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CLINICAL STUDY

Morphometric assessment of normal, suspect and glaucomatous optic discs with Stratus OCT and HRT II

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Abstract

Aims **To compare morphometric parameters and diagnostic performance of the new Stratus Optical Coherence Tomograph (OCT) Disc mode and the Heidelberg Retina Tomograph (HRT); to evaluate OCT's accuracy in determining optic nerve head (ONH) borders.**
Methods **Controls and patients with ocular hypertension, glaucoma-like discs, and glaucoma were imaged with OCT Disc mode, HRT II, and colour disc photography (DISC-PHOT). In a separate session, automatically depicted ONH shape and size in OCT were compared with DISC-PHOT, and disc borders adjusted manually where required. In a masked fashion, all print-outs and photographs were studied and discs classified as normal, borderline, and abnormal. The Cohen kappa method was then applied to test for agreement of classification. Bland–Altman analysis was used for comparison of disc measures.**
Results **In all, 49 eyes were evaluated. Automated disc margin recognition failed in 53%. Misplaced margin points were more frequently found in myopic eyes, but only 31/187 were located in an area of peripapillary atrophy. Agreement of OCT with photography-based diagnosis was excellent in normally looking ONHs, but moderate in discs with large cups, where HRT performed better. OCT values were consistently larger than HRT values for disc and cup area. Compared with HRT, small rim areas and volumes tended to be minimized by OCT, and larger ones to be magnified.**
Conclusions **Stratus OCT Disc protocol performed overall well in differentiating between normal and glaucomatous ONHs. However, failure of disc border recognition was frequently observed, making manual correction necessary. ONH measures cannot be directly compared between HRT and OCT.**

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Introduction

The clinical relevance of a diagnostic imaging method may be seen in its ability to differentiate between normality and abnormality in borderline cases, where the clinician would appreciate support by objective means. Several imaging systems for the quantitative assessment of morphological changes in glaucoma, that is, of the optic nerve head (ONH) and the retinal nerve fibre layer (RNFL), have been advocated in recent years, the youngest in this application being the optical coherence tomography (OCT).[1,2] OCT, an optical analogue of B-scan ultrasonography, is based on low-coherence light in the near-infrared spectrum (840 nm) and creates sagittal optical tissue sections with a resolution of 10–15 μm (OCT 2), and 8–10 μm (OCT 3) [User manual of Stratus OCT 3000, Carl Zeiss Meditec Inc., Jena, Germany].[3–5] OCT is able to measure peripapillary RNFL thickness, and this method has been shown to have good reproducibility, sensitivity, and specificity in differentiating normal from glaucomatous eyes.[6–10] The most recently launched OCT scanning protocol also performs topographic imaging of the ONH allowing quantitative (morphometric) analysis.[10–12]

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The reference system for ONH morphometry in the past 10 years has been scanning laser ophthalmoscopy (SLO) with the Heidelberg Retina Tomograph (HRT), and a huge amount of data about normal and glaucomatous disc topography has thereby been gathered. SLO values have been validated in numerous studies and compared with data from manual disc planimetry and histology-based measurements.[13–18] Important ONH parameters such as the disc area have become part of our clinical approach in diagnostic cases.[19–23] It is therefore indispensable for a new method in this field to be compared with the current standard with respect to both absolute values of the ONH measures and ability to differentiate between normal and abnormal. Schuman *et al*[11] were the first to address this issue comparing OCT 3 with HRT I. They found good correlation between the two devices, but significant differences in absolute values for given parameters. Intrinsic problems of the automated disc margin recognition in eyes with peripapillary atrophy (PPA) were reported.[12] Nevertheless, the new mode of OCT seems promising, since it allows operator-free recognition of optic disc borders, and simultaneous evaluation of RNFL and ONH with the same device.

The purpose of this study was to compare the morphometric parameters and diagnostic performance of Stratus OCT 3000 Disc mode and HRT II in normal, suspect and abnormal optic discs. OCT's accuracy in automatically determining ONH borders and the potential error sources were analysed with the help of time-matched colour disc photographs.

Patients, materials, and methods

Subjects included in the study underwent imaging of the ONH with fundus photography, optical coherence tomography, and confocal scanning laser ophthalmoscopy within 1 week, after giving an informed consent. All participants also underwent a full ophthalmologic examination including slit lamp evaluation, gonioscopy, dilated ophthalmoscopy, and repeated white-on-white automated perimetry (Octopus 101, threshold program G2, Haag-Streit International, Koeniz, Switzerland). Conditions that could cause imaging artefacts or diagnostic bias were avoided. Correspondingly, eyes with myopia <-4.0 diopters (D), hyperopia >3.0 D, astigmatism >2.0 D, best corrected visual acuity (BCVA) <0.5 (10/20), moderate or advanced cataract, pseudophakia, pupil diameter <3 mm, history of diabetes, history of intraocular or neuro-ophthalmologic disorders, or unreliable automated visual fields (reliability factor $>20\%$) were excluded from the study. The purpose was to include eyes with normal, suspicious, and abnormal (glaucomatous) optic discs. The following four clinical categories were allowed:

- *normal controls* (negative family history of glaucoma, IOP <20 mmHg, normally looking ONH, normal VF),
- *ocular hypertension* (OHT) (repeated IOP ≥ 22 mmHg, open angle, normally looking ONH, normal VF),
- *glaucoma suspects* because of largely excavated, glaucoma-like discs (but normal IOP and normal VF), and
- *glaucoma* (confirmed primary open-angle glaucoma with elevated IOP and abnormal VF, that is, reproducible scotomas in the Bjerrum area or nasal depression, or concentric constriction with asymmetry superior/inferior and preserved central VF).

Imaging

Colour ONH slides, 20° area (DISC-PHOT), were acquired with a Topcon TRC-50IA fundus camera (distributed by FISBA Optics, St Gallen, Switzerland) after maximal dilatation of pupils with 0.5% tropicamide and 2.5% phenylephrine.

HRT (Heidelberg Engineering GmbH, Heidelberg, Germany; software vers. 1.7 of the HRT II) was performed in miosis; the individual corneal curvatures were entered, and headpieces for astigmatic correction were used when appropriate. Images were accepted if standard deviation was $<20\,\mu$m, and confidence interval $<50\,\mu$m. To define the contour line, six or more points were positioned at the inner margin of the scleral ring by an experienced operator. The standard protocol and the extended parameter table were then printed out.

All eyes were scanned in mydriasis with the *Stratus OCT 3000* (software version 3.0; Carl Zeiss Meditec Inc., Jena, Germany). Optic disc scans were recorded with optimized z-offset and polarization. The operator was permanently monitoring for steady eye fixation, correct scan position, and good signal-to-noise ratio. Scans were repeated until an image of satisfying quality was obtained. The Fast Optic Disc Scan Protocol (OCT-DISC) was used. The latter protocol performs six cross-sectional radial scans centred on the ONH and spaced 30° from one another (Figure 1). Each cross-section is 4 mm long, and consists of 128 A-scans. The software determines automatically (OCT-DISC_{aut}) the disc margin setting a point at the edge of the retinal pigment epithelium (RPE)/choriocapillaris layer on each side of the disc along a cross-section. Disc contour is then extrapolated by the software based on the resulting 12 edge points (Figure 1Ab–Cb). In each cross-section, the two edge points are connected with a blue line, then a red line is placed 150 μm above (standard cup-offset), and the cup contour positioned

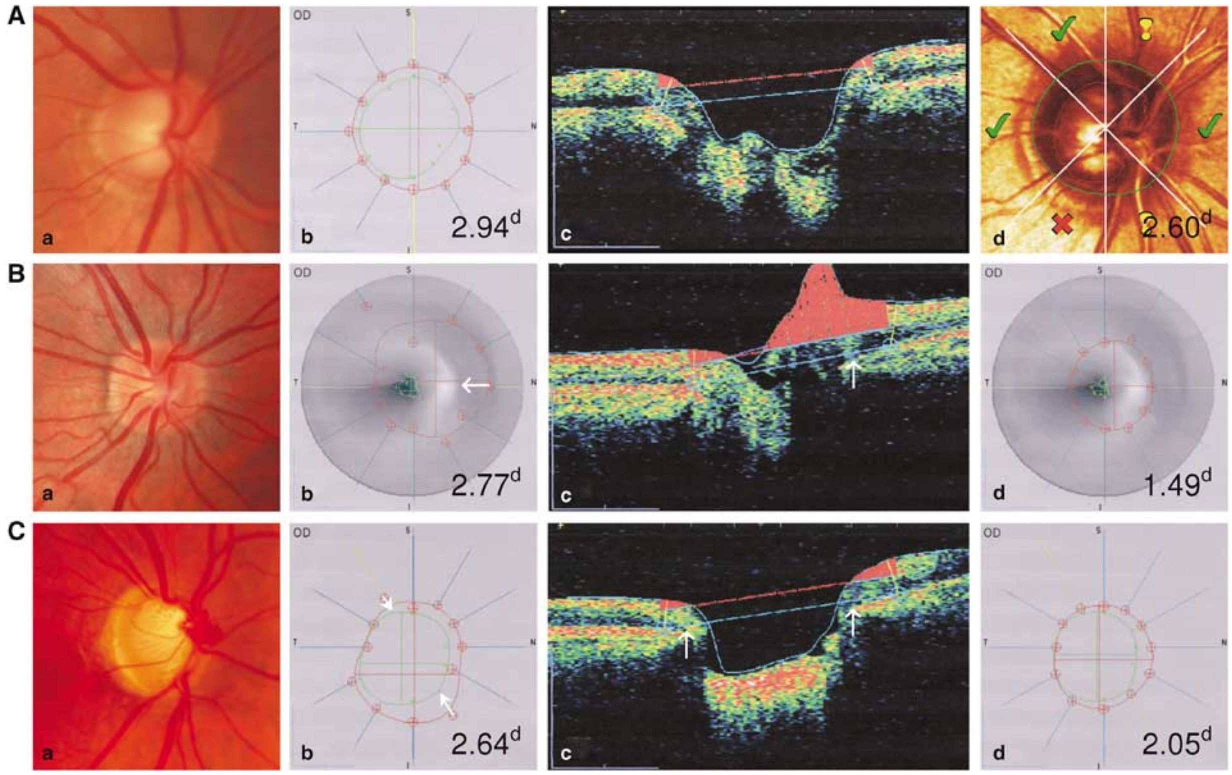

Figure 1 Automatic and manual determination of optic disc margin in OCT, Fast Optic Disc Scan Protocol. Illustration of three optic discs (A, B and C) as depicted in the colour ONH photographs (DISC-PHOT: Aa–Ca), in the OCT mode with automatic disc margin recognition (OCT-DISC$_{aut}$: disc and cup contour drawing, Ab–Cb; cross-sectional scan along the yellow meridian, Ac–Cc), and after manual correction (OCT-DISC$_{man}$; Bd and Cd). (A) Glaucomatous optic disc of normal size. Disc and cup contours in OCT-DISC$_{aut}$ (b) are highly congruent with those appreciated in the photograph. Note that the peripapillary atrophy (PPA) temporal and infero-temporal is not associated with wrong disc margin determination. Since no manual correction was necessary, the corresponding Heidelberg Retina Tomograph image is shown in d. (B) Normal optic disc of relatively small size. There is a misinterpretation of disc shape and size in OCT-DISC$_{aut}$ (b); several disc margin points, predominantly on the nasal side, are displaced too far outwards. The white arrow denotes the manual correction that was carried out along the corresponding meridian. In (c), the original disc margin point position (encircled blue cross) and the manually chosen one (white arrow) are shown. After manual adjustment (d), disc shape and size approximate very well the one in the photograph (a). Regard the considerable change in disc area, and also the absence of PPA. (C) Glaucomatous optic disc of normal size (but smaller than the one in Aa). There is an apparent misinterpretation of disc shape in OCT-DISC$_{aut}$ (b), more pronounced in the inferior half. White arrows indicate the direction of manual adjustment in the denoted meridian. (c) Cross section along the yellow meridian; right-hand side corresponds to infero-nasal, left-hand side to supero-temporal in (b). The true edges of the retinal pigment epithelium (RPE/choriocapillaris complex), marked with arrows, have not been recognized by the automatic mode. After manual correction (d), a marked improvement, and a good disc shape congruence with the photograph can be appreciated. In this case, PPA may have played a role for disc margin misalignment in the temporal but not in the infero-nasal sector. [d]Disc area (mm^2).

at the crossing of this offset-line with the rim slopes (Figure 1Ac–Cc).

Manual OCT session

Since automatic determination of ONH borders resulted in some cases in discs of irregular and unnatural shape and size, in a separate session, all discs and scans per disc were studied and manually redrawn (OCT-DISC$_{man}$) when appropriate by one of the authors (AM; Figure 1Bd, Cd). Cup-offset was left unchanged. The colour photographs were used as reference for this session. Disc shape as originally depicted by OCT-DISC$_{aut}$ was classified as either congruent or mildly, moderately or severely incongruent with the one in the photographs. To evaluate for potential error sources in the automated mode, disc area change after manual fitting, number of corrected margin points per eye, and number of corrected points within the PPA area were recorded, and eyes were divided into two groups: with none or mild shape incongruence, and disc area change after manual fitting $<20\%$ (good-congruence group); and with moderate or severe shape incongruence and/or disc area change $\geq 20\%$ (bad-congruence group).

Image-based classification of ONH

Apart from comparing the numeric disc parameters, we looked at the overall performance of the two imaging systems in classifying an optic disc as normal or abnormal taking the disc photograph evaluation as a reference. At 4 weeks after the last patient had completed the study, all colour slides were evaluated in a masked, random fashion by one of the authors (MI). Discs were classified as normal, borderline, or abnormal (glaucomatous). After another 4 weeks, print-outs of HRT, OCT-DISC_{aut}, and OCT-DISC_{man} were classified as normal, borderline or abnormal independently by two of the authors (MI and AM) according to the discriminating citeria given in Table 1. In cases of disagreement (11 eyes), the masked print-outs were studied by all three authors together, and a final decision was taken.

Comparison and statistical analysis

Disc shape (reference: DISC-PHOT) and disc area (reference: OCT-DISC_{man}) misinterpretation of OCT-DISC_{aut} as well as potential error sources in OCT automated mode were analysed by using the χ^2 test, the Fisher exact test, and the unpaired *t*-test. Bland–Altman analysis was performed to investigate agreement of ONH measures between OCT-DISC and HRT.[24] Association between the two related variables was expressed by the Pearson correlation coefficient *r*, and *P*-values for *r* were calculated using the *t*-approximation. Differences in ONH measures between the four diagnostic entities (normal controls, ocular hypertensives, glaucoma-like discs, and glaucoma) were tested using one-way analysis of variance (ANOVA) with the Scheffé multiple contrast method. The Cohen kappa method was used for assessing agreement in ONH classification (normal, borderline, or abnormal) between imaging systems.[25] Weighted kappa values were interpreted according to Landis and Koch.[26] Statistical significance was considered if $P<0.05$.

Results

A total of 54 eyes of 31 individuals were included in the study. Eight participants were healthy members of the department; for their convenience, both eyes were examined but only one eye was dilated and imaged. All other individuals were regular patients recruited during their outpatient visits. Five eyes had to be excluded prior to analysis because of unreliable visual fields (2), unacceptable quality of disc photographs (1), and HRT images (2). Thus, 49 eyes were available for the final analysis. The demographic and clinical characteristics are summarized in Table 2.

OCT disc margin recognition

When comparing automatically defined OCT disc shape with the one in the colour disc photographs (Table 3), 10 of 49 ONHs were considered congruent (no manual correction required), 13 showed only mild shape discrepancy ($10+13=23$ eyes in the good-congruence group); 18 eyes exhibited moderate to severe shape incongruence— that is, horizontally instead of vertically oval; with an unnaturally projecting circumference, etc (Figure 1)— and another eight discs presented with a

Table 1 Criteria for classification of ONH with HRT and OCT

Discriminating criteria	*Abnormal*	*Borderline*
HRT		
Moorfields classification (at least superior or inferior quadrant)	Outside normal limits	Borderline
Depression of green contour line below the zero level	Clear-cut[a]	Mild in one or more quadrants
Rim area (mm^2) for discs of normal size (disc area 1.6–2.8 mm^2)	<1.00	1.00–1.10
Rim area (mm^2) for discs of large size (disc area >2.8 mm^2)	<1.10	1.10–1.20
FSM discriminant function (Mikelberg)	<0.0	<0.0 (like abnormal)
OCT-DISC		
Rim area (mm^2) for discs of normal size (disc area 1.6–2.8 mm^2)	<1.00	1.00–1.10
Rim area (mm^2) for discs of large size (disc area >2.8 mm^2)	<1.10	1.10–1.20
Vertical cup-to-disc ratio for normal size disc	>0.7	0.61–0.7
Cup shape (as depicted in the OCT print-out)	Clearly vertically elongated	Slightly vertically elongated
Rim width/configuration	Thinnest superior or inferior/notch	Not obeying the ISNT rule[b]

ONH = optic nerve head, HRT = Heidelberg Retina Tomograph II, OCT-DISC = ONH imaging and analysis by optical coherence tomography (disc mode of Stratus OCT 3000).
[a]Both 'humps' flattened below the zero line or a strong asymmetry, the flattened 'hump' correspondig to the thinner rim sector.
[b]ISNT rule = rim width inferior > superior > nasal > temporal.

Table 2 Demographic and clinical characteristics

	Normal	*Ocular hypertensives*	*Glaucoma-like discs*	*Glaucoma*
Demographic characteristics				
Eyes/subjects (*n*)	14/11	9/5	9/5	17/10
Female/male (*n*)	7/4	1/4	3/2	7/3
Age (years); mean (SD)	43.6 (14.5)	56.8 (13.6)	52.8 (11.1)	68.4 (8.5)
Clinical characteristics; mean (SD)				
BCVA (decimal); mean (range)	1.29 (1.0–1.6)	1.10 (1.0–1.6)	1.07 (1.0–1.6)	0.92 (0.5–1.25)
Refraction (SE in D)	−0.98 (1.12)	0.29 (0.77)	0.07 (0.48)	0.35 (1.80)
Mean defect Octopus VF (dB)	0.69 (1.25)	−0.73 (0.47)	0.50 (1.55)	3.67 (3.22)
Loss variance Octopus VF (dB^2)	3.23 (1.23)	3.00 (1.08)	3.40 (1.02)	23.64 (16.79)
Peak IOP (mmHg)	14.4 (3.0)	27.7 (3.7)	14.8 (1.9)	26.1 (7.8)
Central corneal thickness (μm)	545 (38)	587 (28)	585 (46)	561 (29)

BCVA = best corrected visual acuity calculated by logMAR (log of the minimum angle of resolution) conversion, SE = spherical equivalent, D = diopters, IOP = intraocular pressure, Octopus VF = visual field in automated perimetry (Octopus 101).

Table 3 Factors associated with failure of automatic disc margin recognition in OCT

	OCT-DISC$_{aut}$ with good congruence[a] (n = 23)	*OCT-DISC$_{aut}$ with bad congruence*[a] (n = 26)	P-*value*
Disc area (mm^2); Mean (SD)			
OCT-DISC$_{aut}$	2.35 (0.53)	2.74 (0.51)	0.01[b]
OCT-DISC$_{man}$	2.21 (0.43)	2.12 (0.32)	0.37[b]
HRT	2.00 (0.40)	2.00 (0.38)	0.99[b]
Peripapillary atrophy (PPA)			
Eyes with PPA (n)	7	13	0.27[c]
Corrected points within the PPA area/total number of corrected points	3/55 (5%)	28/132 (21%)	0.01[d]
Refraction[e] (D); Mean (SD)	+0.30 (1.23)	−0.44 (1.43)	0.06[b]
ONH classification[f]; (n)			
Normal	13	11	0.48[c]
Borderline and abnormal	10	15	
Clinical diagnosis; (n)			
Non-glaucoma[g]	16	16	0.77[c]
Glaucoma	7	10	

For abbreviations, see Figure 1 and Table 1.
[a]Disc shape was compared between OCT-DISC$_{aut}$ and the colour optic disc slides. After manual correction of disc borders, the change in disc area was noted in %. To evaluate for potential error sources of failed automatic disc margin detection, two groups were compared: no or mild disc shape error and disc area change <20% (good congruence), and moderate or severe disc shape error and/or disc area change ≥20% (bad congruence).
[b]Unpaired *t*-test (two-tailed *P*).
[c]χ^2 test.
[d]Fisher exact test (two-tailed *P*).
[e]Refraction = spherical equivalent in diopters (D).
[f]ONH classification based on colour optic disc slides.
[g]Non-glaucoma includes normal, ocular hypertensives and glaucoma-like discs.

satisfactorily depicted shape, but an apparently enlarged size (18 + 8 = 26 eyes in the bad-congruence group). A total of 187 points (ie, 32% of a maximum of 49 × 12 = 588 points) were manually corrected, mean 2.4 points/eye in the good-congruence group, and 5.1 points/eye in the bad-congruence group ($P < 0.001$). The vast majority of incorrectly determined disc margin points were positioned outside the evident edge of the RPE/choriocapillaris complex, leading to an ‘enlargement’ of the disc. After manual correction, the mean decrease of OCT disc area was 5.8% in the good-congruence group, and 31.2% in the bad-congruence group ($P < 0.0001$), and disc size did not differ between the groups any more ($P = 0.37$).

The following parameters were assessed for *association with disc margin misplacement*: ‘true’ disc area (ie, in

OCT-DISC$_{man}$ and in HRT), ONH classification (ie, normal or borderline and abnormal), clinical diagnosis, refraction, and peripapillary atrophy. Only the latter two tended to be correlated with automated disc margin recognition failure. Mean refraction was more myopic in the bad-congruence group ($P = 0.06$). This trend was supported by the finding of a significant negative correlation between refraction and disc area change after manual correction (Pearson $r = -0.31$; $P = 0.03$). PPA, on the one hand, was significantly more frequently associated with misplaced disc margin points in the bad-congruence group than in the good-congruence group (28/132 *vs* 3/55, $P = 0.01$); on the other hand, there were only 13 out of 26 eyes in the former group that had any PPA at all, and only 21% of the misplaced points were located in the PPA area (Table 3).

Agreement of ONH measures between OCT and HRT

When all 49 eyes were considered, following correlation coefficients (r) were found: OCT-DISC$_{aut}$ *vs* HRT: 0.50 for disc area, 0.47 for rim area, and 0.39 for rim volume; OCT-DISC$_{man}$ *vs* HRT: 0.67 for disc area, 0.70 for rim area, and 0.43 for rim volume ($P < 0.02$ for all comparisons).

Bland–Altman analysis was performed to investigate agreement between OCT and HRT measures (Figure 2). Considerable systematic error and variation were observed. In the scatter plot, OCT-DISC$_{aut}$ disc areas (Figure 2Aa, black circles) were clearly larger than those of HRT, almost all data points lying above the equality line. Bias and variation were reduced for OCT-DISC$_{man}$ (white circles), but they still remained within a considerable range.

Considering rim area and, particularly, rim volume, a proportional error between both devices was reflected in all plots (Figure 2Ab–Cb, Ac–Cc), that is, divergence tended to change according to a parameter's absolute value. Discs with small rim areas ($< 1.10\,mm^2$) and volumes ($< 0.24\,mm^3$)—that is, suggestive for glaucoma—tended to show lower values in OCT than in HRT, whereas in ONHs with large rim areas and volumes—that is, within the normal limits—OCT values were higher than those of HRT. That small rim areas and volumes tended to be minimized by OCT, and larger ones to be magnified, was apparent also in the scatter plots (Figure 2Ab, Ac). For both OCT-DISC modes, differences falling within the ± 1.96 SD span ranged considerably—for example, rim area OCT-DISC$_{aut}$: from -0.81 to $1.18\,mm^2$ (Figure 2Bb); rim volume OCT-DISC$_{aut}$: from -0.52 to $0.54\,mm^3$ (Figure 2Bc)—which is likely to be of clinical relevance in the practice. In summary, Bland–Altman analysis revealed a poor agreement of OCT and HRT morphometric measures despite highly significant Pearson correlations.

ONH measures and clinical diagnosis

Quantitative ONH measures acquired with HRT, OCT-DISC$_{aut}$, and OCT-DISC$_{man}$ are given in Table 4.

From an ophthalmoscopic/morphologic point of view, ONH's can be generally grouped into discs that have unremarkable cups, wide neuroretinal rim, and do not look glaucomatous, and discs that have large and deep cups, and look suspicious for glaucoma. From a clinical point of view, eyes can be grouped into such that have and such that do not have glaucoma. Optic disc imaging systems are meant to serve as topographic and diagnostic tools, so we interpreted HRT and OCT parameters in each context.

HRT disc measures

HRT disc area: In this study, eyes with normal looking discs (controls and OHT) had on average smaller ONHs than eyes with large cups (glaucoma-like discs or glaucoma). *HRT cup area* did not differ between normal controls and OHT eyes, and between glaucoma-like and glaucomatous discs. *HRT rim area* was significantly smaller in the glaucoma eyes (mean $0.94\,mm^2$, $P < 0.01$), compared with each of the other three, nonglaucoma groups, those means lying between 1.34 and $1.40\,mm^2$. Remarkably, largely excavated discs without clinical manifestations of glaucoma (glaucoma-like discs) exhibited a mean rim area within the normal range,[1,27,28] and were thus not different from the rim area in the control group ($P = 0.95$). For *HRT rim volume*, a similar trend was observed: although decreasing from normal through the glaucoma-like discs, rim volume remained within the normal range in the three nonglaucoma groups, but was outside normal limits[1,27,28] in the glaucoma group. In summary, HRT morphometric values characterized appropriately the categories of 'normally looking' and 'glaucomatous looking', and 'having glaucoma' *vs* 'not having glaucoma'.

OCT disc measures

In two eyes with small optic discs and small and shallow cups (HRT disc area 1.32 and $1.62\,mm^2$; HRT cup-to-disc area ratio 0.02 and 0.04, respectively), an erroneous rim area of $0.0\,mm^2$ was calculated by OCT software in both automatic and manual mode (cup-to-disc area ratio of 1.0). For analysis, these values were replaced with rim areas equal to the disc areas, and cup-to-disc area ratio was corrected to 0.0.

The systematic error found in the Bland–Altman analysis was reflected by consistently larger OCT-DISC$_{aut}$ disc areas than those of HRT, independent of the clinical diagnosis. In accordance with the proportional error

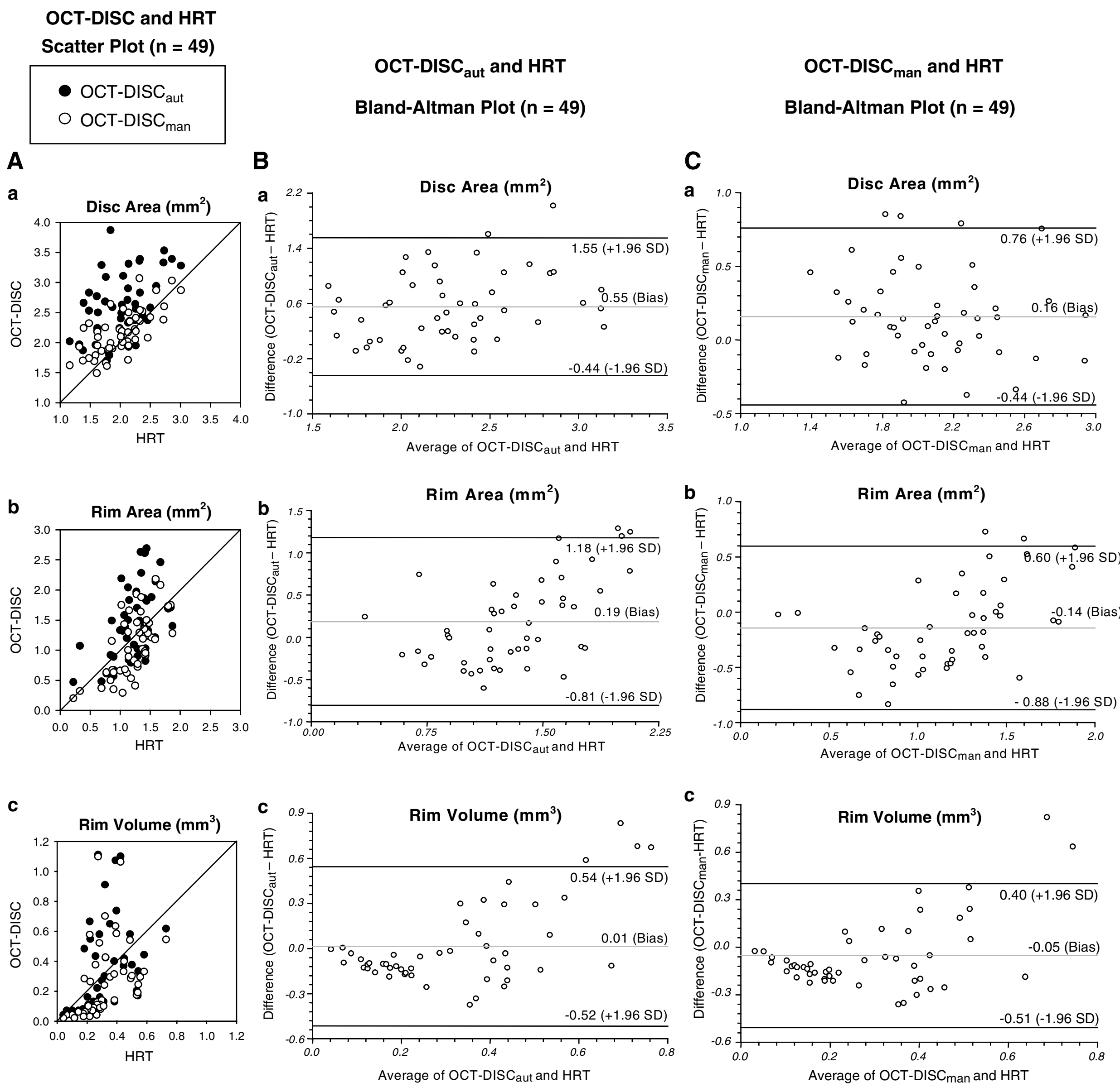

Figure 2 Scatter plots (A) and Bland–Altman plots (B, C) for comparison of disc area, rim area, and rim volume measures obtained by HRT (Heidelberg Retina Tomograph II) and OCT (Stratus OCT 3000) automated and manual disc mode (OCT-DISC$_{aut}$ and OCT-DISC$_{man}$, respectively). (A) The solid diagonal line represents the line of equality ($y=x$). (B, C) The values for the mean, the mean $+1.96$ SD and the mean -1.96 SD of measure difference between both methods are included in the right part of each plot (bias, $+1.96$ SD, and -1.96 SD, respectively).

for rim area and rim volume reported above, OCT-DISC, especially in the automated mode, 'produced' magnified values in normal eyes and ocular hypertensives, and, compared with HRT, reduced values in glaucoma-like and glaucoma discs. As a consequence of this disbalance, extremely low OCT rim volumes in glaucoma were observed. Unlike with HRT, there was a significant difference in rim area and volume between the glaucoma-like discs and the other two, nonglaucoma groups ($P<0.015$ for all comparisons).

Image-based classification of ONH

Table 5 describes the individual results and intra-eye combinations of the image-based classification of ONH as normal, borderline, and abnormal. It renders an

Table 4 Clinical diagnosis and ONH measures obtained with HRT and OCT

	Normal (n = *14*)	*Ocular hypertensives* (n = *9*)	*Glaucoma-like discs* (n = *9*)	*Glaucoma* (n = *17*)
	Mean (SD)			
Disc area (mm^2)				
HRT	1.75 (0.32)	1.68 (0.35)	2.49 (0.33)	2.13 (0.22)
OCT-DISC$_{aut}$	2.29 (0.50)	2.50 (0.29)	2.86 (0.46)	2.66 (0.65)
OCT-DISC$_{man}$	1.89 (0.28)	2.09 (0.26)	2.51 (0.34)	2.24 (0.35)
Cup area (mm^2)				
HRT	0.35 (0.16)	0.32 (0.18)	1.15 (0.38)	1.19 (0.44)
OCT-DISC$_{aut}$	0.51 (0.27)	0.52 (0.35)	1.65 (0.68)	1.75 (0.63)
OCT-DISC$_{man}$	0.48 (0.28)	0.47 (0.35)	1.58 (0.58)	1.64 (0.48)
Cup-to-disc area ratio				
HRT	0.20 (0.08)	0.19 (0.09)	0.45 (0.09)	0.55 (0.16)
OCT-DISC$_{aut}$	0.23 (0.12)	0.21 (0.13)	0.57 (0.16)	0.65 (0.12)
OCT-DISC$_{man}$	0.25 (0.13)	0.23 (0.16)	0.62 (0.17)	0.72 (0.14)
Rim area (mm^2)				
HRT	1.40 (0.25)	1.36 (0.30)	1.34 (0.08)	0.94 (0.34)
OCT-DISC$_{aut}$	1.78 (0.54)	1.98 (0.34)	1.20 (0.32)	0.91 (0.30)
OCT-DISC$_{man}$	1.41 (0.27)	1.62 (0.39)	0.93 (0.32)	0.60 (0.25)
Rim volume (mm^3)				
HRT	0.43 (0.13)	0.34 (0.13)	0.30 (0.08)	0.21 (0.12)
OCT-DISC$_{aut}$	0.51 (0.28)	0.63 (0.27)	0.19 (0.10)	0.09 (0.04)
OCT-DISC$_{man}$	0.41 (0.23)	0.51 (0.28)	0.13 (0.08)	0.07 (0.05)

For abbreviations, see Figure 1.

impression how a diagnosis was made with Stratus OCT according to the criteria suggested in Table 1, and how it corresponded with the diagnosis made with the 'standard' methods—disc photography and HRT. Statistically, good to very good agreement between all imaging methods was observed ($\kappa = 0.66$–0.89). Agreement was best between DISC-PHOT and HRT ($\kappa = 0.89$). OCT-DISC$_{man}$ showed slightly better agreement with the photographic and HRT judgement than OCT-DISC$_{aut}$. Discrepancy in classification was more frequently observed with largely excavated discs (groups glaucoma-like and glaucoma), where OCT-DISC$_{aut}$ and OCT-DISC$_{man}$ tended to diagnose more 'aggressively', that is, borderline instead of normal, and abnormal instead of borderline.

Discussion

Our data show that the optic disc mode of Stratus OCT can reliably differentiate between normal and glaucoma, but its morphometric values cannot be directly compared with those of HRT. The problem, however, is that normative morphometric data are available, and have been established as clinically useful, from ONH morphometry of the past 25 years.[19–23] It is therefore prudent for a new morphometric method to be assessed both for its ability to distinguish normality from abnormality, and to give interpretable and categorizable morphometric values.

Automatic recognition of disc margin, disc size, and shape with Stratus OCT

Once established in glaucoma care, OCT print-outs are likely to begin serving as image documents widely replacing other types of disc images, much the way HRT does now. It is therefore relevant that ONH size and shape are realistically depicted. In this study, we observed an erroneous automatic recognition of disc margin in 53% of the eyes, resulting in a pronounced disc shape and size misalignment. In a recently published work, Savini *et al*[29] also reported an unsatisfactory automatic recognition of ONH edges in 61.1%. The additional manual session gave us the opportunity to investigate this phenomenon more closely, and to analyse for associated factors. The role of PPA as a potential error source has been previously recognized.[12] In our group, PPA turned out to be involved in less than 50% of the cases of failed disc margin recognition. Moreover, only 17% of manually corrected disc margin points were located within the PPA area. This clearly demonstrates that PPA is not the only, and maybe not the most

Table 5 Classification of ONH as normal (N), borderline (B), or abnormal (A), and agreement between the imaging methods

Clinical diagnosis	*Eyes (n)*	*DISC-PHOT*	*HRT*	*OCT-DISC$_{aut}$*	*OCT-DISC$_{man}$*
Normal ($n=14$)	11	N	N	N	N
	1	N	N	N	B
	1	N	B	N	B
	1	N	B	A	A
OHT ($n=9$)	7	N	N	N	N
	2	N	N	N	B
Glaucoma-like discs ($n=9$)	1	B	N	N	N
	1	A	B	N	B
	1	B	B	B	A
	1	B	B	A	A
	1	A	A	B	A
	1	B	A	A	A
	3	A	A	A	A
Glaucoma ($n=17$)	9	A	A	A	A
	4	A	A	B	A
	3	B	B	A	A
	1[a]	N	N	B	B
Agreement (kappa[b])					
DISC-PHOT			0.89	0.66	0.69
HRT		0.89		0.73	0.79
OCT-DISC$_{aut}$		0.66	0.73		0.77
OCT-DISC$_{man}$		0.69	0.79	0.77	

For abbreviations, see Figure 1 and Table 1. Separated for clinical diagnosis, each line shows the number of eyes with an identical classification pattern.
[a]This subject had small discs that did not look glaucomatous on ophthalmoscopy; diagnosis of POAG was based on IOP 26–32 mmHg, central corneal thickness 520 μm, and reproducible visual field defects in the Bjerrum area; the partner eye is included in the line above.
[b]Cohen's kappa, weighted; $P<0.0001$ for all comparisons shown.

important, factor for suboptimal automated disc border recognition in OCT. Disc size and clinical diagnosis seemed not to play a role at all. Myopic refraction, on the other hand, tended to be more frequently associated with confusing automated placement of disc borders. Therefore, manual adjustment of disc margin points using a colour disc photograph as a reference is recommended with the present software, and may help obtaining a more realistic ONH image with the OCT.

Correlation between disc measures in OCT automated and manual modes

While manual fitting systematically reduced values for disc and rim area, it had little to no effect on cup area. This may explain to a certain extent the more 'aggressive' diagnosis of OCT-DISC$_{man}$, tending to skew the classification toward abnormal, particularly in eyes with big and deep cups. Since manual determination of RPE/choriocapillaris edges is doing what the software is supposed to do automatically, it should be assumed that OCT-DISC$_{man}$ gives an ideal picture of what OCT is designed to give. Evaluation with regard to morphometric and diagnostic reliability should therefore be based widely on OCT-DISC$_{man}$ results.

In largely excavated discs (being the primary target of morphological evaluation in clinical practice), cups tend to be depicted too large, and rims too narrow. We speculate that reducing the cup-offset from 150 μm to (roughly estimated) 50 μm (ie, the cup margin would lie only 50 μm above RPE) might improve OCT performance in these cases. Hrynchak *et al* also made the observation that if cup contour was positioned at 1/2 of the total cup depth, that is, very close to the RPE level, OCT cup-to-disc ratio correlated much better with the stereoscopic clinical estimation than when cup contour was positioned at 1/3 cup depth.[30] On the other hand, a cup-offset of 50 μm may lead to an unsatisfactory imaging of ONHs with very shallow cups, resulting more frequently in discs with no cupping.[30] This seems to be an intrinsic characteristic of a method that uses as a reference level a structure (the RPE, corresponding approximately to the outer edge of the scleral ring) that is relatively stationary in its z-axis, being independent of the retinal tissue thickness overlying it.

ONH measures and clinical diagnosis

HRT disc values
In our group, HRT disc measurements correlated consistently with the clinical category and the clinical understanding—controls and ocular hypertensives exhibited normal values throughout; glaucoma eyes differed significantly and had abnormal parameters; glaucoma-like discs revealed cup areas comparable with the POAG eyes, but rim areas and volumes comparable with the normal eyes; glaucoma-like discs had the largest disc sizes.

OCT disc values
In the same context, there was a considerable difference in rim area and volume between normal and OHT eyes, on the one hand, and glaucoma suspects and glaucoma eyes, on the other (Table 4), in the transition of OCT parameters from normal to glaucoma. This difference was particularly striking regarding the rim volume, the latter mean values (OCT-DISC$_{aut}$) being roughly three-fold smaller in the glaucoma-suspect, and five to six-fold smaller in the glaucoma group compared to the other two groups. This stands in dissonance with what we would expect clinically. Baring in mind that the glaucomatous process is rather a continuum from normal to abnormal, the issue of cut-off values of these OCT parameters needs to be addressed. OCT rim volume in our study (both OCT-DISC$_{aut}$ and OCT-DISC$_{man}$) would have classified all glaucoma-like discs as clearly glaucomatous. The fact that manual placement of disc borders—that actually brought OCT disc shape and size much closer to the objectively observed in the ONH photographs—led to an increase of the above disproportion, may further implicate the necessity of adjusting the software algorithm with regard to cup-offset.

Based on our current understanding of anatomy, histology and morphometry, it is generally accepted that the scleral ring of Elschnig delineates the outer ONH borders.[14–16,20] This rule was respected by us when determining HRT disc contour. Since the scleral ring is not imaged with the OCT, the algorithm is trained to locate disc border at the RPE/choriocapillaris edge. Histologically, in a 'typical' eye, RPE/choriocapillaris abuts on the outer edge of Elschnig's ring. Thus, by definition, optic discs imaged by OCT would appear larger compared to HRT. Theoretically, this difference should reflect the width and area of Elschnig's ring. There was, however, a much broader scatter of measurement differences, so that factors other than disc definition and anatomy should be sought to explain HRT/OCT discrepancies.

Agreement between Stratus OCT and HRT II disc measures

In their study in 2003, Schuman *et al*[11] found a good correlation between HRT I and OCT 3 disc measures. We also observed statistically significant correlations between HRT II and Stratus OCT disc parameters, better for OCT-DISC$_{man}$ than for OCT-DISC$_{aut}$, when applying the Pearson correlation. However, most OCT-DISC mean values were systematically larger than those in HRT (Table 4). This held true for disc area, cup area and cup-to-disc area ratio throughout the groups. OCT rim area and rim volume were larger than HRT values only in the eyes with normally looking optic discs (small and shallow cups, normal controls, and OHT), while in the eyes with glaucomatous looking discs (big and deep cups), OCT mean values were smaller than those in HRT. This 'change in direction' has not been reported previously. The Bland–Altman analysis revealed proportional errors and large dispersal of measurement differences between the two methods. Considering the latter as well as the above-discussed particularities in the definition of disc and cup margins, it does not seem likely that diagnostic ranges from planimetry and confocal scanning laser ophthalmoscopy could be adopted and continued in OCT disc imaging analysis.

Differentiating between normal and abnormal optic discs

Apart from the comparative analysis of topographic measures, we evaluated the 'practicability' of OCT disc diagnostic using masked assessment of the Stratus OCT print-out. In classifying optic nerve heads as normal, borderline, and abnormal, OCT-DISC protocol demonstrated an overall good agreement with the current standards for ONH evaluation, the colour photographs, and the HRT, although HRT II exhibited better consistency with the photographs. A limitation of this analysis is our definition of diagnostic criteria for normal and abnormal. Since there were no generally established discriminating criteria for OCT-DISC at the time of the study, and there was no integrated evaluation scale in its software, we adopted criteria based on HRT and ophthalmoscopy principles. We found thereby that when disc borders were satisfactorily depicted, macroscopic interpretation of the schematic disc and cup drawing in the OCT print-out enabled a diagnosis.

Conclusions

The OCT-DISC protocol performed overall well in differentiating between normal and glaucomatous ONHs, and showed, on the whole, a good diagnostic agreement with photographs and HRT. These positive diagnostic results stood in certain discrepancy with the frequent failure of disc border recognition, the latter accounting for unrealistic disc shapes and areas, and gross dissimilarities with HRT topographic values in some of the cases. A manual correction of disc borders was necessary more frequently, but not exclusively, in myopic eyes and eyes with peripapillary atrophy. According to the results of this study, morphometric parameters cannot be directly compared between HRT and OCT. OCT Disc mode tended to depict normal discs with wide neuroretinal rim as even 'more normal', and discs with a narrower rim and a large cup as even 'more abnormal', that is, it tended to enhance both normality and abnormality. Defining an own OCT-DISC normative database and possibly adjusting disc border recognition and cup-offset algorithms might further improve OCT morphometric performance.

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