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Original Article

Optic nerve head assessment: comparison of Cirrus optic coherence tomography and Heidelberg Retinal Tomograph 3

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Abstract

Background: The purpose of this study was to analyse the relationship between optic nerve head (ONH) parameters measured by spectral domain optical coherence tomography and confocal scanning laser ophthalmoscope.

Design: Prospective, cross-sectional study. Hospital setting.

Participants: One hundred seventy-three subjects (85 glaucoma and 88 normal subjects).

Methods: One eye from each individual was selected randomly for ONH imaging by the spectral domain Cirrus OCT and Heidelberg Retinal Tomograph 3 (HRT3).

Main Outcome Measures: Four ONH parameters that are measured by both technologies (average cup-to-disc ratio [CDR], rim area, disc area and cup volume) were analysed and compared for differences, agreement of the categorical classification, diagnostic sensitivities and specificities and the area under the receiver operating characteristic curves (AUC).

Results: ONH parameters, as determined by the two technologies were significantly different but strongly correlated. Proportional bias was demonstrated for all measurements. The agreement of categorical classification was excellent for CDR ($\kappa = 0.94$) and good for rim area and cup volume ($\kappa = 0.63$ and 0.71, respectively). The highest sensitivities at fixed specificities were achieved by Cirrus OCT. AUCs for CDR, rim area, disc area and cup volume were not significantly different between the two technologies.

Conclusions: The diagnostic capability of ONH measurements by both technologies is similar. Paired ONH measurements by Cirrus OCT and HRT3 are strongly correlated but significantly different and proportionally biased. The results preclude interchangeable use of the absolute values, but categorical classification of ONH parameters may be interchangeable in clinical practice.

Key words: Cirrus Optical Coherence Tomography, Heidelberg Retinal Tomograph 3, optic nerve head measurement.

Introduction

Progressive death of retinal ganglion cells and their axons is the hallmark of glaucomatous optic neuropathy.[1] The ability to detect subtle changes in the retinal nerve fibre layer (RNFL) and optic nerve head (ONH) over time is critical in the management of glaucoma. Disc photography and standard perimetry do not detect sensitively subtle early changes; while photography has poor inter-observer agreement and

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is unable to detect diffuse glaucomatous loss,[2] standard automated perimetry only detects visual field loss after substantial loss of retinal ganglion cell axons.[3]

Computerized imaging modalities have been developed to provide objective and reproducible quantitative measurements of RNFL thickness and ONH anatomy. The confocal scanning laser ophthalmoscope (Heidelberg Retina Tomography [HRT]; Heidelberg Engineering, Heidelberg, Germany) obtains topographic imaging of the optic disc and peri-papillary retina. The older version, HRT2 and the newer version HRT3 were demonstrated to have a high degree of discrimination between healthy and glaucomatous eyes[4–10] and became popular in ONH assessment.

The optical coherence tomography (OCT) is a non-contact, non-invasive imaging technique that obtains in vivo, high-resolution, cross-sectional images of microstructure in biological tissues. While RNFL thickness measurements by time-domain (TD) OCT has been extensively investigated, only a few reports have emerged on its performance in ONH measurements, with variable results.[11,12]

Spectral domain OCT (SD OCT), such as the Cirrus OCT (Carl Zeiss Meditec, Inc., Dublin, CA), offers faster image acquisition and better image resolution than TD OCT. The use of RNFL thickness measurements by SD OCT has been studied thoroughly, including in the authors' recent published study,[13] and is often an integral part of glaucoma patients' assessment. With a recent software module, the Cirrus OCT also measures ONH parameters and compares results with a normative database. These measurements were found to be repeatable and reproducible both in healthy and glaucoma patients.[14,15] Cirrus OCT measurements of ONH parameters and RNFL thickness to be equal in their ability to discriminate between normal and glaucomatous eyes.[16]

Few recent studies have compared ONH measurements by Cirrus OCT and HRT3 in terms of absolute values, their correlation and analysis of differences,[17–20] but none has compared their agreement in categorical classification (within normal limits, borderline and outside normal limits) or their ability to discriminate glaucoma patients from normal individuals. The purpose of this study was to compare ONH measurements by the established HRT3 and the relatively newly introduced Cirrus OCT ONH module for all clinical comparisons.

Methods

Subjects

This prospective comparative study was conducted in accordance with the ethical standards of the Declaration of Helsinki 1995 (as revised in Edinburgh 2000) and approved by the South East and Illawarra Area Health Service Research Ethics Committee. A total of 173 subjects (88 normal subjects and 85 glaucoma patients) followed from January 2010 to December 2010 at the Sydney Eye Hospital, Sydney, Australia were enrolled. One eye from each subject was selected randomly if both eyes were eligible. Control subjects had a normal visual field, and no history of intraocular pressure greater than 21 mmHg. Glaucoma was defined by the presence of visual field defects as described below. All subjects underwent a full ophthalmic examination, including measurement of visual acuity, refraction, tonometry, gonioscopy and fundus examination. The inclusion criteria included visual acuity of 20/40 or better with a spherical error between +4.0 and −7.0 diopters. Subjects with clinical evidence of macular disease, past refractive or retinal surgery, neurologic pathology or diabetes were excluded. The inclusion and exclusion criteria applied to both normal and glaucoma groups. Each eligible eye was imaged by the Cirrus OCT and HRT3 and had visual fields performed by a team of trained technicians masked to other clinical information at the same visit.

Visual field examination

Visual field testing was performed using standard automated threshold perimetry (SITA Standard 24–2, Humphrey Field Analyzer II, Carl Zeiss Meditec, Dublin, CA). A reliable visual field had fixation losses, false-positive, and false-negative errors less than 20%. Average visual field sensitivity was expressed as mean deviation (MD) and pattern standard deviation (PSD). Criteria for glaucomatous visual field defect were:[21] Glaucoma Hemifield Test outside normal limits, PSD with $P < 5\%$ or a cluster of three or more points in the pattern deviation plot in a single hemifield (superior or inferior) with $P < 5\%$, one of which needed a $P < 1\%$. Any one of the preceding criteria, confirmed by at least two consecutive examinations, was considered sufficient evidence to be labelled a glaucomatous visual field defect.

Cirrus HD-OCT optic nerve head parameters measurement

Spectral-domain OCT imaging was performed with Cirrus HD-OCT software (Version 5.1.0.96, Carl Zeiss Meditec, Inc., Dublin, CA). The Cirrus HD-OCT uses a super luminescent diode laser with a centre wavelength of 840 nm.[22] The acquisition rate of the Cirrus OCT is 27000 A-scans per second. The transverse and axial resolutions are 15 μm and 5 μm,

respectively. A line-scanning ophthalmoscope with a frame rate of 20 Hz provides a fundus viewpoint to indicate the location of scan pattern on the fundus. Because the line-scanning ophthalmoscope is synchronized with the OCT imaging, any eye movement during scan acquisition can be detected as a discontinuity in the fundus image. The optic disc cube is a glaucoma scan protocol that images the optic disc and the parapapillary retinal region covering an area of 6×6 mm^2 (200×200 data points). The built-in algorithms locate the centre of the optic disc even if it is not well centred in the scan image.[23] The software identifies the disc centre by finding a dark spot near the centre of the scan that has a shape and size consistent with a range of optic discs. Besides the retinal nerve fibre layer (RNFL) thickness measurements, five ONH parameters are measured: rim area, disc area, average cup-to-disc ratio (CDR), vertical CDR and cup volume. The average CDR is given by the square-root of the ratio of the area of the cup to the area of the disc. The vertical CDR is the ratio of the cup diameter to the disc diameter in the vertical meridian. Cup volume is a 3-dimensional (3D) measurement defined as the volume between a plane created by the cup outline at the vitreous interface and the posterior surface of the ONH. This Cirrus OCT software (version 5.1.0.96) offers four classification categories for normative ONH parameters, except for the disc area: the 95th to 100th percentiles were hyper-normal (white colour on thickness map); fifth to 95th percentiles were normal (green); first to fifth percentiles were borderline (yellow); and <1st percentile was abnormal (red). In this study, white and green were regarded as normal. The fundus image and the signal strength (range, 1–10) were reviewed in each scan. Scans with movement artefact or signal strength of less than 7 were excluded from the analysis.

Confocal scanning laser ophthalmoscope imaging

Confocal scanning laser ophthalmoscopy was performed with the HRT3 (HRT; Heidelberg Engineering, GmbH, Dossenheim, Germany). A 3-dimensional topographic image consisting of $384 \times 384 \times 16$ up to $384 \times 384 \times 64$ pixels is constructed from multiple focal planes axially along the optic nerve head. An average of three consecutive scans is obtained and aligned to compose a single mean topography for analysis. Experienced examiners outlined the optic disc margin on the mean topographic image. Once the contour line has been drawn, the software automatically calculates the optic disc measurements. The reference plane is defined at 50 μm posterior to the mean retinal height between 350° and 356° along the contour line. The area above the reference plane confined within the contour line is defined as the rim and below as the cup. All subjects had image quality standard deviation <30 μm. Few ONH and the RNFL measurements are printed in the main printout of HRT3 software and are indicated by a categorical classification. A green check (within normal limits) is given for a measurement value within 95% normal range; a yellow exclamation mark (borderline) is given for a measurement value between the lower 95% and the lower 99.9% of normal distribution; and a red cross (outside normal limits) is given for a measurement value below the lower 99.9% of the normal distribution. The measurements of many other ONH parameters are given in the 'stereometric parameters' table in a different screen of the software, and are coloured for categorical classification as described (green, yellow and red).

Of all ONH parameters measured by HRT3, four are measured also by Cirrus OCT and were compared in this study: rim area, disc area, linear CDR (equivalent to average CDR on Cirrus OCT) and cup volume. For the purpose of simplicity, in this study we use the term CDR instead of average or linear CDR.

Statistical methods

Analyses were performed using the Statistical Package for the Social Sciences 15.0 (SPSS Inc., Chicago, IL) and MedCalc 11.0 (MedCalc Software, Mariakerke, Belgium). Student paired *t*-tests were used to compare the Cirrus OCT and HRT3 measurements. Pearson's correlation coefficient was used to determine correlation between paired measurements. Bland–Altman plots were graphed for the analysis of differences between measurements by the two instruments. Agreement of the categorical classifications of rim area, average CDR and rim volume between Cirrus OCT and HRT3 was calculated using the κ coefficient. The agreement cannot by assessed for disc area because both technologies lack categorical classification for this parameter. When the agreement is assessed for all three categorical classifications, for example, within normal limits (WNL), borderline and outside normal limits (ONL), then the agreement is given by the value of 'weighted κ'. For simplicity reasons, borderline classification can be considered as WNL and then the agreement between the technologies is assessed as 'most specific criteria', or, 'to be on the safe side', borderline classification could be considered as ONL, and then the agreement between the technologies is assessed as 'least specific criteria' (see Table 1 for graphic illustration). In the latter two options, κ is the parameter of agreement. For all κ statistics, a value between 0.0, and 0.2 indicates poor agreement,

Table 1. Methods for calculations of agreement of categorical classifications (Kappa statistics – the κ coefficient)

Scenario				Coefficient used
All three categorical classifications considered separately	WNL	BL	ONL	Weighted κ
Most specific criteria	WNL	BL	ONL	κ
	WNL			
Least specific criteria	WNL	BL	ONL	κ
		ONL		

Most specific criteria: borderline classification is considered as within normal limits (least sensitive criteria).

Least specific criteria: borderline classification is considered as outside normal limits (most sensitive criteria). BL, borderline; ONL, outside normal limits; WNL, within normal limits.

Table 2. Demographic data from normal and glaucomatous eyes

	Normal (n = 88)	Glaucoma (n = 85)	P
Age (years)	67.38 ± 11.97	69.96 ± 1.13	0.18
Female (%)	54.55%	41.18%	0.61
Right eye (%)	52.27%	51.76%	0.22
Spherical equivalent (diopters)	0.18 ± 1.98	–0.34 ± 2.24	0.12
Snellen best corrected visual acuity	0.94 ± 0.23	0.85 ± 0.26	0.01
Disc area by HRT3 (mm^2)	2.09 ± 0.42	2.06 ± 0.50	0.69
Disc area by Cirrus OCT (mm^2)	2.03 ± 0.35	2.01 ± 0.47	0.76
MD of visual field (dB)	–0.68 ± 1.6	–7.89 ± 7.03	<0.001
PSD of visual field (dB)	1.74 ± 0.47	6.45 ± 3.64	<0.001

MD, mean deviation; HRT, Heidelberg retina tomograph; OCT, optical coherence tomography; PSD, pattern standard deviation; SD, standard deviation.

between 0.21 and 0.40, fair, between 0.41 and 0.60, moderate, from 0.61 to 0.80, good and 0.81 through 1, almost perfect agreement.[24] Sensitivities and specificities for ONH parameters were calculated for OCT and HRT3 compared with the visual field classifications. The receiver operating characteristic (ROC) curves were used to determine the discriminatory capabilities between healthy and glaucomatous eyes. Areas under the ROC curves (AUC) were compared using the method of De Long and De Long.[25]

Results

Demographic and ONH parameters results

The baseline demographic characteristics of healthy subjects and subjects with glaucoma are shown in Table 2. No significant differences were observed in age, gender, right *versus* left eyes, spherical equivalent, Snellen best corrected visual acuity (BCVA) and disc area (by both HRT3 and Cirrus OCT) between the two groups. The MD and PSD values of the visual fields were significantly greater in the subjects with glaucoma. Rim area, CDR and cup volume measurements by HRT3 and Cirrus OCT were significantly different. Disc area measurements were marginally different for the whole study group and statistically equal for the normal and glaucoma subgroups separately (Table 3).

Correlation between measurements

A significant correlation between Cirrus OCT and HRT3 was found for all paired measurements of ONH parameters (Fig. 1). The values for CDR measurements were: $r_o = 0.8$; $r^2 = 0.64$, $P < 0.001$, for the rim area: $r_o = 0.65$; $r^2 = 0.42$, $P < 0.001$, for cup volume: $r_o = 0.88$ $r^2 = 0.77$, $P < 0.001$, and for disc area: $r_o = 0.74$; $r^2 = 0.55$, $P < 0.001$.

Analysis of differences

Bland–Altman plots demonstrated a systematic proportional bias for the measurements by the two technologies for all ONH parameters (Fig. 2). For rim area, disc area and CDR, the HRT 3 minus Cirrus OCT difference was positively proportional to the parameter's value while for cup volume, the difference was negatively proportional to parameter's value.

Agreement of categorical classification

Table 4 shows the agreement between the two technologies according to the three options; 'all

Table 3. Measurements of ONH parameters (±SD) by Cirrus OCT and HRT3

	Cirrus OCT	HRT3	*P*
Rim area	All patients (*n* = 173) 1.02 ± 0.31 mm^2	All patients (*n* = 173) 1.29 ± 0.4 mm^2	*P* < 0.001
	Normal subgroup (*n* = 85) 1.17 ± 0.22 mm^2	Normal subgroup (*n* = 85) 1.44 ± 0.30 mm^2	*P* < 0.001
	Glaucoma subgroup (*n* = 88) 0.87 ± 0.32 mm^2	Glaucoma subgroup (*n* = 88) 1.13 ± 0.43 mm^2	*P* < 0.001
Disc area	All patients (*n* = 173) 2.02 ± 0.41 mm^2	All patients (*n* = 173) 2.08 ± 0.46 mm^2	*P* = 0.031
	Normal subgroup (*n* = 85) 2.03 ± 0.35 mm^2	Normal subgroup (*n* = 85) 2.09 ± 0.42 mm^2	*P* = 0.09
	Glaucoma subgroup (*n* = 88) 2.01 ± 0.47 mm^2	Glaucoma subgroup (*n* = 88) 2.06 ± 0.50 mm^2	*P* = 0.18
Cup volume	All patients (*n* = 173) 0.36 ± 0.33 mm^3	All patients (*n* = 173) 0.22 ± 0.32 mm^3	*P* < 0.001
	Normal subgroup (*n* = 85) 0.28 ± 0.19 mm^3	Normal subgroup (*n* = 85) 0.16 ± 0.14 mm^3	*P* < 0.001
	Glaucoma subgroup (*n* = 88) 0.45 ± 0.41 mm^3	Glaucoma subgroup (*n* = 88) 0.29 ± 0.43 mm^3	*P* < 0.001
CDR	All patients (*n* = 173) 0.67 ± 0.14	All patients (*n* = 173) 0.58 ± 0.18	*P* < 0.001
	Normal subgroup (*n* = 85) 0.62 ± 0.12	Normal subgroup (*n* = 85) 0.52 ± 0.16	*P* < 0.001
	Glaucoma subgroup (*n* = 88) 0.72 ± 0.15	Glaucoma subgroup (*n* = 88) 0.63 ± 0.18	*P* < 0.001

CDR, average\linear cup to disc ratio; HRT, Heidelberg Retina Tomograph; OCT, optical coherence tomography; ONH, optic nerve head.

Table 4. Agreement (kappa) between Cirrus OCT and HRT3 for ONH categorical classification, based on all classification categories, and most and least specific criteria[†]

		Agreement (interpretation)	95% confidence interval
Rim area	All categories	Weighted κ = 0.48 (moderate)	0.36–0.60
	Most specific criteria	κ = 0.45 (moderate)	0.29–0.61
	Least specific criteria	κ = 0.63 (good)	0.51–0.76
Cup volume	All categories	Weighted κ = 0.37 (fair)	0.23–0.52
	Most specific criteria	κ = 0.71 (good)	0.55–0.88
	Least specific criteria	κ = 0.50 (moderate)	0.35–0.65
CDR	All categories	Weighted κ = 0.32 (fair)	0.19–0.44
	Most specific criteria	κ = 0.84 (excellent)	0.74–0.93
	Least specific criteria	κ = 0.94 (excellent)	0.89–1.0

[†]All classification categories = within normal limits, borderline, outside normal limits; most specific criteria = borderline classification is considered as within normal limits; least specific criteria = borderline classification is considered as outside normal limits.

CDR, average\linear cup to disc ratio; HRT, Heidelberg Retina Tomograph; OCT, optical coherence tomography; ONH, optic nerve head.

classifications categories', and most and least specific classification, as described in the Methods section. For the least specific criteria, excellent or good agreements were seen between the two technologies for CDR and rim area categorical classification (κ = 0.94 and κ = 0.63, respectively). Good agreement was also seen for cup volume categorical classification with the use of most specific criteria (κ = 0.71).

Diagnostic performance for glaucoma detection

As in assessment of agreement, diagnostic performance can only be assessed for CDR, rim area and rim volume, because both Cirrus OCT and HRT3 lack categorical classification for disc area.

The sensitivities at 98% Specificity for both Cirrus OCT and HRT3 were poor for all three ONH

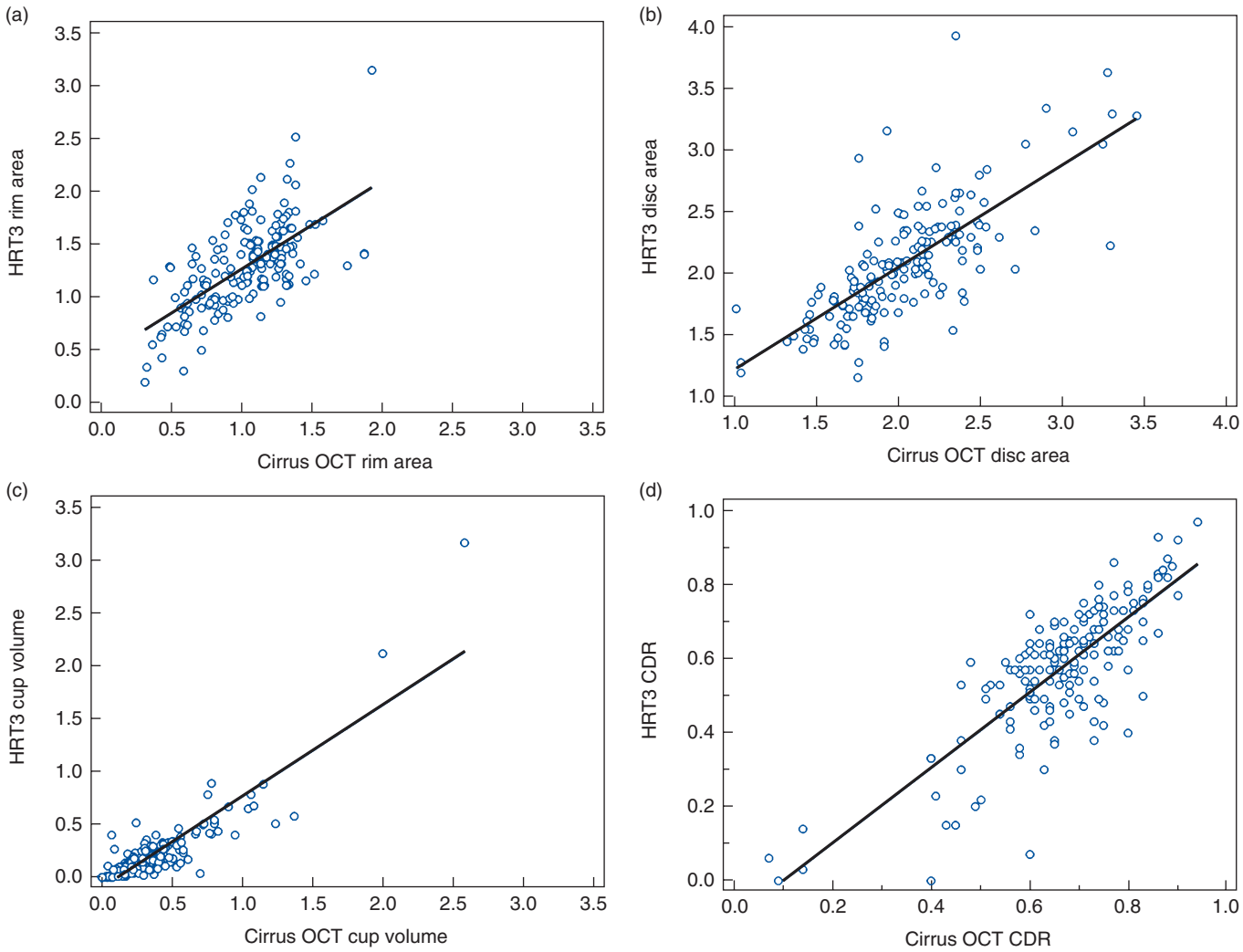

Figure 1. Correlation of the (a) rim area, (b) disc area, (c) cup volume and (d) cup-to-disc (CDR) measurements by Cirrus optical coherence tomography (OCT) and Heidelberg Retina Tomograph (HRT) 3. Significant correlation is found between paired measurements by the two technologies.

parameters tested (Table 5). When 80% specificity was evaluated, the sensitivities became moderate, with no apparent difference between the two technologies. The best sensitivities at 80% specificity were seen for the rim area measurement: 68.24% for Cirrus OCT and 62.35% for HRT3, followed by CDR measurement: 63.53% for Cirrus OCT and 57.65% for HRT3. The diagnostic sensitivity of cup volume measurement was poor both at 98% and 80% specificities.

The AUCs of CDR, rim area, rim volume and disc area measured by the two technologies are shown in Figure 3. The values for the AUCs are in Table 6.

No statistically significant difference was seen between the paired measurements. The largest AUCs were observed for CDR and rim area, while cup volume and disc area attained lower AUCs.

Discussion

Over the last decade, OCT technology has been used extensively to image the posterior pole of the eye in several diseases. Structural changes of the optic disc more commonly have been assessed and quantified by RNFL thickness, with ONH analysis by OCT receiving less attention. On the other hand, confocal scanning laser ophthalmoscope technology, with HRT2 and HRT 3 instruments, has been used mainly for ONH analysis.[4,7,10]

With the introduction of ONH modules for OCT and specifically since the incorporation of a normative database, ONH measurements with OCT have increased in popularity. The ONH analysis protocol, released on Cirrus OCT in 2010, has been shown to yield repeatable measurements with a

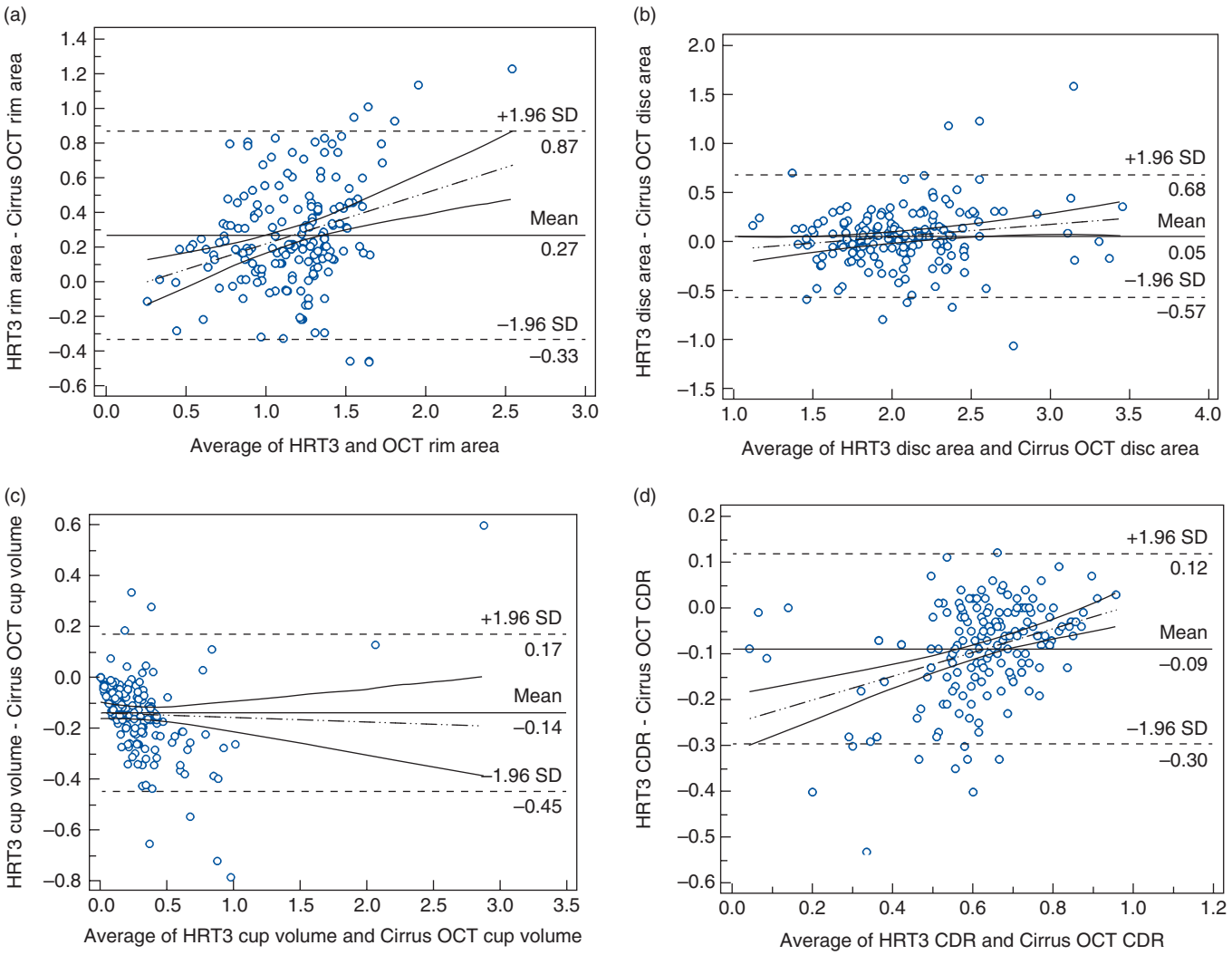

Figure 2. Bland–Altman analysis of difference for the (a) rim area, (b) disc area, (c) cup volume, and (d) cup-to-disc (CDR) measurements between Heidelberg Retina Tomograph (HRT) 3 and Cirrus optical coherence tomography (OCT). The difference (HRT 3 measurement – Cirrus OCT measurement) between both measurements is plotted against the average of both measurements (HRT 3 measurement – Cirrus OCT measurement/2). The line of equality (solid) is plotted with the 95% limits of agreement (dashed). Proportional bias is seen for all paired measurements. See text.

diagnostic accuracy as high as that achieved for RNFL thickness.[13,15]

We directly compared the performance of the Cirrus OCT ONH module with ONH measurements with the long accepted HRT3. For a direct comparison, only the shared parameters of the two technologies were assessed. Both Cirrus OCT and HRT3 measure additional ONH parameters but only four parameters are common to both technologies: rim area, disc area, CDR and cup volume.

Despite a strong and significant correlation between Cirrus OCT and HRT3 for all ONH parameters, measurements by HRT3 and Cirrus OCT for all four joint ONH parameters were different in absolute values for the whole study group, as well as for the normal and glaucoma patients subgroups (Table 3). However, the difference for disc area was statistically marginal for the whole study group and statistically equal for the normal and glaucoma patient subgroups separately. This latter finding is interesting because in HRT3, the examiner manually outlines the contour of the optic disc margin, while in OCT it is done automatically.

The differences between the measurements are not surprising and are attributable to different methods of ONH measurements: the OCT measures it directly while the HRT refers to a reference plane. Ideally, the absolute value for any ONH parameter should be the same with both instruments, just as one measures a similar weight with electronic and mechanical scales regardless of their different mechanisms of action. This is not the case for ONH assessment by HRT3 and

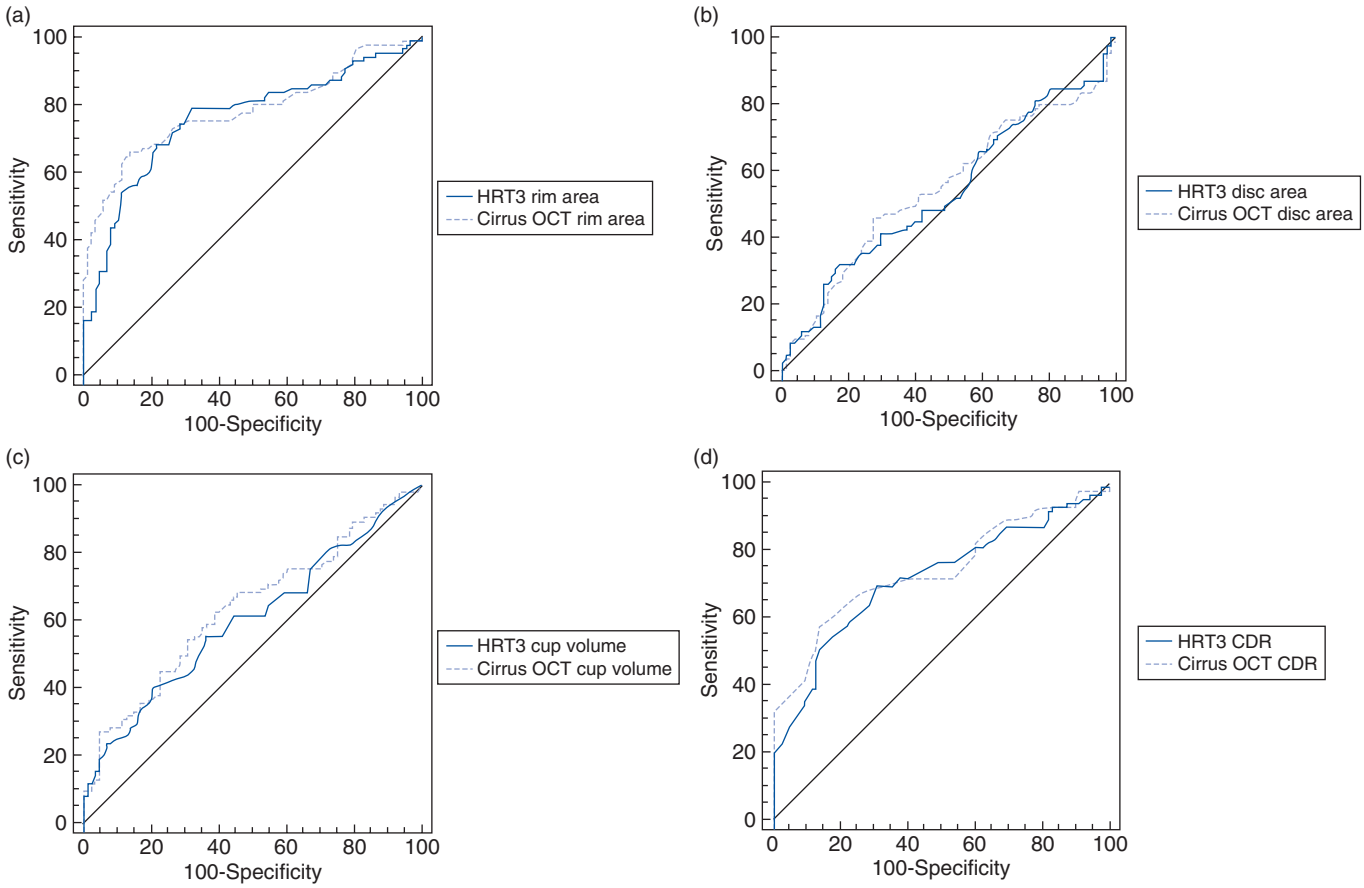

Figure 3. Receiver operating characteristic curve for discriminating between healthy and glaucomatous eyes using the Heidelberg Retina Tomograph (HRT) 3 and Cirrus optical coherence tomography (OCT), for the (a) rim area, (b) disc area, (c) cup volume and (d) cup-to-disc (CDR). Dotted line represents the Cirrus OCT measurement and solid line the HRT 3 measurement. See Table 6 for area under the receiver operating characteristic curves (AUC) values.

Table 5. Diagnostic sensitivities at 98% and 80% specificities of ONH measurements for Cirrus OCT and HRT3

Sensitivity (95% confidence interval) at 98% specificity		
	Cirrus OCT	HRT3
Rim area	38.82 (28.4–50.0)	16.47 (9.3–26.1)
Cup volume	11.76 (5.8–20.6)	11.76 (5.8–20.6)
CDR	34.12 (24.2–45.2)	22.35 (14.0–32.7)
Sensitivity (95% confidence interval) at 80% Specificity		
	Cirrus OCT	HRT3
Rim area	68.24 (57.2–77.9)	62.35 (51.2–72.6)
Cup volume	36.47 (26.3–47.6)	37.65 (27.4–48.8)
CDR	63.53 (52.4–73.7)	57.65 (46.4–68.3)

CDR, average cup to disc ratio; HRT, Heidelberg Retina Tomograph; OCT, optical coherence tomography; ONH, optic nerve head.

Table 6. Pairwise comparison of AUC (95% confidence intervals) for ONH parameters measured by Cirrus OCT and HRT3

	Cirrus OCT	HRT3	*P*
Rim area	0.78 (0.713–0.84)	0.76 (0.69–0.82)	0.57
Disc area	0.55 (0.474–0.63)	0.54 (0.46–0.62)	0.73
Cup volume	0.64 (0.558–0.71)	0.60 (0.53–0.68)	0.24
CDR	0.74 (0.67–0.81)	0.72 (0.67–0.79)	0.48

AUC, area under the receiver operating characteristic curves; CDR, average\linear cup-to-disc ratio; HRT, Heidelberg Retina Tomograph; OCT, optical coherence tomography; ONH, optic nerve head.

Cirrus OCT. Although the correlation between ONH measurements by HRT3 and Cirrus OCT was found to be strong and significant, the differences in absolute values allows no interchangeability of values between these two technologies.

The analysis of differences using the Bland–Altman plots revealed a positive proportional bias for rim area and CDR measurements, a negative

Table 7. Summary of recent published data comparing ONH measurements with OCT and HRT

Author	Modalities compared	Patients (Glaucoma\Normals\ Glaucoma suspects)	Main reported findings†			
			Rim area	Disc area	Cup volume	CDR
Yang *et al.*[16]	Cirrus OCT *versus* HRT3	207 (109\98\0)	1. HRT3 measurements are significantly larger 2. No proportional bias	1. HRT3 measurements are significantly larger 2. Positive proportional bias	1. Cirrus OCT measurements are significantly larger 2. Negative proportional bias	1. Cirrus OCT measurements are significantly larger 2. Positive proportional bias
Sato *et al.*[17]	Cirrus OCT *versus* HRT3	117 (96\21\0)	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Negative proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Positive proportional bias
Moghimi *et al.*[18]	Cirrus OCT *versus* HRT3	71‡ (13\37\21)	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias	1. HRT3 measurements are significantly larger 2. Significant correlation 3. No proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Negative proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Positive proportional bias
Foo *et al.*[19]	Cirrus OCT *versus* HRT3	913 (NA)	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias	1. Cirrus OCT and HRT3 measurements were similar 2. Significant correlation 3. Positive proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Negative proportional bias	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Positive proportional bias
Our study	Cirrus OCT *versus* HRT3	173 (88\85\0)	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias 4. Good categorical agreement§ 5. Same diagnostic capability	1. HRT3 measurements are significantly larger 2. Significant correlation 3. Positive proportional bias 4. Same diagnostic capability	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Negative proportional bias 4. Moderate categorical agreement§ 5. Same diagnostic capability	1. Cirrus OCT measurements are significantly larger 2. Significant correlation 3. Positive proportional bias 4. Excellent categorical agreement§ 5. Same diagnostic capability

†When referring to 'proportional bias', the findings were adapted from a Bland–Altman plot where paired values of HRT3 minus Cirrus OCT are plotted against the average values of HRT3 and Cirrus OCT.

‡Referred to eyes, not patients. The breakdown of patients was not given.

§When referring to 'categorical agreement' the least specific criteria were taken: borderline is considered as outside normal limits.

NA, not available.

proportional bias for cup volume, and no systematic proportional bias for measurements of disc area.

These differences can also be attributed to the different method of measurement by the two technologies, and confirm once again that the measurements are not interchangeable.

Recently, there were few published studies comparing the absolute values, correlation and differences in ONH parameters between Cirrus OCT and HRT3.[17–20] Their main findings, along with our main findings are listed in Table 7. There are many agreements between studies. All studies report that Cirrus OCT gives larger values for CDR and cup volume, and that HRT3 gives larger values for rim area and disc area, except for one study that found CDR measurement to be similar. In all studies, as in ours, significant correlation was found between paired Cirrus OCT and HRT3 measurements. All studies have also found the same patterns of proportional biases between paired measurements done by the two technologies.

In clinical life, the detection of glaucoma by imaging technologies such as OCT and HRT often relies on diagnostic classification and not only on actual values of ONH parameters. Our study is the first to compare categorical agreement between the two technologies (Table 6). For CDR, using the least or most specific criteria, an excellent agreement in categorical classification was seen between the two technologies. For rim area and cup volume, the agreement ranged from moderate to good. These findings are important since contrary to absolute values, the categorical classification may be considered to be interchangeable between the two technologies.

Our study is also the first to compare the diagnostic ability of Cirrus OCT and HRT3 ONH measurements to discriminate glaucoma patients from healthy subjects. We found that ONH parameters measurements had a similar diagnostic performance for both technologies. Sensitivities at fixed specificities, as well as the AUCs for all four comparable ONH parameters were roughly equal. The best AUCs were 0.76 to 0.78 for rim area and 0.72 to 0.74 for CDR. This correlates well with another reported study regarding Cirrus ONH diagnostic performance by Mwanza *et al*.,[13] in which rim area and CDR were among the best factors for discrimination between normal and glaucoma patients. In their study, Mwanza *et al*. reported considerably higher AUCs for Cirrus OCT ONH parameters: 0.91 for rim area and 0.89 for CDR for discrimination normal patients from patients with mild to moderate glaucoma, and values of 0.999 for rim area and 0.978 for CDR for discriminating normal subjects from patients with severe glaucoma. Further studies will determine the real diagnostic performance of the Cirrus OCT ONH parameters and their role as potential screening tools for glaucoma detection.

In conclusion, the diagnostic capability of ONH measurements by both technologies was similar in our study. We demonstrated that paired ONH measurements by Cirrus OCT and HRT3 are strongly correlated but statistically different and proportionally biased. This precludes interchangeability of the absolute values between the technologies. Interchangeability in categorical classification may be considered since there is a moderate to excellent agreement in categorical classification between the two technologies.

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