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Discrimination between normal and early glaucomatous eyes with scanning laser polarimeter with fixed and variable corneal compensator settings

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PURPOSE. To evaluate the ability of scanning laser polarimetry (SLP) with a fixed corneal polarization compensator (GDx-FCC Nerve Fiber Analyzer) compared to one with a variable one (GDx-VCC) in the discrimination between healthy and early glaucomatous eyes.
METHODS. Forty patients with early glaucomatous visual field defects, having a mean deviation of 3.1±1.6 dB and a pattern standard deviation of 3.1±0.9 dB, and 40 controls underwent both GDx-FCC and GDx-VCC. One eye per patient was considered. The cut-off point, taken as the value dividing healthy from glaucomatous eyes with highest probability, was determined for each GDx parameter. Linear discriminant functions (LDFs) were separately developed for GDx-FCC and GDx-VCC parameters. Sensitivity, specificity, and area under the receiver operating characteristic curve (AROC) for discriminating between healthy and glaucomatous eyes were calculated for each GDx parameter, both according to the GDx normative database and after the selection of new cut-off points, and for the LDFs.
RESULTS. All software-provided parameters showed low sensitivity and high specificity. The selection of new cut-off points improved the performance of all GDx parameters: VCC parameters performed better than FCC parameters; the largest AROCs were associated with the superior/nasal ratio for the GDx-FCC (0.86) and with the Number for the GDx-VCC (0.87). The LDFs provided an AROC of 0.89 with both the GDx-FCC and the GDx-VCC parameters.
CONCLUSIONS. The GDx-VCC showed a higher ability in the early diagnosis of glaucoma when compared with the GDx-FCC. The individuation of the right cut-off point of selected parameters with both GDx settings performed better than the software-provided parameters, and comparably to the GDx parameters-based LDFs. (Eur J Ophthalmol 2005; 15:468-76)

KEY WORDS. Early primary open-angle glaucoma, Scanning laser polarimetry, Fixed corneal compensator, Variable corneal compensator, Sensitivity, Specificity

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INTRODUCTION

Glaucoma is a progressive optic neuropathy characterized by the loss of retinal ganglion cells, which causes typical morphologic changes of the optic disc and peripapillary retinal nerve fiber layer (RNFL), and corresponding visual field (VF) defects.

The assessment of the peripapillary RNFL is considered to be important in the early diagnosis of glaucoma. In some cases, the earliest detectable glaucoma damage is seen as localized RNFL alterations (1-4).

Scanning laser polarimetry (SLP) is a noninvasive, objective, and reproducible method, designed to evaluate the RNFL thickness in vivo (5). The technique involves measuring the phase shift, otherwise known as retardation, of a polarized light passing through a birefringent

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medium, such as the RNFL (6). The retardation appears to be linearly correlated to the RNFL thickness (7).

Studies have shown that the SLP RNFL thickness measurements appear to be significantly lower in glaucomatous (6) and ocular hypertensive (8) when compared to healthy eyes, although considerable overlapping exists within these groups (9).

Since other ocular birefringent structures exist, such as the macular Henle fiber layer (10), the lens, and the cornea (11), the accuracy of the RNFL measurement taken with the SLP depends on the ability to extrapolate the RNFL birefringence from the total retardance (12).

The GDx Nerve Fiber Analyzer, one of the commercial versions of SLP, utilizes a fixed corneal compensator (FCC) in which the principle is based on the assumption that all subjects have similar anterior segment birefringence (ASB). Its performance, however, is limited, which is due to the marked interindividual variability of the ASB magnitude (M) and axis (A) found in the population (12, 13).

The newly available GDx version, designed to obtain an individualized ASB compensation, is equipped with a variable corneal compensator (VCC), which evaluates and subtracts the ASB from the total retardation measurement at the macula (14).

Current studies have shown that the VCC setting can improve the ability of GDx in discriminating between healthy and glaucomatous eyes (14-16).

The purpose of this study was to compare the diagnostic ability of the GDx Nerve Fiber Analyzer, equipped with a FCC, with that of the new commercial GDx version, the GDx-VCC, in cases of early to moderate glaucoma. The most discriminating parameters for the two settings and the performance of a linear discriminant function (LDF) based on the GDx parameters were also studied.

METHODS

Forty consecutive patients with early to moderate primary open-angle glaucoma (POAG) and 40 controls were considered.

After obtaining informed consent, all subjects underwent an ophthalmologic examination including best-corrected visual acuity (BCVA) evaluation, slit-lamp examination, Goldmann applanation tonometry, gonioscopy, and fundus biomicroscopy, followed by standard achromatic perimetry (SAP), GDx-FCC, and GDx-VCC, all within a period of 3 months.

One eye per patient was selected without bias for the analysis, with the exception of cases in which only one eye met our inclusion criteria.

The inclusion criteria included BCVA ≥0.8; open anterior chamber angle; absence of ocular pathologies other than glaucoma, mild nuclear sclerosis, and rare drusen; and good SLP image quality.

The exclusion criteria included ametropia >±5diopters; pupils <3 mm in diameter; anterior angle alterations; presence of secondary causes of glaucoma; advanced glaucomatous VF defects; papillary anomalies; large peripapillary atrophy; previous intraocular surgery, diabetes mellitus, or neurologic disorders; and medications altering SAP results.

Controls were screened to ensure they all had normal intraocular pressure (IOP) and normal SAP results, and to exclude glaucoma family history or any ocular pathology.

The classification of glaucoma was given to those patients who had both an IOP >21 mmHg before treatment and reproducible SAP glaucomatous defects.

SAP testing was performed using the Humphrey Field Analyzer (HFA) II 750 (Carl Zeiss Meditec Inc., Dublin, CA)

TABLE I - PATIENT DEMOGRAPHICS, HUMPHREY FIELD ANALYZER DATA, AND GDX FCC RESIDUAL ANTERIOR SEGMENT BIREFRINGENCE MAGNITUDE (ASBM) AND AXIS (ASBA)

Groups	Age, yr	MD, dB	PSD, dB	ASBM, nm	ASBA, °
Controls, n = 40	57±7.8 (38-73)	-0.6±1.0	1.6±0.2	16.1±23.7 (0-71)	86±19 nu (40 nu–60 nd)
POAG, n = 40	65.8±8.5 (39-76)	-3.1±1.6	3.1±0.9	11.1±18.2 (0-67)	86±13 nu (68 nu–70 nd)
p value*	<0.02	<0.001	<0.001	NS	NS

Values are mean ± standard deviation (range)
*Mann-Whitney test
MD = Mean deviation; PSD = Pattern standard deviation; nu = Nasally upward; nd = Nasally downward; POAG = Primary open-angle glaucoma; NS = Not significant

30-2 test (17), with Swedish Interactive Threshold Algorithm (SITA) standard strategy.

SAP tests were classified as glaucomatous according to the Anderson criteria (18), in which at least one of the following was present:

1) A cluster of ≥3 points in the pattern deviation probability plot, located in areas that are typical of glaucoma, having a probability level of <5%, with at least one point having a probability level of <1%; none of the points could be edge-points unless they were located immediately above or below the nasal horizontal meridian;
2) PSD probability level of<5%;
3) GHT outside normal limits.

Reliable criteria for HFA tests included false-positive and false-negative responses of <33% and fixation losses of <20%.

Glaucomatous VF defects were classified using the Glaucoma Staging System (19), which classifies severity in five stages. Stages 0, 1, and 2 – i.e., SAP tests having a mean deviation (MD) of better than -9.0 dB and a pattern standard deviation (PSD) of <8.0 dB – were included.

Peripapillary images of all eyes were taken using both GDx-FCC (Nerve Fiber Analyzer, version 2.0.09, Laser Diagnostic Technologies, Inc., San Diego, CA) and GDx-VCC (software version 5.1.0, Laser Diagnostic Technologies, Inc. San Diego, CA).

General details regarding the GDx settings have already been described elsewhere (6, 14).

Residual anterior segment birefringence magnitude (ASBM) and anterior segment birefringence axis (ASBA) were calculated for the images of the macula taken with GDx-FCC, utilizing the Zhou and Weinreb method (14).

The following parameters were considered:

1) For the GDx-FCC—the 14 parameters listed in the "symmetry analysis" printout, and the deviation from normal values (measured in microns) of the mean RNFL from each of the four peripapillary quadrants;
2) For the GDx-VCC—the 16 parameters listed in the "extended parameter table" printout and the number of points at each probability level located in the peripapillary RNFL.

According to the GDx-normative database, values labeled as outside normal limits and the Number >70 (as suggested by the manufacturer) were considered abnormal.

The cut-off point, which can be defined as the numerical value that divides healthy from glaucomatous eyes with the highest probability, was determined for each GDx parameter.

TABLE II - MEAN VALUES AND STANDARD DEVIATIONS OF THE GDX PARAMETERS IN NORMAL AND GLAUCOMATOUS EYES

Parameters	Controls	POAG	p*
GDx FCC			
The number	15.3±8.4	34.2±15.6	<0.001
Symmetry	0.97±0.1	0.97±0.1	NS
Superior ratio	2.28±0.3	1.84±0.3	<0.001
Inferior ratio	2.38±0.4	1.92±0.4	<0.001
Superior/nasal	2.13±0.3	1.71±0.2	<0.001
Maximum modulation	1.48±0.3	1.01±0.3	<0.001
Superior maximum	90.8±14.3	85.2±15.9	NS
Inferior maximum	93.6±14.2	88.8±17.7	NS
Ellipse modulation	2.7±0.7	1.9±0.7	<0.001
Thickness average	63.9±9.3	65.6±11.9	NS
Ellipse average	68.1±9.0	67.8±12.4	NS
Superior average	73.8±10.9	70.9±13.8	NS
Inferior average	83.6±10.6	80.0±15.3	NS
Superior integral	0.205±0.0	0.201±0.0	NS
Superior quadrant	-4.76±13.4	-7.15±13.8	NS
Inferior quadrant	2.63±13.7	-3.38±16.3	NS
Nasal quadrant	-1.63±8.6	5.35±10.3	<0.01
Temporal quadrant	-1.44±8.5	5.8±9.3	<0.001
GDxVCC			
The number (NFI)	17.6±6.7†	38.4±17.0	<0.001
No. of points <5%	15.8±19.2	33.1±24.4	<0.001
No. of points <1%	3±2	10±8	<0.001
No. of points <0.5%	1.6±0.9	13.5±12	<0.001
TSNIT average	57.0±5.4‡	50.8±8.4‡	<0.001
Superior average	70.2±7.7	58.1±10.2‡	<0.001
Inferior average	63.6±6.3‡	55.9±10.3‡	<0.001
TSNIT SD	22.7±2.8	16.3±5.0	<0.001
Intereye symmetry	0.88±0.1	0.61±0.4	<0.001
Symmetry	1.0±0.1	0.98±0.2	NS
Superior ratio	2.9±0.7†	2.0±0.8	<0.001
Inferior ratio	2.9±0.7†	2.1±0.8	<0.001
Superior/nasal	2.4±0.7	2.0±0.7†	<0.01
Maximum modulation	2.2±0.7†	1.3±0.8†	<0.001
Superior maximum	81.3±10.8‡	69.2±13.9‡	<0.001
Inferior maximum	81.5±9.9‡	71.9±15.4‡	<0.01
Ellipse modulation	3.8±1.1†	2.4±1.1†	<0.001
Normalized sup area	0.144±0.0	0.128±0.1	<0.001
Normalized inf area	0.144±0.0	0.113±0.0	<0.001

*Mann-Whitney test
†Significantly higher than the correspondent FCC parameter
‡Significantly lower than the correspondent FCC parameter
POAG= Primary open-angle glaucoma; NS = Not significant

TABLE III - SPECIFICITY (SP), SENSITIVITY (SE), AND AREA UNDER THE RECEIVER OPERATING CHARACTERISTIC CURVE (AROC) OF THE GDX PARAMETERS ACCORDING TO THE NORMATIVE DATABASE

Parameters	SP, %	SE, %	AROC
GDx FCC			
The number	100	5	0.52
Symmetry	100	0	0
Superior ratio	100	0	0
Inferior ratio	100	5	0.52
Superior/nasal	97.6	20	0.59
Maximum modulation	100	10	0.55
Superior maximum	97.6	7.5	0.53
Inferior maximum	100	5	0.53
Ellipse modulation	100	7.5	0.54
Thickness average	100	0	0
Ellipse average	100	0	0
Superior average	97.6	7.5	0.53
Inferior average	100	2.5	0.51
Superior integral	95.1	7.5	0.51
1quadrant <5%	97.6	7.5	0.53
GDx VCC			
The number (NFI)	100	7.5	0.54
No. of points <5%	24.4	85	0.55
No. of points <1%	78	60	0.69
No. of points <0.5%	87.8	50	0.69
TSNIT average	100	30	0.65*
Superior average	100	35	0.67*
Inferior average	100	25	0.62*
TSNIT SD	100	47.5	0.74
Intereye symmetry	95.1	57.5	0.76
Symmetry	100	0	0
Superior ratio	100	15	0.57*
Inferior ratio	100	12.5	0.56
Superior/nasal	100	0	0†
Maxima modulation	100	12.5	0.56
Superior maximum	95.1	30	0.63
Inferior maximum	100	27.5	0.64
Ellipse modulation	100	0	0†
Normalized sup area	97.6	32.5	0.65
Normalized inf area	100	30	0.65

*Significantly higher than the correspondent FCC parameter (Hanley-McNeil method)
†Significantly lower than the correspondent FCC parameter (Hanley-McNeil method)

Logistic multiple regressions were used to evaluate how well the GDx-FCC and GDx-VCC parameters could detect glaucoma.

All GDx-FCC and GDx-VCC measurements were separately entered in a stepwise discriminant analysis instructed to consider parameters predicting glaucoma with $p<0.05$ to develop a Fisher's LDF.

Sensitivity, specificity, and area under the receiver operating characteristic curve (AROC) for discriminating between healthy and glaucomatous eyes were calculated for each GDx parameter, both according to the GDx-normative database and after the selection of new cut-off points, and for the LDFs. A repeatable abnormal SAP test was considered as the gold standard (20).

Differences in the GDx parameters between healthy and glaucomatous eyes were evaluated using the Mann-Whitney test.

Differences between AROCs were evaluated using the Hanley-McNeil method (21).

Statistical analysis was performed using SPSS 8.0 for Windows (SPSS Inc., Chicago, IL).

A p value of <0.05 was considered statistically significant.

RESULTS

The controls were significantly younger than glaucomatous patients (Tab. I).

Significant differences were found between control and POAG eyes for both MD and PSD values, whereas no differences were noticed in the GDx-FCC residual ASBM and ASBA (Tab. I).

When GDx-FCC measurements between normal and POAG eyes were compared, significant differences were found in the Number; all ratio/modulation parameters except symmetry, and the mean RNFL thickness deviation from normal values for the nasal and temporal quadrants (Tab. II).

Significant differences were found between the control and POAG groups for all GDx-VCC parameters, except symmetry (Tab. II).

In comparison to the FCC values obtained, all GDx-VCC mean thickness values were significantly lower, whereas all ratio/modulation values were significantly higher (except the superior/nasal ratio) (Tab. II).

When the GDx-normative database was used (Tab. III), the parameters of both settings generally showed a low

sensitivity and a high specificity in the diagnosis of glaucoma. The best AROCs were obtained with the two exclusive VCC setting parameters: TSNIT SD (0.74) and intereye symmetry (0.76).

The selection of new cut-off points improved the diagnostic ability of all GDx parameters when compared to the results obtained using the GDx-normative database with both GDx settings (Tab. IV). The AROCs for the FCC parameters ranged from 0.53 (for symmetry) to 0.86 (for superior/nasal ratio). The AROCs for the VCC parameters ranged from 0.56 (for symmetry) to 0.87 (for the Number, with cut-off set at 23).

In comparison to the GDx-FCC, the VCC setting showed a significantly higher diagnostic ability in four of the five thickness parameters, whereas a significant decrease was observed in the AROC of the superior/nasal ratio (Tab. IV).

The GDx-FCC and GDx-VCC parameters that predict glaucoma at $p<0.05$ according to the logistic multiple regressions analysis are listed in Table V.

The LDFs generated by the discriminant analysis for both the GDx-FCC and GDx-VCC parameters are listed in Table VI. No statistically significant differences were found between the AROCs provided by the two LDFs (Hanley-McNeil method, not significant).

TABLE IV - BEST RELATION SPECIFICITY (SP)/SENSITIVITY (SE) AND AREA UNDER THE RECEIVER OPERATING CHARACTERISTIC CURVE (AROC) OF THE GDX PARAMETERS WITH THE SELECTION OF NEW CUT-OFF POINTS

Parameters	SP, %	SE, %	AROC	Cut-off point‡
GDx FCC				
The number	80.5	67.5	0.76	>23
Symmetry	61	52.5	0.53	<0.94
Superior ratio	87.8	77.5	0.83	<1.93
Inferior ratio	78	75	0.79	<2.03
Superior/nasal	85.4	80	0.86	<1.88
Maximum modulation	78	85	0.82	<1.21
Superior maximum	43.9	75	0.58	<95
Inferior maximum	75.6	50	0.59	<86
Ellipse modulation	82.9	75	0.8	<2.13
Thickness average	53.6	45	0.55	<63
Ellipse average	65.8	47.5	0.57	<64
Superior average	82.9	37.5	0.61	<63
Inferior average	78	50	0.64	<76
Superior integral	51.2	67.5	0.55	<0.2
Superior quadrant	53.6	55	0.55	<-6
Inferior quadrant	68.3	57.5	0.63	<-3
Nasal quadrant	58.5	60	0.68	>1
Temporal quadrant	58.5	65	0.64	>0
GDx VCC				
The number (NFI)	82.9	85	0.87*	>23
No. of points <5%	61	77.5	0.75	>9
No. of points<1%	78	60	0.67	>0
No. of points <0.5%	87.8	50	0.67	>0
TSNIT average	87.8	55	0.71*	<51.1
Superior average	78	80	0.78*	<64.1
Inferior average	82.9	67.5	0.76	<58.3
TSNIT SD	90.2	77.5	0.85	<18.7
Intereye symmetry	85.4	75	0.84	<0.85
Symmetry	56.1	55	0.56	<0.97
Superior ratio	65.8	90	0.77	<2.64
Inferior ratio	85.4	85	0.85	<2.51
Superior/nasal	63.4	70	0.65†	<2.15
Maximum modulation	82.9	80	0.84	<1.64
Superior maximum	82.9	72.5	0.78*	<73.3
Inferior maximum	70.7	62.5	0.69	<75.3
Ellipse modulation	85.4	75	0.81	<2.6
Normalized sup area	85.4	75	0.8	<0.125
Normalized inf area	95.1	62.5	0.78	<0.120

*Significantly higher than the correspondent FCC parameter (Hanley-McNeil method)
†Significantly lower than the correspondent FCC parameter (Hanley-McNeil method)
‡The values indicate what was considered abnormal

DISCUSSION

SLP's ability to discriminate between normal and glaucomatous eyes is controversial (6, 9, 22-25). The high data variability evident in literature can be due to differences in the population, sample size, glaucoma severity, GDx software version used, and GDx image quality obtained, as well as accuracy of the ASB compensation (22-30).

Furthermore, a standard procedure for interpreting GDx measurements has yet to be established.

The GDx software-provided parameters have shown a limited sensitivity (26-28, 31). The Number is considered to be the best single GDx parameter, at cut-off levels ranging between 17 and 39 (26, 28, 29, 32). Other methods, such as the identification of new cut-off points (24), the combination of various GDx measurements in an LDF (22, 24, 27, 31), and the Fourier analysis of the RNFL thickness measurements (25, 33), have shown to improve the GDx performances.

Several studies, however, have demonstrated a higher GDx sensitivity in patients with moderate to severe, as

TABLE V - RESULTS OF THE LOGISTIC MULTIPLE REGRESSION ANALYSIS APPLIED TO THE GDX PARAMETERS FOR PREDICTING GLAUCOMA

Parameters	p
GDx FCC	
The number	<0.05
Symmetry	NS
Superior ratio	<0.05
Inferior ratio	<0.05
Superior/nasal	<0.05
Maximum modulation	<0.05
Superior maximum	NS
Inferior maximum	NS
Ellipse modulation	<0.05
Thickness average	NS
Ellipse average	NS
Superior average	NS
Inferior average	NS
Superior integral	NS
Superior quadrant	NS
Inferior quadrant	NS
Nasal quadrant	<0.05
Temporal quadrant	<0.05
GDx VCC	
The number (NFI)	<0.05
No. of points <5%	<0.05
No. of points <1%	<0.05
No. of points <0.5%	<0.05
TSNIT average	<0.05
Superior average	<0.05
Inferior average	<0.05
TSNIT SD	<0.05
Intereye symmetry	<0.05
Symmetry	NS
Superior ratio	<0.05
Inferior ratio	<0.05
Superior/nasal	<0.05
Maximum modulation	<0.05
Superior maximum	<0.05
Inferior maximum	<0.05
Ellipse modulation	<0.05
Normalized sup area	<0.05
Normalized inf area	<0.05

NS = Not significant

opposed to early VF damages (25), and for diffuse, rather than localized, RNFL defects (22). Moreover, an individual ASB correction improved the GDx diagnostic ability (14-16, 34).

The aim of the present study was 1) to compare the performances provided by the GDx-FCC and the new GDx-VCC versions, in order to better understand the advantages offered in the latter; and 2) to provide information that could be useful in day-to-day clinical practice for colleagues utilizing the GDx technology, as well as for those who only own the GDx-FCC version and do not have access to the GDx-VCC.

In the analysis of our data, the controls appeared to be significantly younger than the POAG patients (Tab. I). Considering how age differences between healthy and glaucomatous subjects can affect the data analysis, it is important to note the following: first, as reported by other authors (35), the RNFL age-related loss is much smaller than that induced by glaucoma; secondly, in the cohort of our patients, “age” parameter was not considered as sufficiently discriminant in the LDFs; and finally, the age differences between controls and glaucomatous patients could have theoretically affected the ROC analysis, in that it could have increased the specificity, and consequently the area under the ROC curve.

The literature has shown that GDx-FCC can properly compensate ASB in fewer than 60 to 70% of cases (12). In our study, 60% of controls and 57.5% of the POAG eyes showed an inadequate GDx-FCC ASB compensation, which can be verified by the presence of a “double hump-like” pattern in the macular scans (34).

As already reported (6, 23), the differences in the GDx parameters between healthy and glaucomatous eyes were greater with the GDx-VCC than with the GDx-FCC. All GDx-VCC mean thickness values were significantly lower than those taken with the GDx-FCC for both the normal and POAG groups. Moreover, all FCC thickness parameters failed to differentiate between healthy and POAG eyes (Tab. II).

When the GDx-normative database was used as a reference, the individual FCC and VCC parameters generally showed a low sensitivity and high specificity (Tab. III). The largest AROCs were associated with the TSNIT SD (0.74) and the intereye symmetry parameters (0.76), which are both exclusively found in the VCC setting.

The resulting high specificity and low sensitivity using the normative database of the two instruments could be due to the fact that our patients had early to moderate

TABLE VI - SENSITIVITY, SPECIFICITY, AND AREAS UNDER THE RECEIVER OPERATING CHARACTERISTIC (AROC) CURVE ACCORDING TO THE LINEAR DISCRIMINANT FUNCTIONS

	Linear discriminant function	Cut-off	SE, %	SP, %	AROC
GDx FCC	y = +16.02 - (2.06 x inferior ratio) - (6.04 x superior/nasal)	>0.34	85.0	92.7	0.89
GDx VCC	y = -0.7 + (0.12 x the number) - (1.43 x maximum modulation)	>0.01	87.5	90.2	0.89

SE = Sensitivity; SP = Specificity

glaucoma, and thus the GDx technology could have shown some difficulty in some cases in detecting very early RNFL damage. The better performance observed in the new GDx VCC, in comparison to the former GDx FCC, also could be related to the use of a completely new normative database.

In agreement with previous reports (24), the selection of new cut-off points greatly enhanced the diagnostic ability of all GDx parameters.

The single GDx-VCC parameters generally performed better than FCC parameter, with exception to the superior/nasal ratio. This difference was greater for thickness parameters as opposed to ratio-modulation parameters (Tab. IV).

The best AROCs after the selection of new cut-off points were respectively obtained with the GDx-FCC superior/nasal ratio (0.86) and with the GDx-VCC Number (0.87), both showing a comparable diagnostic ability.

In agreement with other authors (36), the Number yielded acceptable sensitivity and specificity at a critical value of 23 with both GDx settings, showing a higher performance in the VCC setting.

According to the logistic regression analysis (Tab. V), the VCC setting gave rise to more parameters that were able to discriminate between normal and glaucomatous eyes (18 out of 19 of the GDx-VCC parameters versus 8 out of 18 GDx-FCC-parameters).

The GDx parameters-based LDFs for both settings (Tab. VI) performed better than any of the single GDx-software-provided parameters, which confirms results obtained in previous findings (23, 24, 26, 27, 31), and comparably to the identification of new cut-off points.

As reported in other studies (16, 26-28, 37), a greater number of VCC parameters were able to discriminate between normal and glaucomatous eyes when compared to the FCC parameters (Tabs. III–V). This is probably due to a better ASB compensation (14-16), the use of a new normative database, and to the utilization of new parameters (9, 38), even if, as already noticed (39), none of the new parameters performed better than the Number.

The lower performance provided by the GDx-FCC thickness parameters is thought to be due to the normal range width used in the GDx-FCC RNFL thickness measurements (40) and the overall increase in retardance caused by an incorrect ASB compensation (41). This problem can be overcome with the use of ratio/modulation parameters (12).

Finally, the GDx performances found in our study were comparable to those reported by other authors who have studied patients with early to moderate glaucoma. These authors include Weinreb et al (23), who consider a GDx-FCC parameter-based LDF, and Colen et al (39), who report studies using a VCC setting.

In conclusion, the GDx-VCC showed a higher ability in the diagnosis of early glaucomatous damage when compared to the GDx Nerve Fiber Analyzer equipped with an FCC. In addition, ophthalmologists who utilize GDx technology, especially those who have already been utilizing the GDx-FCC version, are invited to use new cut-off points (those provided in this study, others provided in literature, or personal cut-off points), seeing that the utilization of the normative database provided by both GDx-FCC and GDx-VCC showed a very low sensitivity, especially when a population with early to moderate glaucomatous VF defects is analyzed. It is also important to note that the generation of GDx parameters-based LDFs with both GDx settings did not significantly increase the diagnostic ability provided by the individuation of right cut-off points for selected parameters.

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