

At present, modern ophthalmology contains huge amounts of eye fundus images that need to be classified, analyzed, and evaluated (10, 11). The ophthalmologists need a user-friendly, inexpensive, rapid, reproducible, and clinical sure method for the parameterization of eye fundus images (11). For this purpose, the innovative digital planimetry, an algorithm for the parameterization of digital fundus images, has been developed that can be used for the establishment of optic disc pathology and its changes (11). This method is a computer-assisted parameterization of digital fundus images with an interactive algorithm, when the demarcation line is drawn around the optic disc and cup with a computer mouse interactively, but morphometric parameters are automatically calculated by software.

The aim of this study was to assess the correlations between biometric parameters of the optic disc acquired by innovative DP and OCT, CSLO in healthy and glaucoma patients with normal biometric parameters of the eye.

Material and Methods

Study Population

This case-control study was conducted at the Clinic of Ophthalmology, Hospital of Lithuanian University of Health Sciences, from March 2009 to April 2010. The case group comprised 223 patients with glaucoma, residing in Kaunas, who were treated at the Clinic of Ophthalmology, Hospital of Lithuanian University of Health Sciences. A total of 521 healthy 45- to 74-year-old men and women, residing in Kaunas city and randomly selected from the population registry to participate in the international HAPIEE (Health, Alcohol and Psychosocial Factors in Eastern Europe) study, were recruited for the control group.

Inclusion Criteria

The general inclusion criteria for both patients with glaucoma and healthy patients were as follows: no history of optic disc and posterior eye pole diseases, no eye injury or surgery, mild ametropia (spherical equivalent, ±1 D), normal corneal curvature (8±0.25 mm), physiological corneal astigmatism (±0.75 D), uncorrected visual acuity (UCVA) of ⩽0.5by LogMAR, best-corrected visual acuity (BCVA) of ⩽0.2 by LogMAR, intraocular pressure of <21 mm Hg, axial length of 23±0.8 mm, central corneal thickness of 510–550 μm (12), and clear lens (NO <2, C <1.5, P <1). To be enrolled in the control group, the patients had to have no glaucoma. The additional inclusion criteria just for the glaucoma group were as follows: primary open angle glaucoma, glaucomatous visual field defects confirmed by 2 standard computer-based perimetries (Humphrey SITA Standard 24–2 or 30–2) when mean deviation (MD) ranged from –2 dB to –6 dB, and intraocular pressure of >21 mm Hg at diagnosis (by Schötz tonometry).

Exclusion Criteria

The exclusion criteria were as follows: history of the diseases of the optic disc and posterior pole, eye injury or surgery, ametropia when spherical equivalent was less than –1 D or more than +1 D, corneal curvature of less than 7.75 mm or more than 8.25 mm, corneal astigmatism of less than –0.75 D or more than +0.75 D, UCVA of >0.5 by LogMAR, BCVA of >0.2 by LogMAR, intraocular pressure of

>21 mm Hg, axial length of less than 22.2 mm or more than 23.8 mm, central corneal thickness of less than 510 μm or more than 550 μm, lens opacification (NO >2, C >1.5, P >1).

The study was approved by the Institutional Review Board/Ethics Committee. Each participant of the study signed informed consent.

Ophthalmologic Examination

Information on the demographic characteristics (including subject identifier number, age, gender, examination date) and medical history (optic nerve, retina, and retinovascular pathologies; glaucoma; eye injuries and surgeries; eye drops; comorbidities; systemic drugs) was collected using a questionnaire. Full ophthalmologic examination was performed including the evaluation of UCVA and BCVA by LogMAR, refraction and keratometry by an auto ref-keratometer Accuref-K 9001 (Shin-Nippon, Japan), axial length and central corneal thickness by OTI Scan 3000, and intraocular pressure by a Schötz tonometer (Riester, Germany) under anesthesia with 0.5% proxymetacaine. Biomicroscopy of the anterior segment and lens evaluation according to the Lens Opacities Classification System III (LOCS III) after mydriasis with 1% cyclopentolate were performed. The healthy patients underwent frequency doubling technology (N-30-5 FDT Screening) perimetry; and the patients with glaucoma, Humphrey SITA Standard perimetry (24–2 or 30–2).

Digital Planimetry

Digital photographs of the eye fundus, centered on the optic disc, were obtained using a digital fundus camera Zeiss Visucam NM/FA at the 45° setting. The optic disc was morphometrically analyzed by DP. This innovative method is a computer-assisted parameterization of digital fundus images with an interactive algorithm, when the demarcation line is drawn around the areas of interest with a computer mouse. It was done using computer software developed by the Biomedical Engineering Institute, Kaunas University of Technology (11). DP was based on an interactive algorithm implemented in Matlab (2007a, The MathWorks, Inc.). The ophthalmologist using software tools with a computer mouse points to the approximate center of the optic disc on the digital fundus image, and then with the help of a template, selects 12 points on the boundary of the optic disc and cup. The area of the disc was defined as the area within the Elschnig's ring, the cup was defined on the basis of contour, not pallor, and the rim-to-optic cup border was taken as the level at which the slope of the rim steepens. Then, the software approximates ellipses on these points and calculates 14 numerical parameters using the ellipses of the external optic disc and cup boundaries. The parameters assessed in this study were as follows: optic disc, cup, and rim areas; cup-to-disc and rim-to-disc area ratios; and vertical and horizontal cup-to-disc diameter ratios (Fig. 1).

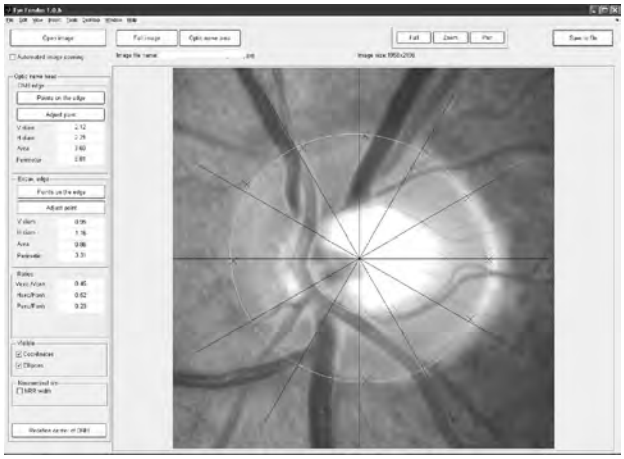

Fig. 1. Optic disc parameterization with digital planimetry
The ophthalmologist points to the approximate center of the optic disc and the boundary of the optic disc and cup using software tools with a computer mouse. Then, the software approximates ellipses on these points and calculates parameters using the ellipses of the external optic disc and cup boundaries.

Optical Coherence Tomography

OCT of the optic disc was performed by Stratus OCT, a computer-assisted optical instrument, that generates cross sectional 2-dimensional images (tomograms) of the optic disc with axial and transverse resolutions of 10 μm and 20 μm, respectively.

The fast optic disc protocol was used for the acquisition of an optic disc scan. This protocol consists of a series of 6 equally spaced 4-mm radial line scans through a common central axis. With each scan pass, the Stratus OCT captures 128 longitudinal (axial) range samples (A-scans). Each A-scan consists of 1024 data points over 2 mm of depth. Thus, the Stratus OCT integrates 131 072 data points to construct a cross-sectional 2-dimensional image (tomogram) of optic disc anatomy. It displays the 6 tomograms in real time using a false color scale that represents the degree of light backscattering from tissues at different depths in the retina (Fig. 2, the analysis screen at the top left presents 1 scan image).

The Optic Nerve Head, an interactive analysis protocol, was used for the quantitative evaluation of optic disc scans. The analysis calculates values for each of the 6 radial line scans (Fig. 2, the analysis screen at the top right presents the results of 1 scan) and then integrates them to give the results for the entire optic disc (Fig. 2, the analysis screen at the bottom right presents the results of 6 integrated scans) and a composite image of the optic

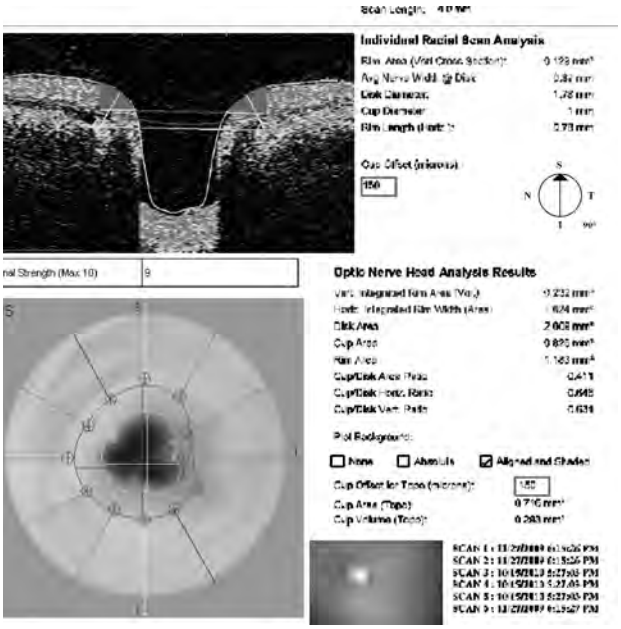

Fig. 2. Optic disc parameterization with optical coherence tomography

The fast optic disc protocol is used for the acquisition of 6 radial scans of the optic disc, and the Optic Nerve Head, an interactive analysis protocol, is used for the quantitative evaluation of optic disc scans. The algorithm automatically detects and measures all features of disc anatomy based on the anatomical markers (disc reference points) on each side of the disc where the retinal pigment epithelium ends. There is a possibility to adjust the placement of the disc reference points interactively in the case of imprecision. Then the Optic Nerve Head protocol calculates the values for each of the 6 radial scans and then integrates them to give the results for the entire optic disc and a composite image of the optic nerve disc constructed from all scans.

nerve head constructed from all scans (Fig. 2, the analysis screen at the bottom left).

For each scan in the group, the Optic Nerve Head protocol detects the anterior surface of the retinal nerve fiber layer (RNFL) and retinal pigment epithelium (RPE). It detects the RNFL surface by searching each A-scan from anterior to posterior until it finds reflectivity above a threshold value. From below the RNFL surface, it searches each A-scan posteriorly for the highest rate of change in reflectivity to find the RPE surface. Having determined these boundaries, the algorithm detects and measures all features of disc anatomy based on the anatomical markers (disc reference points) on each side of the disc where the RPE ends. It locates and measures the disc diameter by tracing a straight line between the two disc reference points and measures the cup diameter on a line parallel to the disc line and offset anteriorly by 150 μm (Fig. 2). It determines the rim area using the cup line as a posterior boundary; for the rim lateral boundaries, it uses lines extended from the disc reference points perpendicular to the disc line and up to the anterior surface of the disc. In the output display, the placement of the disc reference points can be adjusted and thus measurements can be affected. The Optic Nerve Head analysis then combines the analysis and measurement of each individual scan into a composite image and measurements of the whole optic nerve head. The output display on the left side (Fig. 2) shows an individual radial scan analysis and on the right side, the results of Optic Nerve Head analysis (Stratus OCT User Manual, Carl Zeiss Meditec, 2004).

Confocal Scanning Laser Ophthalmoscopy

CSLO of the optic disc was performed using a Heidelberg Retina Tomograph (HRT III, glaucoma module). The Heidelberg Retina Tomograph is a confocal laser scanning system for acquisition and analysis of three-dimensional images of the posterior segment of the eye. A laser light (diode laser with a wavelength of 620 nm) scans the retina in 24-ms sequential scans, starting above the retinal surface, then capturing parallel images at increasing depths. A series of 16 to 64 consecutive and equidistant (1/16 mm) parallel two-dimensional images is thereby captured and combined to produce a layered three-dimensional image (topography image) of the retina. The mean topography image (Fig. 3, the analysis screen at the top right) is calculated using the 3 three-dimensional image series. It is color coded, with dark colors representing elevated structures and light colors representing depressed structures. Each of the two-dimensional image (scan) is composed of 384×384 pixels for a total of 147 456 data points covering a 15° area of the retina. The basis for the computation of the stereometric parameters is the margin of the optic disc, which must be defined manually by placing a contour line along the inner edge of the scleral (Elschnig's) ring. Four points are placed at the temporal, nasal, superior, and inferior disc margins (at 0°, 180°, 90°, and 270°). Thereafter, an additional point between each two of the first 4 points (at 45°, 135°, 225°, and 315°) is placed if necessary. The aids for contour line placement are color change (often color differences between the surrounding retina and optic nerve head serve as an obvious indicator), bending of vessels (changes in the direction of blood vessels), three-dimensional representation of the topography can be displayed with the three-dimensional system (the contour line should appear to rest on stable retinal tissue, not on sloping), interactive retinal surface height profile, and the surface height variation graphics (the retinal surface height should not dip below the reference plane). A scan rate of 24 ms helps avoid eye movement artifact; the topography images with standard deviation scores above 50 μm were excluded from statistical analysis.

After the definition of the disc margin, the HRT software computes a set of stereometric parameters

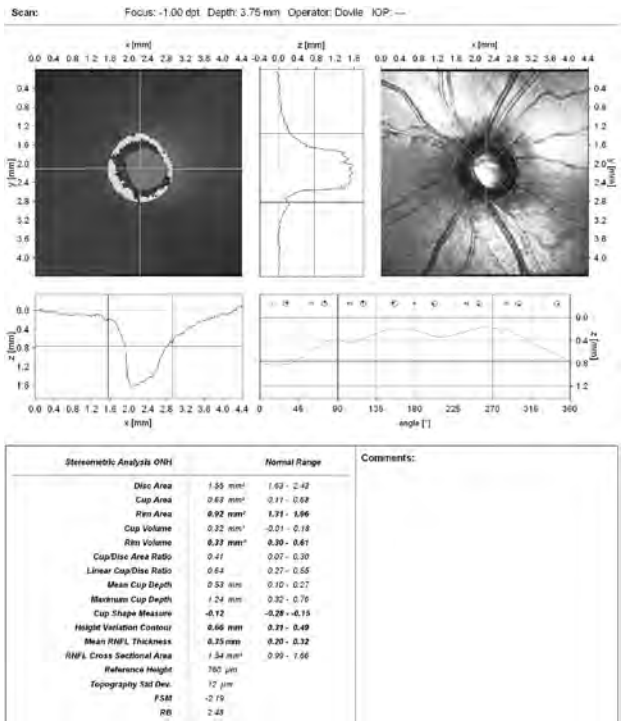

Fig. 3. Optic disc parameterization with confocal scanning laser ophthalmoscopy

The Heidelberg Retina Tomograph is a confocal laser scanning system for the acquisition and analysis of three-dimensional images of the optic disc. At first, the margin of the optic disc must be defined manually by placing a contour line along the inner edge of the scleral ring. After the definition of the disc margin, the Heidelberg Retina Tomograph software computes a set of stereometric parameters that quantitatively describe the shape of the optic disc.

that quantitatively describe the shape of the optic disc (HRT User Manual, Heidelberg Engineering, 2007) (Fig. 3).

Statistical Analysis

Data analysis was carried out using the Microsoft Office Excel 2007 and SPSS 16 for Mac. The Pearson correlation was employed in order to detect the associations between the variables, and the Student *t* test was used to compare the results between two groups. The 95% confidence intervals were calculated based on asymptotic normal distribution. Differences were considered significant if a *P* value was less than 0.05.

Results

Characteristics of Study Population

Of the 223 patients with glaucoma, 40 were selected for the case group (40 eyes; 6 men and 34 women, with a mean age of 64 years; SD, 9.6). Of the 521 participants with normal biometric parameters of the eye, 32 were enrolled into the control group (32 eyes, 12 men and 20 women, with a mean age of 58.8 years; SD, 5.7). The characteristics of healthy patients (control group) and glaucoma patients (case group) are summarized in Table 1. There were no significant differences in the biometric parameters (spherical equivalent, corneal curvature, corneal astigmatism, axial length, and central corneal thickness) comparing the two groups.

Results of Optic Disc Parameterization

Table 2 shows the values of optic disc parameters measured by DP, OCT, and CSLO in the control and case groups. Comparison of the optic disc parameters measured using 3 different techniques within both the groups revealed significant differences in most cases ($P<0.05$), except for the cup area and the vertical cup-to-disc diameter ratio comparing DP with CSLO in both the groups, the disc area comparing CSLO with OCT in both the groups, and the rim area comparing CSLO with OCT in the case group ($P>0.05$).

Comparison of optic disc parameters between the control and case groups showed that there were significant differences in most parameters of the optic disc, measured by 3 different techniques, between the control and case groups, except for the optic disc area measured by all 3 techniques and the rim area measured by DP (Table 2).

Correlation Between Parameters Measured by DP, CSLO, and OCT

The disc area measured using DP strongly and significantly correlated with that measured using CSLO and OCT in both the groups (*r* ranging from 0.7 to 0.89, all $P<0.001$) (Table 3). Similarly, the cup area, the cup-to-disc and rim-to-disc area ratios, and the vertical cup-to-disc diameter ratio measured by DP strongly correlated with those measured by CSLO and OCT in the case group (*r* ranging from 0.71 to 0.82, all $P<0.001$) and moderately in the control group (*r* ranging from 0.41 to 0.67, *P* ranging from <0.001 to 0.03). However, the rim area measured by DP parameterization moderately correlated with that measured by CSLO and OCT ($r=0.44$, $P=0.01$; and $r=0.41$, $P=0.02$; respectively) only in the control group, with no significant correlation in the case group.

All optic disc parameters measured by CSLO were strongly correlated with those measured by OCT in both the groups (*r* ranging from 0.71 to 0.84, all $P<0.001$), except for the rim area and the vertical cup-to-disc diameter ratio in the control group, where the correlation was found to be moderate ($r=0.48$, $P<0.005$; and $r=0.47$, $P<0.007$; respectively) (Table 3).

Discussion

This study examined the correlation between the parameters of the optic disc in patients with

Table 1. Characteristics of Study Population

Variable	Control Group	Case Group	*P**
Age, years	58.8 (5.7)	64 (9.6)	<0.003
UCVA, logMAR	0.06 (0.13)	0.28 (0.27)	<0.000
BCVA, logMAR	0.009 (0.099)	0.16 (0.16)	<0.000
Spherical equivalent, D	0.45 (0.46)	0.31 (1.22)	NS
Corneal curvature, R1 mm	7.8 (0.25)	7.7 (0.23)	NS
Corneal curvature, R2 mm	7.71 (0.23)	7.61 (0.24)	NS
Corneal astigmatism, D	–0.68 (0.34)	–0.55 (0.36)	NS
Axis of corneal astigmatism, °	84.42 (77.49)	86.36 (65.79)	NS
Axial length, mm	23.06 (0.77)	23.1 (0.83)	NS
Central corneal thickness, μm	549.16 (38.88)	533.95 (36.02)	NS
Intraocular pressure, mm Hg	16.75 (2.2)	14.6 (2.68)	<0.000
NO, LOCS III	1.17 (0.35)	1.48 (0.63)	<0.009
C, LOCS III	0.16 (0.2)	0.75 (0.88)	<0.000
P, LOCS III	0.1	0.19 (0.5)	NS

Values are given as mean (SD). UCVA, uncorrected visual acuity (logMAR); BCVA, best corrected visual acuity (logMAR); NO, nuclear opalescence; C, cortical; P, posterior subcapsular LOCS III classification at slit lamp; NS, not significant.
*Student *t* test.

Table 2. Comparison of the parameters of the optic disc in the control and case groups and between the groups

Parameter	Control Group			*P**	Case Group			*P*†	*P*‡
	DP[1]	CSLO[2]	OCT[3]		DP[1]	CSLO[2]	OCT[3]		
Disc area, mm²	3.15 (0.45)	2.17 (0.29)	2.27 (0.34)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=NS	3.30 (0.68)	2.26 (0.44)	2.44 (0.52)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=NS	P_{DP}=NS P_{CSLO}=NS P_{OCT}=NS
Cup area, mm²	0.60 (0.29)	0.60 (0.22)	0.86 (0.34)	$P_{1\text{ vs. }2}$=NS $P_{1\text{ vs. }3}$<0.002 $P_{2\text{ vs. }3}$<0.0001	0.91 (0.44)	0.95 (0.54)	1.29 (0.69)	$P_{1\text{ vs. }2}$=NS $P_{1\text{ vs. }3}$<0.004 $P_{2\text{ vs. }3}$=0.02	P_{DP}<0.0009 P_{CSLO}<0.0012 P_{OCT}<0.0018
Rim area, mm²	2.55 (0.36)	1.57 (0.23)	1.41 (0.27)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.0114	2.39 (0.45)	1.31 (0.38)	1.15 (0.39)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=NS	P_{DP}=NS P_{CSLO}<0.0012 P_{OCT}<0.0019
Cup-to-disc area ratio	0.19 (0.08)	0.27 (0.08)	0.37 (0.12)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$<0.0001	0.27 (0.09)	0.41 (0.17)	0.51 (0.18)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.01	P_{DP}<0.0001 P_{CSLO}<0.0001 P_{OCT}<0.0005
Rim-to-disc area ratio	0.81 (0.08)	0.73 (0.08)	0.63 (0.12)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.0003	0.73 (0.09)	0.59 (0.17)	0.49 (0.18)	$P_{1\text{ vs. }2}$<0.0001 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.01	P_{DP}<0.0001 P_{CSLO}<0.0001 P_{OCT}<0.0005
Horizontal cup-to-disc diameter ratio	0.45 (0.10)	0.54 (0.13)	0.60 (0.13)	$P_{1\text{ vs. }2}$=0.003 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.04	0.51 (0.09)	0.62 (0.16)	0.69 (0.16)	$P_{1\text{ vs. }2}$=0.0004 $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.03	P_{DP}<0.0089 P_{CSLO}<0.0255 P_{OCT}<0.0085
Vertical cup-to-disc diameter ratio	0.40 (0.09)	0.44 (0.11)	0.59 (0.10)	$P_{1\text{ vs. }2}$=NS $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$<0.0001	0.51 (0.11)	0.55 (0.19)	0.70 (0.14)	$P_{1\text{ vs. }2}$=NS $P_{1\text{ vs. }3}$<0.0001 $P_{2\text{ vs. }3}$=0.0001	P_{DP}<0.00002 P_{CSLO}<0.0032 P_{OCT}<0.0002

Values are given as mean (SD). DP, digital planimetry; CSLO, confocal scanning laser ophthalmoscopy; OCT, optical coherence tomography.
*Student *t* test *P* values comparing parameters within the control group; †Student *t* test *P* values comparing parameters within the case group; ‡Student *t* test *P* values comparing parameters between the control and case groups; NS, not significant.

Table 3. Correlations Between Parameters Measured by Digital Planimetry, Confocal Scanning Laser Ophthalmoscopy, and Optical Coherence Tomography in the Control and Case Groups

Parameter	Control Group						Case Group					
	CSLO vs. DP		OCT vs. DP		CSLO vs. OCT		CSLO vs. DP		OCT vs. DP		CSLO vs. OCT	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Disc area	0.89	<0.001	0.72	<0.001	0.71	<0.001	0.82	<0.001	0.70	<0.001	0.74	<0.001
Cup area	0.65	<0.001	0.67	<0.001	0.81	<0.001	0.82	<0.001	0.81	<0.001	0.84	<0.001
Rim area	0.44	0.01	0.41	0.02	0.48	0.005	0.26	NS	0.17	NS	0.73	<0.001
Cup-to-disc area ratio	0.43	0.012	0.55	0.001	0.72	<0.001	0.71	<0.001	0.73	<0.001	0.80	<0.001
Rim-to-disc area ratio	0.44	0.012	0.56	<0.001	0.71	<0.001	0.71	<0.001	0.73	<0.001	0.80	<0.001
Horizontal cup-to-disc diameter ratio	0.39	0.03	0.51	0.003	0.71	<0.001	0.64	<0.001	0.66	<0.001	0.75	<0.001
Vertical cup-to-disc diameter ratio	0.41	0.02	0.51	0.003	0.47	0.007	0.77	<0.001	0.72	<0.001	0.79	<0.001

CSLO, confocal scanning laser ophthalmoscopy; DP, digital planimetry; OCT, optical coherence tomography.

glaucoma and healthy patients with normal biometric parameters of the eye, measured by 3 different techniques. To our knowledge, this is the first study where the optic disc was evaluated using 3 different modalities (DP, OCT, and CSLO) at the same visit.

In clinical practice, only few ophthalmologists have access to laser methods or especially to histomorphometry, and in routine clinical practice, an evaluation of the optic disc is usually performed at slit lamp (13) or fundus camera. Each of these methods has its strengths and weaknesses (4).

Histomorphometry. The mean optic disc size measured using this technique in healthy eyes range from 2.57 to 2.81 mm^2. The main advantage is that measurements do not depend on magnification correction errors. It is a complicated, time-consuming, and expensive morphometric method, previously used only by several researchers. Other limitations include the availability of eyes, histological changes in the tissue postmortem, and specialized equipment and methods for the tissue fixation required (14).

Biomicroscopy Using Magnifying Lenses and Retina Scale. It is an easy, rapid, and inexpensive method. Disadvantages are magnification correction errors (varying distance from the eye to lens) especially in case of a high refractive error; the optic disc size is underestimated under conditions of myopia and overestimated under conditions of hyperopia (15).

Confocal Scanning Laser Ophthalmoscopy. The mean optic disc size measured with CSLO varies from 1.74 to 2.47 mm^2. It is a rapid, objective, and reproducible method; mydriasis is optional, and data analysis is automated. An ophthalmologist defines the margins of the optic disc subjectively, and it is one of the disadvantages of this disc (16).

Optical Coherence Tomography. The mean optic disc size measured using this modality ranges from 2.10 to 2.35 mm^2. Advantages of this technique include an objective, automated demarcation of the optic disc margins based on the margins of the retinal pigment epithelium/choriocapillaris layer. Disadvantages include the following: it is an expensive method, there is a need for mydriasis and clear media, and a scan template should be adjusted for normal vision and average axial length of the eye (17).

Digital Planimetry. The mean optic disc area measured using DP varies from 1.7 to 2.89 mm^2 (18). It is an innovative, easy, rapid, objective, reproducible, and inexpensive method, available for each ophthalmologist and providing automated data analysis (11). Digital planimetry may be used with a portative fundus camera. An ophthalmologist, as in the case of CSLO, defines the optic disc margins interactively (11), and it is a source of subjectivity.

A precise and direct evaluation of optic disc parameters is only feasible during vitrectomy or histological examination of specimens (14). The results of optic disc parameterization depend on the methods and instruments used. The size of the optic disc also depends on the magnification properties of the eye; corneal curvature, axial length, and ametropia may influence the results (4). Therefore, in order to avoid the bias due to biometric eye characteristics in our study, the eyes with the spherical anterior corneal surface (19), physiological corneal astigmatism, normal axial length, and mild ametropia were chosen (12).

Although the measurements of optic disc areas acquired by DP, CSLO, and OCT are generally strongly correlated, the measurements of absolute optic disc area can significantly differ (4). In this study, the optic disc area as measured using DP was larger than that using CSLO and OCT both in glaucoma and healthy patients. The measured size of the optic disc depends on the measurement technique utilized (4). In the case of DP, in our study, flat digital optic disc images were evaluated by an interactive algorithm. The area of the optic disc was defined as the area within the Elschnig's ring; the cup was defined based on the contour, not pallor. Consequently, the absolute disc size is greater using DP in comparison with laser methods. In the case of OCT, two-dimensional optic disc images were evaluated, with an automated demarcation of the disc margin as the end of the retinal pigment epithelium/choriocapillaris layer (17). In this study, the fast optic disc protocol was used for the acquisition of optic disc images, and the Optic Nerve Head, an interactive analysis protocol, was employed for the quantitative evaluation of optic disc scan images (Fig. 2).

In case of CSLO, the basis for the computation of the stereometric parameters is the margin of the optic disc, which must be defined manually by placing a contour line along the inner edge of the scleral (Elschnig's) ring (16) (Fig. 3).

It is well recognized that laser methods are rapid, objective, reproducible and data analysis is automated, but they are expensive and not available for all ophthalmologists (13, 20). The assessment of the digital images of the eye fundus is one the most relevant and frequently used methods for the diagnosis of glaucoma. It is more easily mastered, accessible, and inexpensive as compared with laser methods (20). Evaluation of the digital images of the optic disc remains the golden standard in the diagnosis and evaluation of glaucoma (21–24).

Despite the fact that the absolute parameters of the optic disc vary with the measurement technique used (4, 23), this study demonstrated strong correlations between the biometric parameters of the optic disc measured by DP and those measured by OCT and CSLO in patients with glaucoma and healthy patients with normal biometric parameters of the eye. Our results are consistent with the findings of

other studies. Samarawickrama et al. examined 1765 healthy children and reported that the mean optic disc and cup areas measured by OCT were significantly smaller than those measured using DP (2.15 and 0.47 mm^2 vs. 2.40 and 0.51 mm^2, respectively; $P<0.01$). However, there were no significant differences in the vertical and horizontal cup-to-disc diameter ratios, and cup-to-disc area ratio comparing these two different techniques (0.41, 0.45, and 0.22 for OCT vs. 0.41, 0.44 and 0.21 for DP, respectively; $P>0.05$) (25). In agreement with these findings, a study by Ramakrishnan et al. involving 41 subjects demonstrated the mean optic disc and cup areas to be smaller as measured by OCT than those measured using DP (2.37 and 1.29 mm^2 vs. 2.83 and 1.56 mm^2, respectively; $P<0.001$) (26). However, all parameters of the optic disc measured by DP and OCT were found to be significantly correlated ($r>0.5$, $P<0.001$) (25, 27).

Some studies comparing the measurements done using CSLO and DP demonstrated that the rim area, rim-to-optic disc area ratio (28), and cup-to-optic disc ratio measured with CSLO were significantly greater than those measured by DP (29, 30). The most likely reason for these differences is that CSLO measures the vessel trunk as part of the neuroretinal rim (23, 28). Contrary, a study by Azuara-Blanco et al. reported that the rim area measured by CSLO was significantly smaller than that by DP (1.33 mm^2 vs. 1.58 mm^2, $P<0.01$), while cup-to-optic disc area ratio did not differ (31). Other studies demonstrated that the cup-to-optic disc ratio measured by CSLO strongly correlated with that measured by DP: vertical cup-to-optic disc diameter ratio ($r=0.78$, $P<0.001$) (32) and cup and optic disc area ($r=0.8$, $P<0.001$) (33). Other studies demonstrated the parameters measured by CSLO and DP to be moderately correlated (31–34). Especially strong correlation was observed for the linear cup-to-optic disc ratio ($r=0.9$, $P<0.001$) (32).

In our study, correlations between the parameters of the optic disc measured by DP and those measured using OCT and CSLO were found to be stronger in patients with glaucoma than healthy patients. It could be explained by a relative lack of the axonal tissue of glaucomatous optic discs that leads to the easier delineation of the margins than in normal optic discs (35).

There are difficulties to compare the measurements of the optic disc using DP among studies because authors are using different modalities and algorithms. Meyer and Howard overviewed 23 published studies on the results of digital parameterization where different fundus cameras and algorithms were used. The parameters of the optic disc differed significantly even though similar populations were investigated. The normalization coefficients were calculated: for Zeiss fundus camera, 1; Rodenstok Optic Disc Analyzer, 1.51; Topcon fundus camera, 1.04; Heidelberg Retina Tomograph, 1.15; and TopSS scanning laser ophthalmoscope, 1.29. According to the authors, these coefficients can be useful in comparison of results found across the different studies (36).

Conclusions

Strong correlations between the parameters of the optic disc measured by DP, OCT, and CSLO were found. There were significant differences in the parameters between healthy and glaucoma eyes measured using DP; therefore, this technique may be used for diagnosis, management, and screening of glaucoma.

Statement of Conflict of Interest

The authors state no conflict of interest.

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