eyes with elevated IOP, neither the optic disc appearance nor the perimetric results were taken into account.[49] These findings, including ours using HRT II, suggest that eyes with higher IOP tend to have greater cup even in normal eyes.

In the present report, after adjusting for the potential confounders, CCT showed weak but significant negative correlations with a few cup-related parameters, suggesting that eyes with a thinner cornea tended to have a greater cup (Tables 4 and 5 [available at http://aaojournal.org]). This may have some clinical implication, if one considers the recently reported findings that thinner cornea is a risk factor for developing glaucoma from ocular hypertensive eyes in the Ocular Hypertension Treatment Study[50] and the European Glaucoma Prevention Study.[51]

One limitation of the present report is the exclusion of a significant proportion of eyes that did not undergo HRT II measurements or in which HRT II images could not be obtained, or those without good-quality optic disc images. Because the excluded subjects were significantly older than the included subjects and age was significantly related to many HRT parameters, the exclusion may have influenced the current results, and the interpretation of age-related changes in HRT parameters in the current subjects should be done with caution. Another limitation of the present report is that only normal subjects with good central vision, no high refractive error, and clear ocular media were included in the analyses. Our definitions of normality may have excluded some potentially normal subjects from the analyses. Despite these limitations, our data provide a reference range of normality for HRT parameters based on a large sample of normal Japanese subjects. The reference range for normality provided in this report becomes a basis for comparison of optic disc characteristics between normal and glaucomatous eyes. Whether the reference range can improve the ability of glaucoma diagnosis in Japanese subjects requires further research.

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Table 1. Heidelberg Retina Tomograph Parameters in Right and Left Eyes in 1540 Normal Subjects of Whom Both Right and Left Eyes Were Eligible

	Right Eyes	Left Eyes	P Value*	Correlation Coefficient†	Absolute Difference
Disc area (mm^2)	2.06±0.41 (2.04–2.08)	2.07±0.41 (2.05–2.09)	0.087	0.830 (<0.001)	0.18±0.15 (0.17–0.19)
Cup area (mm^2)	0.51±0.34 (0.49–0.52)	0.50±0.35 (0.48–0.52)	0.327	0.821 (<0.001)	0.16±0.14 (0.15–0.16)
Rim area (mm^2)	1.55±0.29 (1.54–1.57)	1.57±0.29 (1.55–1.58)	0.012	0.647 (<0.001)	0.19±0.16 (0.18–0.19)
Cup-to-disc area ratio	0.23±0.13 (0.23–0.24)	0.23±0.13 (0.22–0.24)	0.063	0.769 (<0.001)	0.07±0.06 (0.06–0.07)
Cup volume (mm^3)	0.11±0.12 (0.11–0.12)	0.11±0.12 (0.10–0.11)	0.030	0.802 (<0.001)	0.05±0.06 (0.05–0.05)
Rim volume (mm^3)	0.41±0.14 (0.40–0.42)	0.43±0.15 (0.42–0.43)	<0.001	0.529 (<0.001)	0.11±0.09 (0.10–0.11)
Mean cup depth (mm)	0.21±0.09 (0.20–0.21)	0.20±0.09 (0.20–0.21)	0.246	0.776 (<0.001)	0.04±0.04 (0.04–0.05)
Maximum cup depth (mm)	0.57±0.20 (0.56–0.58)	0.58±0.21 (0.56–0.58)	0.596	0.726 (<0.001)	0.12±0.10 (0.11–0.12)
Height variation contour (mm)	0.39±0.09 (0.38–0.39)	0.40±0.10 (0.39–0.40)	<0.001	0.450 (<0.001)	0.08±0.07 (0.08–0.08)
Cup shape measure	−0.19±0.07 (−0.19–0.19)	−0.19±0.07 (−0.20–0.19)	0.478	0.493 (<0.001)	0.05±0.04 (0.05–0.06)
Mean RNFL thickness (mm)	0.26±0.07 (0.25–0.26)	0.26±0.08 (0.26–0.27)	0.013	0.534 (<0.001)	0.05±0.04 (0.05–0.06)
RNFL cross-sectional area (mm^2)	1.30±0.34 (1.28–1.31)	1.32±0.37 (1.30–1.34)	0.011	0.511 (<0.001)	0.28±0.23 (0.27–0.29)

RNFL = retinal nerve fiber layer.
Data are shown as "mean±standard deviation (95% confidence interval)."
*P value on comparison between right and left eyes (paired t test).
†Pearson's correlation coefficients with P values in the parentheses. Because of multiple comparisons among the 12 Heidelberg Retina Tomograph parameters, Bonferroni correction was applied with a level of significance of 0.0042.

Table 3. Correlation Coefficients of Simple Linear Regression Analyses

	Age		Height		Weight		Systolic Blood Pressure	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
Disc area	−0.13 (<0.001)	−0.11 (0.001)	NS	0.09 (0.008)	NS	NS	NS	NS
Cup area	NS	NS	NS	0.07 (0.034)	NS	NS	NS	NS
Rim area	−0.11 (0.002)	−0.15 (<0.001)	NS	NS	NS	NS	NS	NS
Cup-to-disc area ratio	NS	NS	NS	NS	NS	NS	NS	NS
Cup volume	−0.10 (0.007)	NS	NS	0.11 (<0.001)	NS	NS	NS	NS
Rim volume	−0.18 (<0.001)	−0.21 (<0.001)	NS	0.07 (0.035)	NS	NS	−0.08 (0.031)	−0.08 (0.012)
Mean cup depth	−0.15 (<0.001)	−0.07 (0.025)	0.13 (<0.001)	0.12 (<0.001)	0.08 (0.033)	NS	NS	NS
Maximum cup depth	−0.20 (<0.001)	−0.10 (0.002)	0.15 (<0.001)	0.13 (<0.001)	0.09 (0.015)	NS	NS	NS
Height variation contour	−0.17 (<0.001)	−0.17 (<0.001)	0.10 (0.008)	0.07 (0.025)	0.07 (0.044)	NS	−0.10 (0.008)	−0.08 (0.011)
Cup shape measure	0.08 (0.034)	0.14 (<0.001)	NS	−0.07 (0.039)	NS	NS	NS	NS
Mean RNFL thickness	−0.29 (<0.001)	−0.27 (<0.001)	0.18 (<0.001)	0.12 (<0.001)	0.14 (<0.001)	NS	−0.13 (0.001)	−0.12 (<0.001)
RNFL cross-sectional area	−0.33 (<0.001)	−0.3 (<0.001)	0.17 (<0.001)	0.14 (<0.001)	0.13 (<0.001)	NS	−0.13 (0.001)	−0.13 (<0.001)

NS = not significant (P>0.05); RNFL = retinal nerve fiber layer.
Pearson's correlation coefficients are shown with P values in the parentheses.
*Spherical equivalent values.

in 1769 Normal Right Eyes of 787 Male and 982 Female Subjects

Diastolic Blood Pressure		Ocular Perfusion Pressure		Refractive Error*		Intraocular Pressure		Central Corneal Thickness	
Male	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*
NS	NS	NS	NS	NS	NS	−0.08 (0.04)	NS	NS	NS
NS	NS	NS	NS	NS	0.07 (0.25)	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	−0.09 (0.016)	NS	NS	NS
NS	NS	NS	NS	NS	0.08 (0.013)	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	−0.20 (<0.001)	−0.18 (<0.001)	NS	NS	0.07 (0.043)	NS
NS	NS	NS	NS	−0.13 (<0.001)	NS	NS	NS	NS	NS
NS	NS	NS	NS	−0.16 (<0.001)	NS	NS	NS	NS	NS
NS	NS	−0.08 (0.020)	NS	−0.27 (<0.001)	−0.18 (<0.001)	NS	NS	NS	NS
NS	NS	NS	NS	NS	0.08 (0.010)	NS	NS	NS	NS
NS	NS	−0.80 (0.024)	−0.08 (0.016)	−0.32 (<0.001)	−0.25 (<0.001)	NS	NS	NS	NS
NS	NS	−0.07 (0.046)	−0.08 (0.014)	−0.31 (<0.001)	−0.21 (<0.001)	NS	NS	NS	NS

Table 4. Partial Correlation Coefficients in Multiple Regression Analysis on Each of the Heidelberg Retina Tomograph Parameters in 1769 Normal Eyes of 787 Male and 982 Female Subjects

	Age	Height	Weight	Systolic Blood Pressure	Ocular Perfusion Pressure	Refractive Error	Intraocular Pressure	Central Corneal Thickness	Gender
Disc area	−0.14 (<0.001)	NS	NS	NS	NS	0.09 (<0.001)	NS	NS	NS
Cup area	NS	0.04 (0.049)	NS	NS	NS	0.07 (0.005)	NS	NS	NS
Rim area	−0.15 (<0.001)	−0.07 (0.003)	NS	NS	NS	0.05 (0.035)	NS	NS	NS
Cup-to-disc area ratio	NS	0.07 (0.002)	NS	NS	NS	0.06 (0.020)	NS	NS	NS
Cup volume	−0.06 (0.008)	0.06 (0.008)	NS	NS	NS	0.07 (0.002)	NS	−0.05 (0.037)	NS
Rim volume	−0.12 (<0.001)	−0.05 (0.024)	NS	NS	NS	−0.12 (<0.001)	NS	NS	NS
Mean cup depth	−0.05 (0.037)	0.09 (<0.001)	NS	NS	NS	NS	NS	NS	NS
Maximum cup depth	−0.07 (0.002)	0.08 (<0.001)	NS	NS	NS	NS	NS	−0.05 (0.049)	NS
Height variation contour	−0.06 (0.015)	NS	NS	NS	NS	−0.16 (<0.001)	NS	NS	NS
Cup shape measure	0.08 (0.001)	NS	NS	NS	NS	NS	NS	NS	NS
Mean RNFL thickness	−0.14 (<0.001)	NS	NS	NS	NS	−0.16 (<0.001)	NS	NS	NS
RNFL cross-sectional area	−0.19 (<0.001)	NS	NS	NS	NS	−0.12 (<0.001)	NS	NS	NS

NS = not significant ($P>0.05$); RNFL = retinal nerve fiber layer.
Multiple regression analysis with each Heidelberg retina tomograph parameter as the dependent variable and age, height, weight, systolic and diastolic blood pressure, ocular perfusion pressure, refractive error (spherical equivalent), intraocular pressure, central corneal thickness, and gender as the independent variables. Partial correlation coefficients are shown with *P* values in the parentheses. Diastolic blood pressure was excluded from the model because of strong correlation between systolic and diastolic pressure.

Table 5. Partial Correlation Coefficients in Multiple Regression Analysis Including Disc Area as an Independent Variable on Each of the Heidelberg Retina Tomograph Parameters in 1769 Normal Eyes of 787 Male and 982 Female Subjects

	Age	Height	Weight	Systolic Blood Pressure	Ocular Perfusion Pressure	Refractive Error	Intraocular Pressure	Central Corneal Thickness	Gender	Disc Area
Cup area	0.09 (<0.001)	0.08 (0.001)	NS	NS	NS	NS	NS	NS	NS	0.73 (<0.001)
Rim area	−0.09 (<0.001)	−0.08 (0.001)	NS	NS	NS	NS	NS	NS	NS	0.56 (<0.001)
Cup-to-disc area ratio	0.09 (<0.001)	0.09 (<0.001)	NS	NS	NS	NS	NS	NS	NS	0.53 (<0.001)
Cup volume	NS	0.09 (<0.001)	NS	NS	NS	NS	0.05 (0.037)	−0.05 (0.040)	NS	0.60 (<0.001)
Rim volume	−0.11 (<0.001)	−0.05 (0.026)	NS	NS	NS	−0.13 (<0.001)	NS	NS	NS	0.13 (<0.001)
Mean cup depth	NS	0.10 (<0.001)	NS	NS	NS	NS	0.05 (0.041)	NS	NS	0.44 (<0.001)
Maximum cup depth	NS	0.09 (<0.001)	NS	NS	NS	NS	0.05 (0.026)	NS	NS	0.33 (<0.001)
Height variation contour	−0.07 (0.007)	NS	NS	NS	NS	−0.16 (<0.001)	NS	NS	NS	−0.05 (0.027)
Cup shape measure	0.14 (<0.001)	NS	NS	NS	NS	NS	NS	NS	NS	0.39 (<0.001)
Mean RNFL thickness	−0.17 (<0.001)	NS	NS	NS	NS	−0.15 (<0.001)	NS	NS	NS	−0.18 (<0.001)
RNFL cross-sectional area	−0.17 (<0.001)	NS	NS	NS	NS	−0.14 (<0.001)	NS	NS	NS	0.19 (<0.001)

NS = not significant ($P>0.05$); RNFL = retinal nerve fiber layer.
Multiple regression analysis with each Heidelberg retina tomograph parameter as the dependent variable and age, height, weight, systolic and diastolic blood pressure, ocular perfusion pressure, refractive error (spherical equivalent), intraocular pressure, central corneal thickness, gender, and disc area as the independent variables. Partial correlation coefficients are shown with *P* values in the parentheses. Diastolic blood pressure was excluded from the model because of strong correlation between systolic and diastolic pressure.

Table 6. Correlation Coefficients of Each Pair of the Heidelberg Retina Tomograph Parameters in 1769 Normal Eyes

	Disc Area	Cup Area	Rim Area	Cup-to-Disc Area Ratio	Cup Volume	Rim Volume	Mean Cup Depth	Maximum Cup Depth	Height Variation Contour	Cup Shape Measure	Mean RNFL Thickness
Cup area	0.72										
Rim area	0.56	−0.17									
Cup-to-disc area ratio	0.52	0.95	−0.39								
Cup volume	0.61	0.90	−0.21	0.85							
Rim volume	0.13	−0.38	0.64	−0.51	−0.34						
Mean cup depth	0.44	0.79	−0.33	0.84	0.86	−0.20					
Maximum cup depth	0.34	0.65	−0.29	0.71	0.73	−0.13	0.92				
Height variation contour	−0.05*	−0.14	0.10	−0.16	−0.11	0.68	0.16	0.24			
Cup shape measure	0.37	0.58	−0.17	0.57	0.48	−0.23	0.46	0.12	−0.09		
Mean RNFL thickness	−0.15	−0.29	0.13	−0.30	−0.23	0.75	0.07*	0.16	0.83	−0.20	
RNFL cross-sectional area	0.20	−0.05*	0.34	−0.12	−0.03*	0.80	0.22	0.28	0.80	−0.07	0.93

RNFL = retinal nerve fiber layer.
Pearson's correlation coefficients are shown. All correlation coefficients except those with asterisks (*) show *P* values of ≤0.001.

Optic Disc Topography and Peripapillary Retinal Nerve Fiber Layer Thickness in Nonarteritic Ischemic Optic Neuropathy and Open-Angle Glaucoma

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Objective: To evaluate the results of scanning laser tomography and scanning laser polarimetry (SLP) and the correlations with visual field damage (VFD) in eyes with nonarteritic ischemic optic neuropathy (n-AION) compared with eyes with open-angle glaucoma (OAG).

Design: Cross-sectional study.

Participants: Thirty-three eyes of 33 patients with n-AION and 33 eyes with OAG whose age and VFD evaluated with the Humphrey field analyzer were matched to those of the n-AION eyes.

Main Outcome Measures: The parameters of optic disc topography obtained with the Heidelberg Retina Tomograph II (HRT II) and retinal nerve fiber layer (RNFL) thickness with GDx with variable corneal compensation and the correlation to VFD.

Results: The cup area, cup-to-disc area ratio, and mean cup depth were significantly smaller, and the cup shape measure more negative, in the n-AION eyes than in the OAG eyes ($P<0.001$), whereas rim area was significantly greater ($P<0.001$). Multivariate analyses showed that none of disc area, rim area, and mean cup depth in the n-AION eyes and only rim area ($P = 0.029$) in the OAG eyes was significantly associated with mean deviation (MD). Ellipse average of RNFL thickness significantly correlated with MD in the n-AION eyes ($P = 0.045$) and in the OAG eyes ($P = 0.022$).

Conclusions: Disc topography of eyes with n-AION was quantitatively characterized by small and shallow cupping and a relatively large rim area compared to eyes with OAG matched for age and VFD. In eyes with n-AION, significant correlation with VFD was found only for the RNFL thickness evaluated with SLP but not for the HRT II parameters. *Ophthalmology 2006;113:1340–1344 © 2006 by the American Academy of Ophthalmology.*

Nonarteritic anterior ischemic optic neuropathy (n-AION) is thought to result from acute perfusion insufficiency around the optic nerve head (ONH). Although the exact etiology of ischemia in n-AION is unknown, decreased circulation to the posterior ciliary arteries is thought to be the main cause of the disease.[1,2] Unlike arteritic AION, complete occlusion of posterior ciliary arteries is not mandatory and circulation resumes after the acute phase.[1] Systemic diseases such as ischemic heart disease,[3] hypercholesterolemia,[3] diabetes mellitus,[3–5] hypotension,[6,7] and possibly hypertension[4] are thought to be risk factors for n-AION.

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In patients who develop n-AION, the ONHs have anatomic characteristics such as small disc area, no to minimal physiologic cupping, and an increased number of branches of the central retinal vessels within the disc; they are often referred to as the "disc at risk."[8] In addition to empirical and qualitative knowledge, some quantitative studies using fundus photographs have reported small discs, small cup-to-disc ratios, or both.[9–12] Three-dimensional and quantitative methods of evaluation of the ONH morphology and retinal nerve fiber layer (RNFL) thickness using confocal scanning laser ophthalmoscopy, the Heidelberg Retina Tomograph II (HRT II, Heidelberg Engineering, Dossenheim, Germany), and scanning laser polarimetry (SLP), the GDx Nerve Fiber Analyzer with Variable Corneal Compensation (GDx VCC, Laser Diagnostic Technologies, Inc., San Diego, CA), have been developed recently but have not been used to study n-AION eyes, with the exception of a few studies.[13–15] Moreover, the relationship between the morphologic changes and visual field damage (VFD) in n-AION eyes has never been investigated.

The aims of this cross-sectional study were to (1) evaluate the OHN topography and the RNFL thickness in

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n-AION eyes and (2) assess the correlation of these parameters with VFD and compare with eyes with OAG matched by age and VFD.

Materials and Methods

Thirty-three consecutive patients (33 eyes) with n-AION who met the inclusion criteria between January 2002 and December 2003 at the Inouye Eye Hospital or the outpatient clinic of the Department of Ophthalmology, University of Tokyo Graduate School of Medicine, were included after providing informed consent. The study was approved by the Institutional Ethics Committee and adhered to the tenets of the Declaration of Helsinki. Inclusion criteria were as follows: (1) eyes with a history of acute onset of n-AION ≥4 months before enrollment in the study, (2) eyes in which reliable assessments of visual field, HRT II, and GDx VCC were available, and (3) eyes without ocular diseases, except n-AION and slight cataract, that could affect the results of visual field testing, GDx VCC, and HRT II.

n-AION was diagnosed based on a history of an acute event of optic disc swelling, superficial hemorrhage at the optic disc border and adjacent retina, or both as the cause of an acute, painless, and incomplete visual loss. Because most of the patients in the current study were referred from other hospitals or clinics, the objective symptoms of the acute phase of n-AION were confirmed by ourselves in 11 of the 33 eyes studied. In the other 22 eyes, we reconfirmed the existence of objective symptoms in the acute phase by asking the referring ophthalmologists. We also conducted detailed interviews of the patients to confirm the sudden visual loss or other symptoms at the onset of the disease. No patient had findings suggestive of arteritic-AION described by Beck et al[12] that includes systemic symptoms of giant cell arteritis, sudden marked visual loss to the level of hand motions or less, a chalky-white swollen optic disc, occlusion of 1 or the other posterior ciliary artery observed on fluorescein fundus angiography, and a high erythrocyte sedimentation rate (>50 mm/hour). Fluorescein angiography had been performed in 25 of the 33 patients, excluding those with a history of drug allergy or renal or hepatic dysfunctions. Erythrocyte sedimentation rate testing was performed in 15 patients in whom possibility of inflammatory vascular diseases or temporal arteritis could not be excluded. No patients underwent biopsy of the temporal artery. Because ≥4 months had passed after the acute onset, the swelling and hemorrhages of the disc had subsided, and the disc borders were clearly delineated at the time of this study.

The 3-dimensional features of the ONH were determined using the HRT II. For each patient, 3 topographic images were obtained, combined, and automatically aligned to create a single mean topographic image used for analysis. Magnification errors were corrected using the patients' corneal curvature measurements. An experienced examiner outlined the optic disc margin on the mean topographic image while viewing color photographs of the optic disc. Good-quality images required focused reflectance with a standard deviation ≤50 μm. The topographic parameters studied were disc area, cup area, rim area, cup-to-disc area ratio, cup volume, rim volume, mean cup depth, and cup shape measure for the comparison between the n-AION and OAG eyes, and disc area, rim area, and mean cup depth for the multivariate analysis of the correlation with VFD.

The thickness of the peripapillary RNFL was evaluated by an experienced examiner with GDx VCC, which is a modified SLP system with a variable corneal compensator. A SLP macular image first was obtained to determine the eye-specific corneal polarization axis and magnitude. A polarimetry image around the optic disc then was obtained by compensating for the eye-specific corneal polarization. The quality of the polarimetry image was evaluated with the Q-score provided by the GDx VCC standard software, and images with a Q-score of ≤7 were not used in this study. The GDx VCC parameters investigated in this study were ellipse average (TSNIT average), superior average, and inferior average.

Visual field testing was performed with the 30-2 program of the Swedish Interactive Threshold Algorithm standard strategy of the Humphrey Visual Field Analyzer (HFA; Carl Zeiss Meditec, Oberkochen, Germany). Only reliable results (fixation loss <20%, false-positive error <33%, or false-negative error <33%) were used. For each patient with n-AION or OAG, the visual field examination and ocular imaging with the HRT II and GDx VCC were completed within 1 month of each other. The HFA parameters investigated were mean deviation (MD), average of total deviation in the superior hemifield (TD_{sup}), and average of total deviation in the inferior hemifield (TD_{inf}).

From the stored data of patients with OAG from whom reliable HFA, GDx VCC, and HRT II measurements had been obtained in the same 2 clinics and during the same time period, 33 OAG eyes were randomly chosen with age and MDs that matched to those of the AION eyes. For each pair of eyes, the differences in the age and MD did not differ by >3 years and >2 dB, respectively. However, the location of VFD and the degree of damage in each superior or inferior hemifield was not matched between the 2 groups.

OAG was diagnosed based on normal open angles, typical glaucomatous optic disc appearances corresponding to VFD, the absence of apparent pale color of the optic disc, and the absence of any contributing ocular or specific systemic disorders. The typical glaucomatous optic disc appearance included enlargement of the vertical cup-to-disc ratio, apparent difference of the vertical cup-to-disc ratio between both eyes, local narrowing of the neural rim, splinter hemorrhage, and/or visible nerve fiber layer defect.

Statistical Analysis

Means of the data were compared between the n-AION eyes and the OAG eyes using Student's *t* test. According to the Bonferroni's method, $P<0.05$/the number of the comparisons was considered statistically significant with consideration for the multiple comparisons. The prevalence of dominant superior or inferior hemifield damage in the HFA results was compared between the 2 groups using the Fisher exact test. Because disc area, rim area, and mean cup depth were correlated with each other, their correlation with MD was calculated using the multiple regression analysis in which the dependent variable was MD and independent variables were disc area, rim area, and mean cup depth. The multiple regression analyses in which dependent variable was MD, TD_{sup}, or TD_{inf} and the independent variables disc area and the corresponding RNFL thickness (TSNIT average, inferior average, or superior average, respectively) were performed. Statistical analyses were performed using a statistical software package, SPSS 13.0J for Windows (SPSS Japan Inc., Tokyo, Japan).

Results

There were no statistically significant differences between the n-AION eyes and the OAG eyes in gender, refractive error, or VFD ($P>0.05/6$ with Bonferroni's correction) except visual acuity, which was significantly worse in the n-AION eyes ($P = 0.003<0.05/6$) (Table 1).

Beside the 33 eyes with n-AION included in the current study, 16, 8, and 5 eyes were excluded because of unreliable results on the HRT II, GDx VCC, or both, respectively. There was no significant difference in age (61.8±10.4 vs. 63.8±11.7 years, $P =$

Table 1. Patient Demographic Data

	n-AION	OAG	P Value*
Men/women	17/16	18/15	0.6
Age (y)	61.8±10.4	61.8±10.3	—
Best-corrected visual acuity (log MAR)	0.31±0.54	0.04±0.38	0.003†
Refractive error (diopters)	−1.1±3.4	−3.1±3.5	0.022
Mean deviation (dB)	−12.3±8.3	−12.3±8.2	—
Pattern standard deviation (dB)	10.6±5.8	10.8±4.6	0.9
TD_{sup} (dB)	−8.20±9.22	−14.5±10.4	0.011
TD_{inf} (dB)	−13.9±10.4	−9.6±8.6	0.077

log MAR = logarithm of the minimal angle of resolution; dB = decibels; n-AION = nonarteritic anterior ischemic optic neuropathy; OAG = open-angle glaucoma; TD_{inf} = average of total deviation in the inferior hemifield; TD_{sup} = average of total deviation in the superior hemifield. Values are expressed as the mean ± standard deviation.
*Unpaired *t* test except for men/women, for which the chi-square test was used.
†Statistically significant with consideration for the multiple comparisons ($P<0.01$).

0.5, unpaired *t* test), visual acuity (0.31±0.54 vs. 0.81±1.58 in logarithm of the minimal angle of resolution, $P = 0.1$), and VFD (−12.3±8.3 vs. −11.8±9.9 dB in MD, $P = 0.4$) between the 33 included eyes and 29 excluded eyes.

TD_{inf} was significantly worse than TD_{sup} ($P<0.05$, unpaired *t* test) in 16 of 33 eyes with n-AION and in 7 of 33 eyes with OAG, respectively. TD_{sup} was significantly worse than TD_{inf} ($P<0.05$) in 7 of 33 eyes with n-AION and in 16 of 33 eyes with OAG, respectively. These figures were significantly different between n-AION and OAG ($P = 0.009$, Fisher exact test).

The cup area, cup-to-disc area ratio, cup volume, and mean cup depth were significantly smaller, and the cup shape measure more negative in the n-AION eyes than in the OAG eyes, whereas the rim area was significantly greater in the n-AION eyes (all $P<0.001$). The superior average of RNFL thickness obtained with GDx VCC was smaller in the n-AION eyes ($P = 0.001$), whereas no significant difference was seen in the TSNIT average and inferior average of RNFL thickness between the 2 groups ($P = 0.1$ and 0.7, respectively) (Table 2). The superior average was significantly smaller than the inferior average in the n-AION eyes ($P = 0.001$, paired *t* test), whereas the superior average was significantly greater in the OAG eyes ($P = 0.002$). But the absolute differences between the superior and inferior averages were not significantly different between the n-AION and OAG eyes ($P = 0.090$).

The multiple regression analyses showed that disc area, rim area, and mean cup depth in the n-AION eyes were not associated with MD ($P>0.2$); only rim area ($P = 0.029$) in the OAG eyes were significantly associated with MD (Table 3). TSNIT average and MD were correlated in both the n-AION ($P = 0.045$) and OAG ($P = 0.022$) eyes, respectively. Superior ($P<0.001$) and inferior ($P = 0.003$) averages in the n-AION eyes and superior ($P = 0.039$) average in the OAG eyes were significantly correlated with the corresponding VFD (Table 4).

Table 2. HRT II and GDx VCC Parameters

Parameter	n-AION	OAG	P Value*
HRT II			
Disc area (mm²)	1.94±0.38	2.20±0.56	0.031
Cup area (mm²)	0.41±0.45	1.09±0.67	<0.001†
Rim area (mm²)	1.49±0.55	1.04±0.32	<0.001†
Cup-to-disc area ratio	0.21±0.20	0.48±0.19	<0.001†
Cup volume (mm³)	0.07±0.13	0.30±0.29	<0.001†
Rim volume (mm³)	0.37±0.20	0.28±0.17	0.053
Mean cup depth (mm)	0.13±0.07	0.29±0.10	<0.001†
Cup shape measure	−0.18±0.07	−0.07±0.06	<0.001†
GDx VCC			
TSNIT average (μm)	40.7±11.0	44.9±10.1	0.1
Superior average (μm)	42.6±12.7	53.0±12.0	0.001†
Inferior average (μm)	46.7±16.2	45.4±12.3	0.7

GDx VCC = GDx Nerve Fiber Analyzer with Variable Corneal Compensation; HRT II = Heidelberg Retina Tomograph II; n-AION = nonarteritic anterior ischemic optic neuropathy; OAG = open-angle glaucoma; TSNIT average = ellipse average.
Values are expressed as mean ± standard deviation.
*Unpaired t test.
†Statistically significant with consideration for multiple comparisons.

Table 3. Results of the Multiple Regression Analyses for the HRT Parameters Associated with Mean Deviation

	n-AION		OAG	
HRT II Parameter	*Standardized β*	*P Value*	*Standardized β*	*P Value*
Disc area	−0.042	0.871	0.012	0.949
Rim area	−0.016	0.967	0.433	0.029
Mean cup depth	0.389	0.277	0.384	0.061

HRT II = Heidelberg Retina Tomograph II; n-AION = nonarteritic anterior ischemic optic neuropathy; OAG = open-angle glaucoma.

Discussion

In the typical clinical course of n-AION, disc swelling and hemorrhages on the disc or at the margins are seen at the time of onset. The disc swelling tends to resolve within 2 months; pallor appears earlier, frequently by 1 month.[16] Colen et al[14] report a case of n-AION in which the RNFL thickness obtained by SLP with fixed corneal compensation (FCC) decreased from 62 to 49 μm within the first month after onset and then remained unchanged. Considering these factors, in the current study we included only eyes with follow-up periods of ≥4 months after the onset of n-AION.

The ONHs in n-AION eyes are characterized by a small disc area, no or minimal cupping, and an increased number of branches of the central retinal vessels within the disc.[8] Studies using quantitative measures on fundus photographs revealed a smaller disc size of 2.74±0.45 mm² in n-AION eyes (vs. 3.34±0.73 mm² in normal eyes),[9] 2.31±0.26 mm² (vs. 2.71±0.68 mm² in normal eyes),[10] and smaller cup-to-disc ratios of 0.154±0.117[11] and 0.16±0.15 (vs. 0.31±0.19 in normal eyes).[12] We could not demonstrate this finding, but our study was not sufficiently powered to do so. Moreover, in the current study, small and shallow cupping in eyes with n-AION, compared to eyes with OAG matched for age and MD, was demonstrated quantitatively. The cup area, mean cup depth, and cup-to-disc area ratio were approximately half and the cup volume one fourth of the values in the OAG eyes.

Table 4. Results of the Multiple Regression Analyses for the GDx VCC Parameters Associated with the Corresponding Visual Filed Damage

Parameter	n-AION		OAG	
	Standardized β	*P Value*	*Standardized β*	*P Value*
TSNIT average for MD	0.41	0.045	0.42	0.022
Inferior average for TD_{sup}	0.67	<0.001	0.31	0.102
Superior average for TD_{inf}	0.59	0.003	0.38	0.039

GDx VCC = GDx Nerve Fiber Analyzer with Variable Corneal Compensation; MD = mean deviation; n-AION = nonarteritic anterior ischemic optic neuropathy; OAG = open-angle glaucoma; TSNIT average = ellipse average; TD_{sup} = average of total deviation in the superior hemifield; TD_{inf} = average of total deviation in the inferior hemifield.

The current study is also the first documentation of RNFL thickness measured using SLP with VCC in eyes after n-AION. Banks et al[13] measured the RNFL thickness in eyes with n-AION or AION using SLP with FCC.[13] Those authors reported the average thicknesses as 59±7 and 51±9 μm in the acute (n = 18 eyes) and chronic (n = 20 eyes) phases, respectively. Colen et al.[14] reported the follow-up of 1 case of n-AION using SLP with FCC, in which the RNFL thickness (the "superior average") decreased from 62 μm 10 days after onset to 48 μm 9 months later. Compared to those reports, the TSNIT averages in 33 n-AION eyes of the current study (40.7±11.0 μm) were relatively smaller. Because anterior segment birefringence varies widely in human eyes, SLP with FCC often provides inappropriate data on RNFL thickness.[17,18] Moreover, the RNFL thickness values tend to be higher with FCC than with VCC,[18] possibly explaining the discrepancy in RNFL thickness in n-AION eyes between the current and previous studies.[13,14]

In the n-AION eyes of this study, the superior average of RNFL thickness was significantly smaller than the inferior average. This is contrary to the results in normal[19,20] or OAG[19] eyes and the current results on OAG, and suggested that the superior region of the ONH was more commonly affected in n-AION. Although the HRT parameters did not significantly correlate with VFD, the results of GDx VCC were significantly associated with the corresponding VFD with regression coefficients of 0.41 to 0.67 (Table 3).

Eyes with slight cataract were included in the current study. Even slight cataract can possibly affect the results of visual field testing. However, Carrillo et al[21] recently reported that the average change in MD after extraction of cataract in OAG patients whose preoperative log MAR visual acuity averaged 0.24 (between 20/30 and 20/40) was <0.1 dB and not statistically significant, suggesting that at least slight or mild cataract should not have apparent effects on the average of MD in a group of patients. Moreover, in the current study, because age of the n-AION patients and that of the OAG patients were matched (61.8±10.4 vs. 61.8±10.3 years), the total amount of the influence of (slight) cataract should be similar between the 2 groups, if it existed.

Most of the patients with n-AION had no experience with visual field testing using the HFA prior to this study, whereas the patients with OAG had several experiences. According to Heijl et al,[22] improvement of MD between the initial and second tests of the HFA in newly diagnosed glaucoma patients averaged 2.81 dB, which corresponded to 23% of the average of MD of the current n-AION eyes (−12.3 dB). Therefore, differences in the HRT parameters between the n-AION eyes and the OAG eyes, which ranged 30% to 320% (Table 2), cannot be explained completely by the influence of learning effects in the HFA testing.

In conclusion, the ONH topography in n-AION eyes was quantitatively characterized by small and shallow cupping and a relatively larger rim area compared to the age- and MD-matched OAG eyes. In n-AION eyes, the RNFL thickness evaluated with GDx VCC showed a good correlation with VFD, whereas the HRT results did not significantly correlate with VFD.

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