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CLINICAL STUDY

Scanning laser polarimetry in patients with acute angle-closure glaucoma

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Abstract

Purpose **To detect differences in retinal nerve fibre layer (RNFL) measurements between patients with acute angle-closure glaucoma (AACG) and normal subjects using scanning laser polarimetry.**

Methods **This was a comparative cross-sectional study, where 32 eyes of 32 patients with AACG and 28 eyes of 28 normal subjects were imaged using scanning laser polarimetry (The Nerve Fibre Analyzer GDx, Laser Diagnostic Technology Inc., San Diego, CA, USA). The average RNFL thickness in four quadrants and various GDx parameters between the two groups were compared using Mann–Whitney tests with Bonferroni correction.**

Results **There were no significant differences in RNFL measurements for the average thickness, ellipse average, inferior, superior, nasal, and temporal average values between the AACG eyes and normal eyes. There were significant differences in some GDx parameters, including superior/nasal ratio ($P = 0.036$), superior ratio ($P = 0.01$), the GDx number ($P = 0.003$), inferior ratio ($P < 0.001$), maximum modulation ($P < 0.001$), and ellipse modulation ($P < 0.001$).**

Conclusions **Various GDx parameters exhibit significant changes in patients following short-duration AACG episodes, making GDx RNFL measurements useful for the diagnosis and follow-up of AACG.**

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Keywords: scanning laser polarimetry; GDx; retinal nerve fibre layer; acute angle-closure glaucoma

Introduction

It is well known that optic nerve and visual field damage can occur with the sudden, extreme rises in intraocular pressure (IOP) associated with primary acute angle-closure glaucoma (AACG), even if the increased IOP is only of short duration. Both AACG and chronic glaucoma can damage the optic disc, but, in addition to this, AACG can damage elements of the anterior segments, such as the cornea, lens, and iris.[1] Accordingly, perimetric examination during acute attacks is difficult and usually unreliable. After ACCG remission, visual field defects vary greatly in severity and type.[2–4]

Scanning laser polarimetry (The Nerve Fiber Analyzer GDx, Laser Diagnostic Technology Inc., San Diego, CA, USA) is a computerized laser scanning device designed for the objective and quantitative measurement of retinal nerve fibre layer (RNFL) thickness and loss. Good sensitivity and specificity for separating normal from glaucomatous eyes, and high reproducibility have been demonstrated for the instrument.[5,6] The quantification of RNFL thickness using the GDx in normal subjects, patients with ocular hypertension (OH) and primary open-angle glaucoma (POAG), has been described in various studies.[7–9]

Primary angle-closure glaucoma (PACG) is the most frequent form of glaucoma in Mongolian-type Asian populations. The prevalence of PACG varies by race, ranging from 0.1% in Caucasians, to 1.3% in Chinese populations, and up to 5% in Eskimos over 40 years of age. The prevalence of AACG has been reported as being 0.18% in those aged over 40 years in Europe, and the incidence of AACG has been reported as being 12.2 per 10 00 000 per year in those aged over 30 years in Asia.[10,11] Given the prevalence of AACG, an understanding of RNFL changes in AACG as measured by the GDx will assist the assessment and management of AACG. This study used the GDx to evaluate RNFL thickness and various GDx parameters after AACG remission, using normal control eyes for comparison.

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Materials and methods

This was a prospective and comparative study in which cross-sectional observations were made with RNFL measurements using scanning laser polarimetry. Age- and gender-matched controls were used in the study. Patients were recruited from those undergoing treatment in the emergency or outpatient departments of the Chang Gung Memorial Hospital, Kaohsiung County, Taiwan, over a 2- year period. All patients and control subjects were of Chinese origin.

In the study, the following AACG definition was used: (1) the presence of at least two symptoms: eye pain, headache, blurred vision, and vomiting; (2) the presence of the following signs: conjunctival congestion, a mid-dilated unreactive pupil, and corneal oedema; (3) closure of the chamber angle found on gonioscopic examination; (4) IOP >40 mmHg using Perkins applanation tonometry.

The inclusion criteria were as follows: (1) duration of AACG attack <48 h, and the definition of duration was from onset of symptoms to medical consultation; (2) IOP <21 mmHg after antiglaucoma medications prescribed during a medical consultation, laser iridotomy performed within 3 days of onset, and IOP below 21 mmHg persisting 1 month after laser iridotomy with or without medication; (3) best-corrected visual acuity (BCVA) $\geq 20/50$, and, refraction of less than ± 5.0 D (sphere) and 2.5 D (cylinder) 1 month following remission of the attack; (4) the reliability criteria for the visual fields were a false negative less than 33%, a false positive less than 33%, and a fixation loss less than 20%.

The exclusion criteria were as follows: (1) a history of a previous AACG episode; (2) chronic PACG with suspected superimposition of an acute attack, that is, patients with gonioscopic findings of peripheral anterior synechia (PAS) after laser iridotomy, or a cup-to-disc ratio of more than 0.5; (3) a history of medications used to control IOP; (4) previous corneal disease; and (5) corneal oedema or corneal opacity persisting after the AACG attack.

The BCVA, refraction, and RNFL measurements were made 1 month after remission of the AACG using the GDx. The automated visual fields were completed within 2 weeks of the GDx examination. The automated perimetry was performed using a Humphrey Field Analyzer 30-2 full threshold program (Humphrey Instruments, San Leandro, CA, USA). In patients with bilateral AACG, one eye of each patient was randomly selected for investigation.

The study included 28 eyes from 28 sex- and age-matched normal individuals without glaucoma as a control group. These normal subjects had (1) a BCVA $\geq 20/50$, (2) refraction of less than ± 5.0 D (sphere) and 2.5 D (cylinder), (3) IOP <21 mmHg, (4) an open angle, (5) a cup-to-disc ratio of less than 0.5, with asymmetry of the vertical cup-to-disc ratio less than 0.2 between eyes, (6) no family history of glaucoma, and (7) a normal visual field test, namely, the glaucoma hemifield test (GHT) had to be within normal limits and the corrected pattern standard deviation (CPSD) index had to be within the 95% confidence interval (P-value $>5\%$). Normal subjects recruited were volunteers or friends of patients. One eye of each normal subject was randomly selected for use in the study. All patients and controls were phakic and had not undergone any intraocular surgery in the past.

The RNFL measurements were obtained using scanning laser polarimetry (The Nerve Fiber Analyzer GDx, Laser Diagnostic Technologies Inc., San Diego, CA, USA). The details of this technique have been described previously.[12,13] A total of 65 536 retinal locations were measured to create a retardation map corresponding to RNFL thickness over a 15° (256×256 pixel) retinal area. While undergoing scanning, the mean pupil diameters of the normal subjects were 2.8 ± 0.3 mm and the mean pupil diameters of patients with AACG were 5.0 ± 1.2 mm. All patients and controls were analysed without wearing corrected glasses. The optic disc margin was approximated by a circle or ellipse placed around the inner margin of the peripapillary scleral ring by an experienced operator. A measuring circle or ellipse was then generated by the instrument at 1.75 disc diameters concentric with the margin of the disc. Default quadrant positions were applied: the peripapillary band was divided into superior and inferior segments of 120° each, a temporal segment of 50°, and a nasal segment of 70°. The measurements for each eye were obtained from a minimum of three images of good quality (rated as 'pass' by internal GDx software). The image of the best quality was then analysed.

The following values including the RNFL thickness from the temporal and nasal averages and the following 12 standard GDx parameters were chosen for analysis: GDx number, symmetry, superior ratio, inferior ratio, superior/nasal ratio, maximum modulation, ellipse modulation, average thickness, ellipse average, superior average thickness, inferior average thickness, and superior integral. These 12 GDx parameters were identified as the most effective parameters for distinguishing patients with normal RNFL from those with glaucomatous damage. The definitions of these parameters have been described elsewhere.[6,7]

Statistical analyses were performed using JMP software (SAS Institute, Cary, NC, USA). Mann–Whitney tests with Bonferroni correction were used to evaluate differences between both study groups for the 12 standard GDx parameters, the RNFL thickness from the nasal and temporal averages, BCVA, refraction (spherical equivalent), visual field indices including mean defect

(MD), and CPSD. The student's *t*-test and the χ^2 test were used to analyse mean age and the male : female ratio for the two study groups. A *P*-value of less than 0.05 was considered to be statistically significant.

Results

This study enrolled 37 eyes of 37 patients with AACG and 28 eyes of 28 normal subjects. Five eyes with AACG were excluded based on the reliability criteria for their visual field tests. The characteristics of the study population are listed in Table 1. The IOP measurements at presentation were as follows: six eyes were between 41 and 50 mmHg, 21 eyes were between 51 and 60 mmHg, and five eyes were above 60 mmHg. The duration of attack was 20.1 ± 11.9 h, ranging from 1 to 45 h. There were no significant differences in mean age, the male : female ratio, BCVA, refraction, and visual field index : CPSD between the two groups. There were, in contrast, significant differences in visual field index : MD.

Details of the RNFL measurements from the GDx are listed in Table 2. No significant differences were found between the AACG group and the normal group for the average thickness, ellipse average, inferior, superior, nasal, and temporal average RNFL thickness values. The following parameters were significantly reduced in the AACG group when compared with the normal eye group: the superior ratio, inferior ratio, superior/nasal ratio, maximum modulation, ellipse modulation, and a significant increase was found in the GDx number.

Discussion

Douglas *et al*[2] found that the optic disc may appear hyperaemic or oedematous during AACG attacks, and may develop pallor without obvious cupping after remission. Cupping can occur in prolonged attacks when

Table 1 Characteristics of the study population

	Normal subjects (n=*28*)	*Patients with AACG* (n=*32*)	P-*value*
Age (years)	60.0 ± 7.7 (46–74)	62.8 ± 6.3 (50–78)	0.13
Male/female	12/16	9/23	0.23
BCVA (tenth)	0.86 ± 0.19 (20/40–20/20)	0.78 ± 0.24 (20/50–20/20)	0.84
Refraction (D)	0.28 ± 2.08 (−4.75 to +3.625)	0.71 ± 1.68 (−3.375 to +4.75)	1.0
Visual field			
MD (dB)	1.31 ± 1.03 (0–3.04)	6.26 ± 4.80 (0.08–16.6)	0.0006
CPSD (dB)	1.19 ± 0.72 (0–2.06)	2.20 ± 1.65 (0–5.65)	0.28

Values are the mean ± SD. BCVA, best-corrected visual acuity; D, diopter; MD, mean defect; CPSD, corrected pattern standard deviation; AACG, acute angle-closure glaucoma.

Table 2 Retinal nerve fibre layer measurements using the GDx

Parameters	*Normal subjects* (n=*28*)	*Patients with AACG* (n=*32*)	P-*value*
Number	20.0 ± 5.39 (8–29)	35.5 ± 17.4 (12–73)	0.003
Symmetry	0.94 ± 0.11 (0.70–1.15)	0.98 ± 0.11 (0.80–1.39)	1.0
Superior ratio	2.06 ± 0.24 (1.67–2.74)	1.81 ± 0.29 (1.33–2.59)	0.01
Inferior ratio	2.20 ± 0.22 (1.75–2.56)	1.88 ± 0.39 (1.30–3.24)	0.0003
Superior nasal	1.77 ± 0.17 (1.53–2.18)	1.59 ± 0.23 (1.27–2.17)	0.036
Maximum modulation	1.25 ± 0.21 (0.81–1.74)	0.94 ± 0.36 (0.35–2.24)	0.0002
Ellipse modulation	2.19 ± 0.43 (1.57–3.06)	1.61 ± 0.63 (0.63–3.66)	0.0004
Average thickness (μm)	69.6 ± 7.34 (60–84)	69.9 ± 8.84 (57–93)	1.0
Ellipse average (μm)	73.3 ± 7.63 (60–87)	72.5 ± 10.2 (58–98)	1.0
Superior average (μm)	79.8 ± 9.13 (61–100)	76.9 ± 11.9 (58–103)	1.0
Inferior average (μm)	87.3 ± 10.6 (72–105)	82.4 ± 12.3 (60–114)	1.0
Temporal average (μm)	48.6 ± 7.08 (38–67)	52.5 ± 11.4 (34–71)	1.0
Nasal average (μm)	57.1 ± 6.39 (45–69)	60.3 ± 8.61 (47–78)	1.0
Superior integral	0.22 ± 0.03 (0.17–0.30)	0.23 ± 0.04 (0.16–0.32)	1.0

Values are the mean ± SD.

treatment is delayed, and vision may be markedly reduced to hand movement or light perception. These characteristics set AACG apart from chronic angle-closure glaucoma, where optic disc cupping and visual field defects progress in a manner similar to that seen in open-angle glaucoma.

Visual field defects associated with acute, markedly elevated IOP in short-duration AACG are typically generalized reduction of sensitivity and nonspecific generalized or upper field constriction. Enlargement of the blind spot and nerve fibre bundle defects may also be found. After normalization of IOP, the visual field may also normalize.[2] Bonomi *et al*[3] assessed visual field damage 36–48 h after remission of an AACG attack using automated perimetry. The MD ranged from 0.35 to 26.4 dB. The visual field was normal in 15%, but in 85% there was some form of visual field defect present, usually of the generalized type, with a smaller proportion of mixed-type and a few cases presenting with a localized-type defect. At 1 month after remission, 45% were found to be normal. In other reports, 62% of patients had not developed a visual field defect 6 months after the acute episode of AACG.[4]

Visual field defects found with AACG are not compatible with truly glaucomatous neuropathy and RNFL loss. Visual field defects seen with AACG may reflect anterior segment and optic disc changes. The causes of visual field defects in the acute stage may arise from glaucomatous optic neuropathy, optic disc oedema,[2] a fixed dilated pupil, and corneal oedema. After remission, the effects of visual field loss may arise from glaucomatous optic neuropathy, a fixed dilated pupil,[14] and cataract formation or progression.[15] The normal visual field may represent early glaucoma with some RNFL loss. Quigley *et al*[16] reported that as much as 50% of the ganglion cell and its nerve fibre bundles may be lost before a visual field defect can be detected.

GDx measurements of RNFL loss in OH, POAG, and normal-pressure glaucoma have been previously described in detail.[7–9,17] Weinreb *et al*[7] found that with the exception of symmetry, there were statistically significant differences between healthy and glaucomatous eyes with GDx parameters that include the GDx number, superior ratio, inferior ratio, superior/nasal ratio, maximum modulation, superior maximum, inferior maximum, ellipse modulation, average thickness, ellipse average, superior average, inferior average, and superior integral.

Lee Vincent and Mok[8] reported that the total average value, superior value, and inferior value were all found to be significantly lower in the glaucomatous group than in the normal group, with the exception of the nasal and temporal values. The superior/nasal and inferior/nasal ratios were both found to be significantly lower in the glaucoma group.

Kamal and Hitchings[9] and Yamada *et al*[18] found that RNFL thickness was significantly reduced in POAG eyes when compared with normal eyes for the total, superior, and inferior quadrant values, but no significant differences were found between the normal and the ocular hypertension group for the total or each of the quadrant RNFL thickness values. The GDx number, superior/nasal, and inferior/nasal ratios were significantly different in the normal eyes when compared with the glaucomatous eyes, but not significantly different when compared with the ocular hypertension group.[18] From these results, it seems that the most effective GDx parameters for distinguishing normal eyes from glaucomatous eyes are not yet clearly defined.

Factors affecting image acquisition with scanning laser polarimetry include anterior and posterior segment pathologies.[19] Anterior segment pathologies, particularly those localized to the cornea and lens, may influence birefringence and produce spurious RNFL measurements with the GDx. The factors potentially affecting images from patients with AACG include the cornea, cataract formation or progression, and an unreactive mid-dilated pupil.

Corneal oedema occurs during AACG attacks, and after remission the cornea clears and the corneal thickness recovers if there has been no previous endothelial damage from corneal disease or a prolonged attack.[20,21] In this study, patients with previous corneal disease, corneal oedema, and opacity persisting at 1 month after remission, and attack durations exceeding 48 h were excluded. Although corneal thickness was not measured in this study, mean corneal thickness in eyes with a previous episode of AACG was not found to differ from unaffected eyes.[20,21] Reports indicate that RNFL thickness is not significantly correlated to corneal thickness when measured with the GDx, even if a significant correlation was found for the standard GDx parameters.[22]

Cataracts may form or progress after AACG. It is not known whether a cataractous lens influences the polarimetric measurements differently from a clear lens, although noncataractous human lenses have been reported as having no significant effect on RNFL thickness measurements with the GDx when comparing the phakic eyes without cataracts to pseudophakic eyes.[23]

In this study, the GDx was used 1 month after AACG remission for the following reasons: to allow for the cornea to clear so as to minimize the effects of corneal oedema on the GDx, glaukomflecken could diminish or disappear, cataract formation or progression was not prominent at that time, a BCVA $\geq$ 20/50, and finally BCVA and refraction in the AACG group did not differ from the normal control group at 1 month. Based on these considerations, the chance of spurious RNFL

measurement with the GDx was felt to be at a minimum at 1 month.

The main limitation of this study was the unreactive mid-dilated pupils in the AACG group and the undilated pupils in the normal group, although Hoh *et al*[24] reported that pharmacologic mydriasis does not significantly alter RNFL thickness when measured with scanning laser polarimetry. Variations in corneal polarization axis and corneal curvature were not measured, but had the potential to cause significant spurious results.[25] Another limitation of this study was the absence of matching for cataracts using the lens opacities classification system (LOCS score)[26] grading.

In glaucoma, RNFL was more susceptible to loss in the superior and inferior regions than in the nasal and temporal regions.[8] The results of this study indicate that there are significant differences in standard GDx parameters including the GDx number, superior ratio, inferior ratio, superior/nasal ratio, maximum modulation, and ellipse modulation when normal and AACG eyes are compared using the GDx. These significant differences suggest that early RNFL damage from short-duration (<48 h), very high IOP AACG can be detected with these parameters using GDx.

Maximum modulation, ellipse modulation, and the inferior ratio had the highest diagnostic power in this study, and since the two modulation parameters were designed to capture the difference between the thickest and thinnest areas of the RNFL,[6] they may capture features of the RNFL that reflect relatively early loss of RNFL in AACG. The inferior ratio parameter results in this study may indicate that the RNFL was more susceptible to loss in the inferior regions than in the superior region in AACG, although no significant difference was found for the thickness parameter of the inferior average. The ratio parameters including inferior ratio, superior ratio, and the superior/nasal ratio were found to be more sensitive than the superior average and inferior average thickness parameters. Another significant difference noted in this study was the GDx number, which is obtained from a trained neural network that assigns a number from 0 to 100. With a higher number, the glaucoma is more severe. This result suggests that the GDx number is able to diagnose early damage from AACG with some sensitivity.

No significant differences were found for RNFL thickness parameters including the average thickness, ellipse average, superior, inferior, temporal, and nasal averages. The GDx may be limited in its ability to identify early glaucomatous change in RNFL thickness following AACG using these thickness parameters. On the other hand, the negative findings may be because of a lack of power in the relatively small sample sizes in this study, and because patients with significant corneal oedema were excluded, it is likely that patients with AACG in this study had less severe attacks.

In conclusion, there appear to be no significant changes in RNFL thickness parameters including the average thickness, ellipse average, inferior, superior, nasal, and temporal regions in patients after short-duration AACG attacks when compared to normal subjects using the GDx. Some standard GDx parameters showed significant differences, which in addition to automated perimetry may prove useful for the diagnosis and follow-up of AACG, although it is unclear whether anterior segment changes after AACG can influence RNFL measurement with the GDx.

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