ELSEVIER

Comparison of Optic Disc Topography Measured by Retinal Thickness Analyzer with Measurement by Heidelberg Retina Tomograph II

Noriko Itai*, Masaki Tanito*,† and Etsuo Chihara*

*Senshokai Eye Institute, Uji, Kyoto, Japan;
†Department of Ophthalmology, Shimane Medical University, Izumo, Shimane, Japan

Purpose: To compare the optic disc topography measurements from a digitized laser slit-lamp and a confocal scanning laser ophthalmoscope (SLO).

Methods: Ten normal subjects (10 eyes) were recruited. Topographic measurements of the optic disc were performed three times in all eyes using the Retinal Thickness Analyzer (RTA) and the Heidelberg Retina Tomograph II (HRT II), and the mean values determined. The mean values of 11 optic disc parameters were compared between the two instruments by the Wilcoxon signed rank test. To test the reproducibility of the topographic measurements, the coefficients of variation (CV) of the topographic parameters among the three measurements from each of the two instruments were compared using the Wilcoxon signed rank test.

Results: The mean cup depth, mean retinal nerve fiber layer (RNFL) thickness, and RNFL cross-sectional area were significantly smaller when measured by RTA compared with HRT II ($P = .0067$, $P = .0364$, $P = .0467$, respectively). The mean CVs from the RTA were larger than those from the HRT II for all parameters; however, the differences in all parameters did not reach significance.

Conclusion: The RTA measured smaller z-axis values compared with the HRT II. The reproducibility of the topographic data was not significantly different between the instruments.
Jpn J Ophthalmol 2003;47:214–220

Key Words: Disc topography, Heidelberg Retina Tomograph II, reproducibility, Retinal Thickness Analyzer.

Introduction

Damage to the retinal nerve fiber layer (RNFL) and optic disc precedes visual field loss;[1–8] therefore, objective evaluation of the optic disc is clinically important in eyes with glaucoma. Until now, several digitized devices including the confocal scanning laser ophthalmoscope (SLO), the scanning laser polarimeter, and the optical coherence tomography, successfully provided real-time and quantitative information about the optic disc and RNFL. The Heidelberg Retina Tomograph (HRT; Heidelberg Engineering, Heidelberg, Germany), HRT II, a simplified model of HRT, and TopSS (Laser-Diagnostic Technology, San Diego, CA, USA) are confocal SLOs that provide three-dimensional images of the optic nerve head. Accurate and good reproducibility of measurements obtained using these confocal SLOs was reported.[9–15]

The Retinal Thickness Analyzer (RTA; Talia, Technology Ltd., Neve-Ilan, Israel), a digitized laser slit-lamp that uses helium-neon laser (wavelength, 543 nm) as a light source, was originally introduced to evaluate retinal thickness throughout the posterior pole.[16,17] Recently, software that was customized to determine the border of the vitreoretinal interface was added to the RTA, which enables the ophthalmologist to create a topographic map of the optic

Received: June 15, 2002
Correspondence and reprint requests to: Masaki TANITO, MD, Senshokai Eye Institute, 50-1, Iseda-Cho Minamiyama, Uji, Kyoto, 611-0043, Japan

Published by Elsevier Science Inc.

0021-5155/03/$–see front matter
doi:10.1016/S0021-5155(02)00699-8

disc. The RTA may be another three-dimensional image analyzer of the optic nerve head.

Before new devices can be used clinically, assessment of the functions and reproducibility of the measurements is important. The topographic measurements of RTA, however, have not been extensively studied. In this study, we measured the optic disc parameters using the RTA and the HRT II and compared the results.

Materials and Methods

Ten volunteers were recruited from among 30 healthy young female employees of Senshokai Eye Institute. The mean (± SD) age of the subjects was 27.2 ± 2.8 years (range, 23–31 years). One eye of each subject was selected by the toss of a coin for this study. All eyes (3 right eyes and 7 left eyes) were normotensive based on applanation tonometry (mean ± SD, 12.4 ± 1.9 mm Hg; range, 10–15 mm Hg). The mean (±SD) corneal curvature was 7.9 ± 0.2 mm (range, 7.7–8.1 mm), and the mean (±SD) spherical equivalent refractive error was −1.4 ± 1.3 D (range, −3.0–+1.5 D). None of the eyes had a narrow angle, a corrected visual acuity of 0.9 or less on a decimal visual acuity chart, irregular astigmatism, hazy media, an irregularly shaped optic disc, or chorioretinal diseases. After the details of the study were fully explained, informed consent was obtained from all subjects.

RTA Measurements

The RTA optic disc topographic images from all subjects were obtained by one of us (NI). Thirty minutes before the measurements were performed, the pupil was dilated with eye drops of 0.5% tropicamide and 0.5% phenylephrine hydrochloride (Santen, Osaka). The refractive errors and corneal curvatures then were measured with an automated refract-keratometer (RK-2; Canon, Tokyo). The spherical equivalent refractive error and the mean corneal curvature were input by the examiner, and the optic disc then was scanned with the disc topography mode of the RTA. One scan area covers 3 × 3 mm, which consists of 16 optical sagittal cross sections with the green laser (543 nm). Each cross section is 187 μm apart and 3 mm long. In the disc topography mode, four such scans at the superior, inferotemporal, inferonasal, and temporal areas of the optic disc were performed for each measurement. In this study, three independent measurements were repeated in each subject. The image quality was assessed by an experienced operator. After the measurements, the images were analyzed using the RTA disc topography software, version 1.11. A contour line was drawn manually for each of the three measurements by one of us (MT). Using this software, 11 disc topographic parameters, which match the parameters of HRT II, were displayed with a color-coded map as results (Figure 1). The reference plane was set 50 μm below the average height of the contour line at the temporal sector of the disk between −4° and −10° below the horizon (Figure 1). This definition is based on the assumption that the thickness of the papillomacular bundle at the disc contour is about 50 μm. The definitions of 11 disc topographic parameters are summarized in Appendix 1.

HRT II Measurements

The study protocol was similar to that of the RTA study. HRT II optic disc topography was carried out on the same 10 subjects by the same examiner (NI) on the same day that the RTA measurements were done. For each measurement, three high-quality scans covering an area 15° × 15° were obtained. As with the RTA measurements, three independent measurements were performed on each subject. The quality of the images was assessed by the HRT II software and by the operator. After the measurements, a disc contour line was manually drawn by one of us (MT), and the images were analyzed by HRT II software, version 1.6. The same contour line that was drawn for the first analysis was transferred to the second and third analyses with the aid of the HRT II software. The instrumentation settings and parameters of the HRT II were basically the same as those of the HRT[13] as described previously.[18,19]

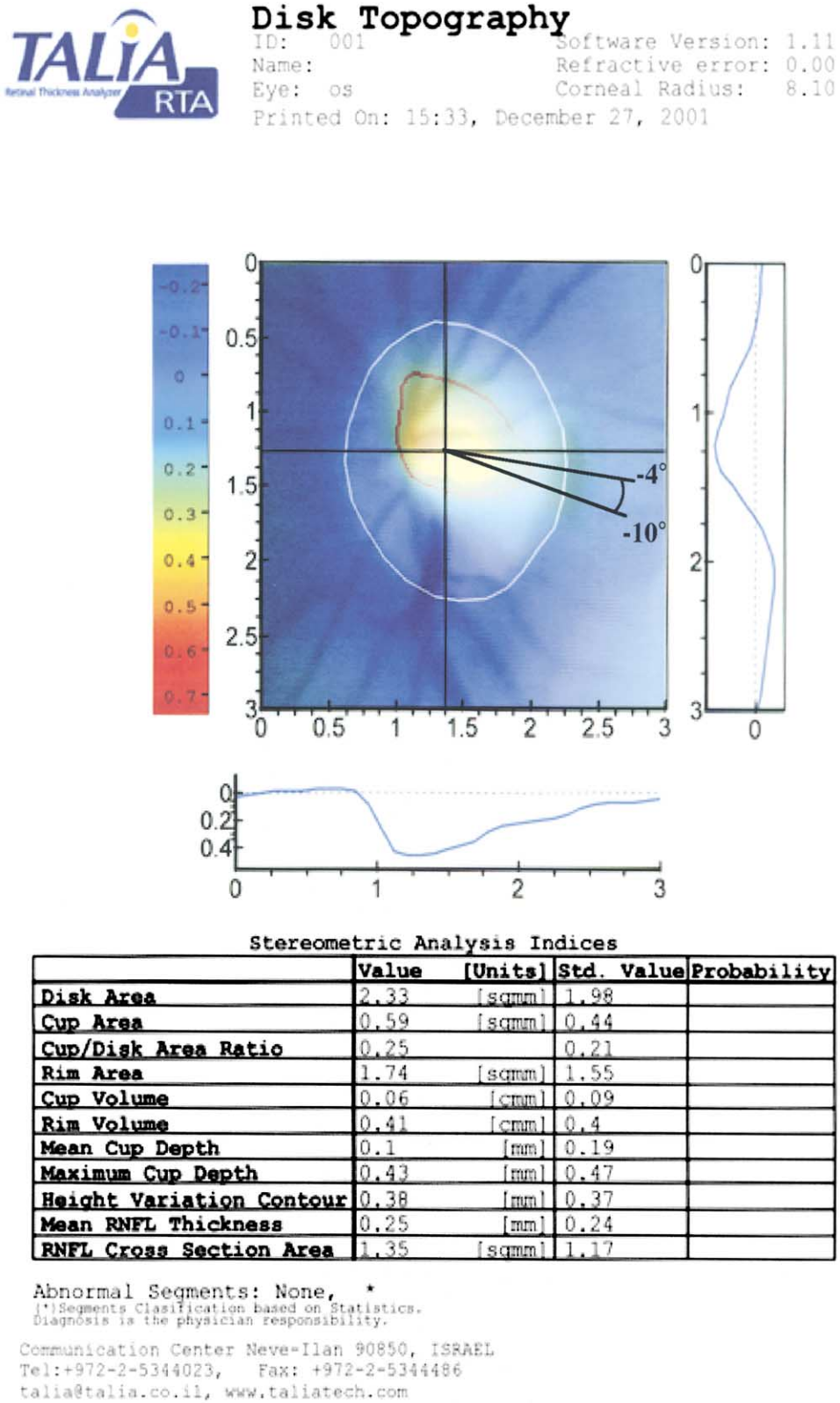
Statistical Analysis

After the RTA and HRT II measurements were obtained, the mean actual values and the mean coefficients of variation (CVs) of the optic disc topographic parameters among the three measurements were calculated for each eye. The CVs were calculated by the following equation:

$$\text{CV}\,(\%) = (\text{standard deviation of 3 measurements}/\text{mean of 3 measurements}) * 100$$

The means of the actual values and the CV of each parameter (determined to evaluate the reproducibility of RTA measurements) among the 10 eyes from the two instruments were compared using the Wilcoxon signed rank test. The parameters evaluated were the disc area, cup area, cup/disc area ratio, rim area, cup volume, rim volume, mean cup depth, maximum cup depth, height variation contour, mean

Jpn J Ophthalmol
Vol 47: 214–220, 2003



Stereometric Analysis Indices

	Value	[Units]	Std. Value	Probability
Disk Area	2.33	[sqmm]	1.98	
Cup Area	0.59	[sqmm]	0.44	
Cup/Disk Area Ratio	0.25		0.21	
Rim Area	1.74	[sqmm]	1.55	
Cup Volume	0.06	[cmm]	0.09	
Rim Volume	0.41	[cmm]	0.4	
Mean Cup Depth	0.1	[mm]	0.19	
Maximum Cup Depth	0.43	[mm]	0.47	
Height Variation Contour	0.38	[mm]	0.37	
Mean RNFL Thickness	0.25	[mm]	0.24	
RNFL Cross Section Area	1.35	[sqmm]	1.17	

Abnormal Segments: None, *
(*)Segments Clasification based on Statistics.
Diagnosis is the physician responsibility.

Communication Center Neve-Ilan 90850, ISRAEL
Tel:+972-2-5344023, Fax: +972-2-5344486
talia@talia.co.il, www.taliatech.com

Figure 1. Results of the analysis of optic disc topography using the Retinal Thickness Analyzer. The reference plane was set at the 50 μm below the average height from −4° to −10° on the temporal area of the contour line. The red line indicates the contour of the optic disc cup.

RNFL thickness, and RNFL cross-section area. All analyses were performed on a Macintosh personal computer with StatView software, version 5.0 (SAS, Cary, NC, USA).

Results

The actual values of the RTA and HRT II parameters for each subject are shown in Tables 1 and 2. The mean cup depth and the mean RNFL thickness were smaller when measured by RTA than when measured by HRT II in 9 of the 10 subjects, and the maximum cup depth and RNFL cross-sectional area were smaller when measured by RTA than by HRT II in 8 of the 10 subjects.

The mean value of each parameter measured by both RTA and HRT II in the 10 subjects are shown in Table 3. The mean actual values of the mean cup depth, mean RNFL thickness, and RNFL cross-sectional area measured by RTA were significantly smaller than those measured by HRT II ($P = .0067$, $P = .0364$, and $P = .0467$, respectively).

The CVs of the parameters measured by the RTA and the HRT II for each subject are shown in Tables 4 and 5, respectively. The CV of the disc area measured by HRT II was 0%, because the same contour line was used for the analyses of the three measurements in each subject.

The mean CVs of the parameters measured by the RTA and HRT II among the 10 subjects are shown in Table 6. The mean CVs of all parameters measured by HRT II were smaller than those measured by RTA. However, there was no statistically significant difference between these RTA and HRT II measurements.

Discussion

Several investigators have reported on the accuracy or reproducibility, or both, of HRT data. Janknecht and Funk[9] reported that the pooled relative error of the cup volume was 11.3% in the model eye, and the pooled CVs of the cup volume were 6.9% in volunteers and 2.4% in the model eye. Rohrschneider et al[10] reported that the mean CVs for measurement in patients with glaucoma, glaucoma suspects, and control groups (n = 13 in each group) were 2.9%, 5.0%, and 3.4%, respectively, for cup area; 4.9%, 4.6%, and 4.6% for cup volume; 5.2%, 3.8%, and 3.3% for mean cup depth; and 5.2%, 4.1%, and 4.0% for maximum cup depth. The CVs of the cup area (6.2%), mean cup depth (3.9%), and maximum cup depth (4.0%) from the HRT II measurements in our study (Table 5) were comparable to those from the HRT in the study of Rohrschneider et al. The CV of the cup volume (12.2%) in our study seems larger than that in the studies of Rohrschneider et al[10] and Janknecht and Funk.[9] In our study, two relatively large CVs of cup volume were included, ie, 27.3% in subject 7 and 22.5% in subject 8 (Table 5), and inclusion of those eyes was thought to be related to the relatively large mean CV of the cup volume. Actually, the standard deviation of this parameter (7.3%) is larger than that of other parameters in Table 5. Recently, Uchida et al[13] reported that the reproducibility of the HRT II was not signifi-

Table 1. Actual Value of Retinal Thickness Analyzer Parameters

Subjects	Disc Area	Cup Area	Cup/Disc Area Ratio	Rim Area	Cup Volume	Rim Volume	Mean Cup Depth	Maximum Cup Depth	Height Variation Contour	Mean RNFL Thickness	RNFL Cross-sectional Area
1	2.19 (mm^2)	0.52 (mm^2)	0.24	1.67 (mm^2)	0.05 (mm^3)	0.39 (mm^3)	0.10 (mm)	0.42 (mm)	0.37 (mm)	0.25 (mm)	1.31 (mm^2)
2	2.12	0.38	0.18	1.74	0.05	0.31	0.14	0.61	0.60	0.21	1.10
3	2.84	1.20	0.42	1.64	0.28	0.27	0.24	0.72	0.33	0.19	1.16
4	2.15	0.34	0.16	1.81	0.05	0.64	0.16	0.47	0.37	0.33	1.60
5	2.89	1.07	0.37	1.81	0.25	0.40	0.23	0.73	0.46	0.22	1.35
6	2.12	0.80	0.38	1.32	0.23	0.28	0.29	0.77	0.38	0.22	1.14
7	2.33	0.32	0.14	2.00	0.03	0.52	0.08	0.50	0.45	0.25	1.36
8	2.68	0.36	0.14	2.32	0.05	0.74	0.15	0.57	0.51	0.29	1.68
9	2.74	0.60	0.22	2.14	0.08	0.49	0.14	0.58	0.40	0.24	1.44
10	3.02	1.42	0.47	1.60	0.31	0.21	0.22	0.82	0.32	0.14	0.84
Mean	2.51	0.70	0.27	1.81	0.14	0.42	0.17	0.62	0.42	0.24	1.30
SD	0.34	0.38	0.12	0.27	0.11	0.16	0.06	0.13	0.08	0.05	0.24
Range	2.12–3.02	0.32–1.42	0.14–0.47	1.32–2.32	0.03–0.31	0.21–0.74	0.08–0.29	0.42–0.82	0.32–0.60	0.14–0.33	0.84–1.68

Data are expressed as the mean of three measurements in each subject. RNFL: retinal nerve fiber layer.

Jpn J Ophthalmol
Vol 47: 214–220, 2003

Table 2. Actual Value of Heidelberg Retina Tomograph II Parameters

Subjects	Disc Area	Cup Area	Cup/Disc Area Ratio	Rim Area	Cup Volume	Rim Volume	Mean Cup Depth	Maximum Cup Depth	Height Variation Contour	Mean RNFL Thickness	RNFL Cross-sectional Area
1	2.16 (mm^2)	0.34 (mm^2)	0.16	1.81 (mm^2)	0.02 (mm^3)	0.66 (mm^3)	0.17 (mm)	0.46 (mm)	0.49 (mm)	0.38 (mm)	1.95 (mm^2)
2	2.29	0.84	0.36	1.46	0.21	0.28	0.25	0.76	0.38	0.23	1.24
3	2.47	1.06	0.43	1.40	0.27	0.27	0.28	0.68	0.30	0.21	1.15
4	1.63	0.17	0.11	1.45	0.03	0.40	0.15	0.66	0.39	0.26	1.19
5	3.15	1.15	0.36	2.00	0.38	0.56	0.33	0.89	0.45	0.28	1.74
6	2.23	0.92	0.41	1.32	0.39	0.33	0.40	0.98	0.42	0.27	1.42
7	1.79	0.32	0.18	1.47	0.04	0.50	0.21	0.64	0.51	0.38	1.79
8	2.58	0.36	0.14	2.22	0.07	0.91	0.26	0.83	0.44	0.33	1.91
9	2.64	0.42	0.16	2.22	0.07	0.57	0.18	0.59	0.40	0.27	1.58
10	2.81	0.61	0.22	2.20	0.10	0.57	0.24	0.65	0.47	0.30	1.77
Mean	2.37	0.62	0.25	1.75	0.16	0.50	0.25	0.71	0.42	0.29	1.57
SD	0.43	0.33	0.12	0.36	0.14	0.19	0.07	0.14	0.06	0.05	0.29
Range	1.63–3.15	0.17–1.15	0.11–0.43	1.32–2.22	0.02–0.39	0.27–0.91	0.15–0.40	0.46–0.98	0.30–0.51	0.21–0.38	1.15–1.95

Data are expressed as the mean of three measurements in each subject. RNFL: retinal nerve fiber layer.

cantly different from the reproducibility of the HRT, and that all topographic parameters obtained from the HRT II showed statistically significant correlation with those from the HRT. Collectively, the HRT II measurements in our study seem comparable to previously reported HRT measurements, except for the reproducibility of the cup volume.

The mean cup depth, maximum cup depth, mean RNFL thickness, and RNFL cross-sectional area are parameters related to the z-axis (Appendix 1). Our results suggest that the z-axis parameters were measured more shallowly by the RTA than by the HRT II (Tables 1, 2, and 3). This difference in z-axis parameters may result from the difference in the principles of measurement between the two devices. In the RTA, the laser slit is projected to the retina obliquely (0.2 radian angle between incident and reflected light beams). However, in the HRT II, the light is projected to the retina almost perpendicularly. In addition, the different light sources in the two instruments (543 nm helium-neon laser and 670 nm red-diode laser) may result in differences in the z-axis parameters. The penetration of the short-wave laser (543 nm) is not as great as that of the long-wave laser (670 nm); thus the data from the green laser may represent images of more superficial nerve tissue than the red laser.

Table 3. Comparison of Actual Values of Parameters Between Retinal Thickness Analyzer (RTA) and Heidelberg Retina Tomograph II (HRT II)

	RTA	HRT II	*P*-Value*
Disc area (mm^2)	2.51 ± 0.36	2.38 ± 0.46	.2408
Cup area (mm^2)	0.70 ± 0.40	0.62 ± 0.35	.2620
Cup/disc area ratio	0.27 ± 0.13	0.25 ± 0.12	.4768
Rim area (mm^2)	1.81 ± 0.29	1.76 ± 0.38	.5147
Cup volume (mm^3)	0.14 ± 0.11	0.16 ± 0.14	.7589
Rim volume (mm^3)	0.43 ± 0.17	0.51 ± 0.20	.1386
Mean cup depth (mm)	0.18 ± 0.07	0.25 ± 0.08	.0067
Maximum cup depth (mm)	0.62 ± 0.14	0.71 ± 0.15	.0664
Height variation contour (mm)	0.42 ± 0.09	0.43 ± 0.06	.6784
Mean RNFL thickness (mm)	0.23 ± 0.05	0.29 ± 0.06	.0364
RNFL cross-sectional area (mm^2)	1.30 ± 0.25	1.57 ± 0.30	.0467

Data are expressed as mean ± SD. RNFL: retinal nerve fiber layer.

*By Wilcoxon signed rank test.

Although the mean CVs of the RTA were larger than those of the HRT II in all parameters, we observed no statistically significant difference in any parameters between the two devices (Table 6). The small sample size may be one cause of this discrepancy. In the HRT II, the contour line of the disc edge for the first measurement could be used for subsequent measurements with the aid of the software, and so the CV of the disc area was 0% in all subjects. Because the reference plane depends on the contour line, and because the analyses of all parameters are affected by the reference plane, the need for new settings of the contour line for each measurement seems a disadvantage of the RTA. Very recently, a new version of RTA software was released and the option to

Table 4. Coefficients of Variation of Retinal Thickness Analyzer Parameters

Subjects	Disc Area	Cup Area	Cup/Disc Area Ratio	Rim Area	Cup Volume	Rim Volume	Mean Cup Depth	Maximum Cup Depth	Height Variation Contour	Mean RNFL Thickness	RNFL Cross-sectional Area
1	1.3 (%)	4.4 (%)	4.2 (%)	1.6 (%)	10.8 (%)	6.8 (%)	0.0 (%)	0.0 (%)	3.1 (%)	2.3 (%)	3.1 (%)
2	1.4	10.5	11.1	3.5	28.6	5.6	18.9	3.4	14.9	5.4	6.4
3	2.5	12.3	14.9	12.8	8.9	7.6	2.4	7.2	3.0	3.0	4.9
4	1.7	15.3	16.5	3.1	0.0	5.5	14.7	16.6	18.7	0.0	12.5
5	1.6	8.4	6.7	2.5	16.0	6.6	8.7	2.4	2.2	5.2	5.3
6	1.2	16.3	16.9	11.2	17.4	16.3	9.1	11.7	16.0	7.9	7.3
7	6.2	8.9	14.3	8.0	21.7	9.9	21.7	9.9	2.2	4.0	7.0
8	7.5	17.3	11.2	6.7	28.6	13.2	7.9	4.6	10.1	2.0	4.0
9	0.8	0.0	0.0	1.0	0.0	1.2	0.0	0.0	1.5	2.4	0.4
10	2.8	9.1	6.4	3.3	10.3	50.1	4.5	11.5	3.6	36.1	38.2
Mean	2.7	10.3	10.2	5.4	14.2	12.3	8.8	6.7	7.5	6.8	8.9
SD	2.2	5.1	5.4	3.9	9.7	13.2	7.2	5.3	6.4	10.0	10.2
Range	0.8–7.5	0.0–17.3	0.0–16.9	1.0–12.8	0.0–28.6	1.2–50.1	0.0–21.7	0.0–16.6	1.5–18.7	0.0–36.1	0.4–38.2

transfer the contour line was added. Accordingly, the reproducibility in the new version of RTA may improve. The mean CVs of the cup area, cup/disc area ratio, cup volume, and rim volume were more than 10% in the RTA. The CVs of the volumetric parameters, ie, the cup volume and rim volume, especially seemed relatively poor (14.2% and 12.3%, respectively), and the ranges of the CVs of these parameters were wide; 0% to 28.6% in the cup volume and 1.2% to 50.1% in the rim volume (Table 4). These results suggest the need for caution in interpreting the progression of or diagnosis of glaucoma using the volumetric parameters of the RTA.

The RTA was originally developed to analyze the retinal thickness of the posterior pole, thus, it is an advantage of the RTA that the retinal thickness and optic disc evaluations can be done using one device. In addition, the optic disc cup edge imaged by the RTA is smooth and close to the clinical impression of cup shape evaluated by stereoscopic examination with a slit-lamp.

In summary, optic disc topographic measurements using the RTA were compared with those obtained using the HRT II. The actual values of the z-axis parameters measured by the RTA were smaller than those obtained using the HRT II; however, the CVs of the

Table 5. Coefficients of Variation of Heidelberg Retina Tomograph II Parameters

Subjects	Disc Area	Cup Area	Cup/Disc Area Ratio	Rim Area	Cup Volume	Rim Volume	Mean Cup Depth	Maximum Cup Depth	Height Variation Contour	Mean RNFL Thickness	RNfL cross-sectional Area
1	0.0(%)	9.0(%)	8.9(%)	1.7(%)	13.9(%)	4.2(%)	2.0(%)	3.2(%)	1.6(%)	2.5(%)	2.6(%)
2	0.0	3.9	3.9	2.2	7.1	4.0	2.9	2.5	1.1	1.7	1.7
3	0.0	3.1	3.0	2.4	7.4	14.6	5.1	2.8	19.3	15.1	15.1
4	0.0	2.2	2.5	0.3	3.6	1.2	1.0	0.9	1.9	0.4	0.4
5	0.0	6.6	6.6	3.8	9.9	11.1	2.8	2.7	4.4	10.7	10.7
6	0.0	3.4	3.5	2.4	4.3	8.6	1.3	1.4	6.7	6.7	6.6
7	0.0	12.3	12.2	2.7	27.3	7.6	1.5	3.5	5.8	5.5	5.5
8	0.0	1.2	1.2	0.2	22.5	5.6	18.0	20.1	0.5	5.3	5.2
9	0.0	9.1	9.2	1.7	15.3	8.3	3.5	2.0	7.8	8.0	8.0
10	0.0	11.3	11.3	3.1	10.8	6.7	0.9	1.0	2.5	4.1	4.1
Mean	0.0	6.2	6.2	2.1	12.2	7.2	3.9	4.0	5.2	6.0	6.0
SD	0.0	3.8	3.7	1.1	7.3	3.6	4.9	5.4	5.3	4.2	4.2
Range	0.0	1.2–12.3	1.2–12.2	0.2–3.8	3.6–27.3	1.2–14.6	0.9–18.0	0.9–20.1	0.5–19.3	0.4–15.1	0.4–15.1

Table 6. Comparison in Coefficient of Variation of Parameters Between Retinal Thickness Analyzer (RTA) and Heidelberg Retina Tomograph II (HRT II)

	RTA	HRTII	*P*-Value*
Disk area	2.7 ± 2.2 (%)	0.0 (%)	—
Cup area	10.3 ± 5.1	6.2 ± 3.8	.2026
Cup/disc area ratio	10.2 ± 5.4	6.2 ± 3.7	.1394
Rim area	5.4 ± 3.9	2.1 ± 1.1	.0526
Cup volume	14.2 ± 9.7	12.2 ± 7.3	.5748
Rim volume	12.3 ± 13.2	7.2 ± 3.6	.3329
Mean cup depth	8.8 ± 7.2	3.9 ± 4.9	.1394
Maximum cup depth	6.7 ± 5.3	4.0 ± 5.4	.2845
Height variation contour	7.5 ± 6.4	5.2 ± 5.3	.2845
Mean RNFL thickness	6.8 ± 10.0	6.0 ± 4.2	.3863
RNFL cross-sectional area	8.9 ± 38.2	6.0 ± 4.2	.7213

Data are expressed as the mean ± SD. RNFL: retinal nerve fiber layer.

*By Wilcoxon signed rank test.

topographic parameters in the RTA were not significantly different from those obtained with the HRT II.

References

1. Sommer A, Miller NR, Pollack I, Maumenee AE, George T. The nerve fiber layer in the diagnosis of glaucoma. Arch Ophthalmol 1977;95:2149–2156.
2. Sommer A, Pollack I, Maumenee AE. Optic disc parameters and onset of glaucomatous field loss. I. Methods and progressive changes in disc morphology. Arch Ophthalmol 1979;97: 1444–1448.
3. Pederson JE, Anderson DR. The mode of progressive disc cupping in ocular hypertension and glaucoma. Arch Ophthalmol 1980;98:490–495.
4. Quigley HA, Addicks EM, Green WR, Maumenee AE. Optic nerve damage in human glaucoma. II. The site of injury and susceptibility to damage. Arch Ophthalmol 1981;99:635–649.
5. Quigley HA, Addicks EM, Green WR. Optic nerve damage in human glaucoma. III. Quantitative correlation of nerve fiber loss and visual field defect in glaucoma, ischemic neuropathy, papilledema, and toxic neuropathy. Arch Ophthalmol 1982;100:135–146.
6. Sommer A, Katz J, Quigley HA, et al Clinically detectable nerve fiber atrophy precedes the onset of glaucomatous field loss. Arch Ophthalmol 1991;109:77–83.
7. Zeyen TG, Caprioli J. Progression of disc and field damage in early glaucoma. Arch Ophthalmol 1993;111:62–65.
8. Pieroth L, Schuman JS, Hertzmark E, et al. Evaluation of focal defects of the nerve fiber layer using optical coherence tomography. Ophthalmology 1999;106:570–579.
9. Janknecht P, Funk J. Optic nerve head analyser and Heidelberg retina tomograph: accuracy and reproducibility of topographic measurements in a model eye and in volunteers. Br J Ophthalmol 1994;78:760–768.
10. Rohrschneider K, Burk RO, Kruse FE, Volcker HE. Reproducibility of the optic nerve head topography with a new laser tomographic scanning device. Ophthalmology 1994;101:1044–1049.
11. Chauhan BC, LeBlanc RP, McCormick TA, Rogers JB. Test-retest variability of topographic measurements with confocal scanning laser tomography in patients with glaucoma and control subjects. Am J Ophthalmol 1994;118:9–15.
12. Zangwill L, Shakiba S, Caprioli J, Weinreb RN. Agreement between clinicians and a confocal scanning laser ophthalmoscope in estimating cup/disk ratios. Am J Ophthalmol 1995; 119:415–421.
13. Uchida H, Tomita G, Kitazawa Y. Clinical evaluation of the Heidelberg Retina Tomograph II. Nippon Ganka Gakkai Zasshi 2000;104:826–829.
14. Geyer O, Michaeli-Cohen A, Silver DM, et al. Reproducibility of topographic measures of the glaucomatous optic nerve head. Br J Ophthalmol 1998;82:14–17.
15. Dong J, Chihara E. Slope analysis of the optic disc in eyes with ocular hypertension and early normal tension glaucoma by confocal scanning laser ophthalmoscope. Br J Ophthalmol 2001;85:56–62.
16. Zeimer RC, Mori MT, Khoobehi B. Feasibility test of a new method to measure retinal thickness noninvasively. Invest Ophthalmol Vis Sci 1989;30:2099–2105.
17. Zeimer R, Shahidi M, Mori M, Zou S, Asrani S. A new method for rapid mapping of the retinal thickness at the posterior pole. Invest Ophthalmol Vis Sci 1996;37:1994–2001.
18. Wollstein G, Garway-Heath DF, Hitchings RA. Identification of early glaucoma cases with the scanning laser ophthalmoscope. Ophthalmology 1998;105:1557–1563.
19. Kamal DS, Viswanathan AC, Garway-Heath DF, Hitchings RA, Poinoosawmy D, Bunce C. Detection of optic disc change with the Heidelberg retina tomograph before confirmed visual field change in ocular hypertensives converting to early glaucoma. Br J Ophthalmol 1999;83:290–294.

Appendix 1. Definitions of Retinal Thickness Analyzer Disc Topographic Parameters

	Units	Definition
Disc area	mm^2	The area of the disc as defined by the disc contour line drawn by the user.
Cup area	mm^2	The area of the cup, which is the area below the reference plane, within the contour line.
Cup/disc area ratio		The ratio between the "cup area" and the "disc area."
Rim area	mm^2	The area of the rim, which is the difference between "disc area" and "cup area."
Cup volume	mm^3	The volume of the cup. This is the volume below the reference plane, within the contour line.
Rim volume	mm^3	The volume of the rim. This is the volume above the reference plane, within the contour line.
Mean cup depth	mm	The mean depth of the cup calculated from the nine adjacent points to the deepest point of the cup.
Maximum cup depth	mm	The maximum depth of the cup.
Height variation contour	mm	The difference between the highest and lowest points along the contour line.
Mean RNFL thickness	mm	The mean height of the retinal surface along the contour line, above the reference plane. This corresponds to the mean nerve fiber thickness along the contour line.
RNFL cross-sectional area	mm^2	The mean RNFL thickness multiplied by the circumference of the contour line.

RNFL: retinal nerve fiber layer.