

Algorithm for Interpreting the Results of Frequency Doubling Perimetry

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- **PURPOSE:** To evaluate an algorithm for the identification of glaucomatous visual field defects with the screening mode of frequency doubling technology.
- **METHODS:** Screening-mode frequency doubling technology and Swedish interactive threshold algorithm perimetry were performed on 137 of 150 consecutive patients referred to a glaucoma specialist. We created an algorithm for the frequency doubling technology that gave increased importance to both more severe defects and defects closer to fixation. These values were then compared with the results

See also pp. 314–322, 328–333, and 376–378.

of the Swedish interactive threshold algorithm visual fields evaluated by the glaucoma hemifield test, two masked glaucoma specialists, and a published definition of glaucomatous damage to determine sensitivity and specificity of the frequency doubling technology screening mode for detecting glaucoma.

- **RESULTS:** The frequency doubling technology score obtained with our algorithm had a sensitivity of 80% or more and specificity of 93% or more irrespective of the criteria for defining glaucoma. Sensitivity increased to 95% in detecting moderate or severe field loss without a compromise in specificity. All subjects with normal visual fields completed the frequency doubling technology examination within 90 seconds. In most cases, eyes were abnormal if they had two peripheral defects or one central defect.

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- **CONCLUSIONS:** Our frequency doubling technology algorithm had both high sensitivity and high specificity in detecting glaucomatous visual field defects, allowing for bilateral screening in less than 5 minutes. (*Am J Ophthalmol* 2000;129:323–327. © 2000 by Elsevier Science Inc. All rights reserved.)

GLAUCOMA IS THE SECOND LEADING CAUSE OF blindness.^{1–3} Chronic open-angle glaucoma can be identified at an early stage only through screening because it is asymptomatic until significant damage has occurred. In fact, prevalence studies in developed countries have found that approximately 50% of subjects are unaware that they have glaucoma.³ Because intraocular pressure lowering therapy can retard the rate of visual field loss, early detection is crucial.

Screening for glaucoma is a daunting problem. Patients need to be screened and appropriately referred if glaucomatous optic nerve damage is to be avoided. Traditional approaches to glaucoma screening, including history taking, tonometry, evaluation of the optic nerve head, assessment of the nerve fiber layer, and tests of peripheral vision, all suffer marked limitations.^{3–13} Rapid tests of the peripheral field have been developed for glaucoma screening, including the Damato campimeter^{14–16} and other screening algorithms on larger perimeters, such as short-wavelength automated perimetry,^{17–20} but none of these has been found to be ideal for screening populations at risk.

An inexpensive, accurate screening device that is easily administered and interpreted is needed. The frequency doubling technology instrument weighs 19 pounds and is easy for both the technician and patient to use. Quigley²¹ recently reported that the screening mode of frequency doubling technology had a sensitivity of 91% and a specificity of 94% with an abnormal glaucoma hemifield test on the Humphrey C-24-2 full-threshold algorithm used as the definition of glaucoma. There is no standard for defining a frequency doubling technology test as abnormal. We present our results with an empiric algorithm for analyzing the frequency doubling technology to assist in determining which screened individuals have an abnormal test.

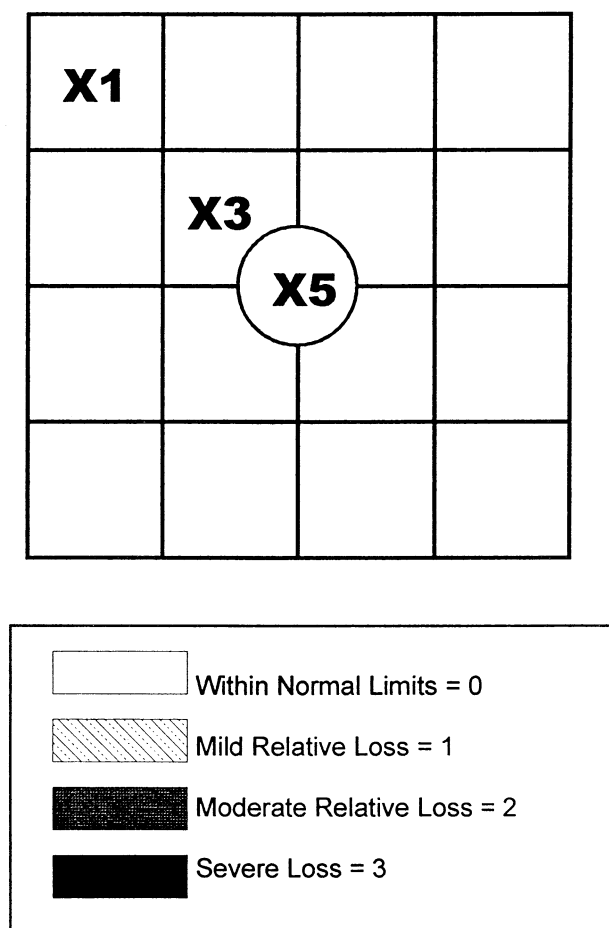


FIGURE 1. Schematic diagram demonstrating how values are assigned in our frequency doubling technology grading scale. Values closer to fixation are scored higher than those further from fixation. Also, denser defects are given higher scores.

METHODS

WE STUDIED 137 OF 150 CONSECUTIVE PATIENTS REFERRED to a glaucoma specialist. Patients were excluded if they were less than 18 years of age (two patients) or if best-corrected visual acuity was less than 20/80 (11 patients). All patients were evaluated by a trained technician who measured visual acuity and administered the screening mode of frequency doubling technology (Welch Allyn in alliance with Humphrey Instruments, Skaneateles, New York) (right eye first). Swedish interactive threshold algorithm (Humphrey Instruments, Dublin, California) perimetry was then performed. We included only the right eye if both eyes were tested.

A grading scheme was created before any knowledge of frequency doubling technology results. We placed increased weight on locations closer to central fixation as well as those with denser visual field defects. The frequency doubling technology screening algorithm tests a

grid of 17 spots, 12 peripheral locations, four additional spots closer to fixation, and one test of fixation (Figure 1). Missed points are retested and bracketed for severity of defect. The defect depth is scored relative to a normative database and printed out by means of a gray scale.

We assumed that peripheral points were more likely to be falsely positive and therefore gave them less weight. We also surmised that denser defects were more likely to represent real abnormalities. On this basis, we assigned a value of 1 to the outside 12 points, a value of 3 to the inner four loci, and a value of 5 to fixation (Figure 1). Each point was graded from 0 to 3 on the basis of the depth of the defect. Normal areas were assigned a value of 0, mild defects were graded as 1, moderate as 2, and severe as 3 on the basis of the frequency doubling technology gray-scale printout. This score of 0 through 3 was multiplied by the weighting factor of 1, 3, or 5. For example, if a single outside box was black on the gray scale, it was allocated one point (value of outside box) times three points (value of severe defect on gray scale), or three total points. A final score was determined by summing all abnormal points with scores ranging from zero for a completely normal test to 87 for a test in which all points were missed at the maximum threshold.

All patients had full-threshold testing by means of Swedish interactive threshold algorithm on the central 24 degrees of the Humphrey visual field analyzer. We employed three distinct methods to classify visual fields. First, we classified visual fields as normal, mildly damaged, moderately damaged, and severely damaged on the basis of the number of abnormal points, the depth of the scotomas, and whether the central 5 degrees of the field were involved.²² Second, an abnormal glaucoma hemifield test defined an abnormal field. We excluded borderline or high sensitivity results from this analysis. Finally, two glaucoma specialists analyzed the visual fields in a masked fashion. They classified each visual field as normal, abnormal, or probably abnormal. The empiric algorithm as well as alternative approaches to interpreting the frequency doubling technology findings were then analyzed to determine the sensitivity and specificity of this test by means of the different visual field-derived definitions of glaucoma.

Between-group differences were analyzed with a *t* test. Cuzick's nonparametric test for trend (an extension of the Wilcoxon rank-sum test) was used to compare differences in patient characteristics relative to visual field severity.²³

RESULTS

THE 137 PATIENTS HAD A MEAN (\pm SD) AGE OF 65 ± 13.9 years, with a range from 22 to 91 years (Table 1). Older individuals had more severe Humphrey visual field defects (Table 2). The mean age of individuals who had an abnormal glaucoma hemifield test was 67.7 vs 62.0 for normal subjects, a statistically significant difference ($P =$

TABLE 1. Demographics of Study Participants

Age (yrs)	
Mean (SD)	65.1 (13.9)
Range	22–91
Sex (no. [%] male)	64 (46.7)
Race (no. [%] white)	102 (74.4)
Intraocular pressure (mm Hg), mean (SD)	17.2 (6.6)

TABLE 2. Demographics of Study Participants Stratified by Humphrey Visual Field Defect Severity²²

	Severity			
	None	Mild	Moderate	Severe
Mean age (yrs)*	62.2	65.4	65.1	69.7
Mean intraocular pressure (mm Hg)	18.0	15.0	16.1	17.9
Mean cup:disk ratio*	0.5	0.7	0.9	0.9

**P* < .01, nonparametric test for trend.

TABLE 3. FDT Score by Severity Level

FDT Score	Severity (No.)			
	No Defect (N = 60)	Mild (N = 25)	Moderate (N = 14)	Severe (N = 38)
0	55	9	1	1
1–2	2	5	3	0
3–25	3	8	9	8
26–50	0	3	1	13
51–87	0	0	0	16

FDT = frequency doubling technology.

.02). Individuals with more severe field loss also had larger mean cup:disk ratios (*P* < .01, linear test for trend). The treated intraocular pressure was similar for all groups. Scores obtained with the algorithm ranged from 0 to 87, with increasingly high scores found in individuals with more severe field loss as defined by the criteria outlined by Hodapp and associates²² (Table 3).

More individuals were classified as abnormal with the glaucoma hemifield test than with either of the two other approaches (Table 4). According to the criteria described above by Hodapp and associates,²² 49% had severe visual field loss, 18% had moderate field loss, and 33% had mild field loss.

The frequency doubling technology score obtained with our algorithm correlated strongly with the mean deviation on the Humphrey visual field (Spearman rho = .74), even when individuals with a frequency doubling technology

TABLE 4. Proportion Categorized as Having Glaucoma by Each of the Three Visual Field Criteria

Criterion	No. (%)		
	Normal	Abnormal	Borderline
Published definition ²²	60 (43.8)	Mild: 25 (18.3) Moderate: 14 (10.2) Severe: 38 (27.7)	—
Glaucoma hemifield test*	53 (38.7)	69 (50.4)	3 (2.2)
Expert's review	51 (37.2)	59 (43.1)	27 (19.7)

*Four subjects (2.9%) had abnormally high sensitivity.

score of zero were excluded (Spearman rho = .67). The frequency doubling technology score achieved both high sensitivity and high specificity for glaucoma with the use of each of the three visual field criteria described above. The frequency doubling technology algorithm had a combined sensitivity greater than 80% (79.5% for the glaucoma hemifield test) and specificity greater than 90% in diagnosing glaucoma with any of the three visual field criteria (Table 5). The frequency doubling technology algorithm had a sensitivity of 96% for detecting moderate or severe visual field loss. Using two or more abnormal points as a cutoff had a sensitivity of 92% (Table 6; *P* > .2 for difference in proportion detected with the algorithm).

Individuals with more severe field loss took longer to complete the frequency doubling technology screening test (Figure 2). All individuals with normal fields by any of the visual field criteria completed the test in less than 90 seconds.

DISCUSSION

THE ALGORITHM WE CREATED FOR INTERPRETING THE frequency doubling technology had both high sensitivity and high specificity. A frequency doubling technology score of 2 or greater identified more than 80% of individuals with glaucoma as defined by a visual field defect on the Humphrey test while maintaining a specificity greater than 90%. The test was 96% sensitive at identifying individuals with moderate or severe field loss.

Our results indicate that the algorithm can be further simplified; an individual's results are abnormal if he or she has any defects in the central five locations. In addition, two or more mild defects or one moderate or severe defect in the outer 12 points also qualifies as an abnormal test.

Furthermore, the test can be stopped at 90 seconds and called abnormal without affecting its performance. No individual with normal results took that long to complete

TABLE 5. Sensitivity and Specificity of the FDT Using an FDT Score >1 to Define a Screen as Abnormal

Abnormality Criterion*	Sensitivity (%)	Specificity (%)
Mild, moderate, and severe perimetric defects ²²	80.5	95.0
Moderate and severe perimetric defects ²²	96.2	95.0
GHT outside normal limits	79.5	92.5
Expert review of field abnormal	86.4	94.1

FDT = frequency doubling technology; GHT = glaucoma hemifield test.
 *These are the Humphrey visual field criteria by which a patient was categorized as having glaucoma.

TABLE 6. Sensitivity and Specificity of the FDT Using More Than One Abnormal Point on the FDT to Define a Screen as Abnormal

Abnormality Criterion*	Sensitivity (%)	Specificity (%)
Mild, moderate, and severe perimetric defects ²²	76.6	95.0
Moderate and severe perimetric defects ²²	92.3	95.0
GHT outside normal limits	76.7	94.3
Expert review of field abnormal	83.1	94.1

FDT = frequency doubling technology; GHT = glaucoma hemifield test.
 *These are the Humphrey visual field criteria by which a patient was categorized as having glaucoma.

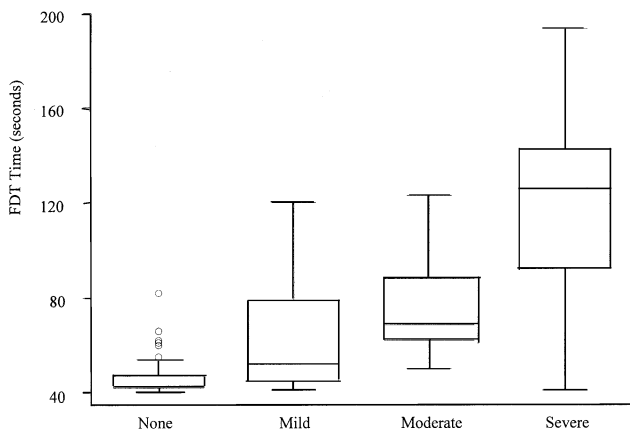


FIGURE 2. Distribution of test times in eyes with varying degrees of perimetric defects.²² No normal eyes had test times greater than 90 seconds. FDT = frequency doubling technology.

the test. This means that the maximum test time for both eyes can be reduced to 3 minutes. Allowing another 2 minutes for instruction makes this one of the fastest screening devices available for glaucoma. Stopping the test as soon as one central point or two peripheral points are identified as abnormal could further shorten the test time.

How do the screening results compare to other currently used approaches? Using an intraocular pressure greater than 21 mm Hg yields a specificity of 92%, but a sensitivity of only 47%.⁹ Higher intraocular pressure cutoffs reduce the sensitivity even further. A vertical cup:disk ratio of 0.5 or more is 89% specific, but only identifies 48% of the cases.⁹ Increasing the cutoff to 0.6 or more improves specificity to 97%, but the sensitivity drops to 24%. Tonometry and disk assessment are the mainstays of routine office-based screening today. Unfortunately, these elements of the routine eye examination miss a large proportion of individuals with glaucoma. Furthermore, disk evaluation has relatively high intraobserver variability and requires highly trained personnel. The frequency doubling technology, which uses an automated machine requiring minimal training, maintained sensitivity greater than 80% even while specificity was greater than 90%.

This study has several limitations. All subjects had been referred to a glaucoma specialist's practice. Most were either glaucoma patients or glaucoma suspects. The "normal" group likely had more individuals with the earliest forms of glaucoma than would be expected in the general population. This makes the high specificity for the test in this study population even more impressive. However, many of the subjects were experienced with the Humphrey visual field, which may have resulted in more accurate test

results on the frequency doubling technology and improved the overall performance. Finally, 49% of those with glaucomatous visual fields had severe visual field defects. This is probably a higher percentage than would be found in a population-based survey of individuals with glaucoma. This large percentage of individuals with more severe disease likely inflated the sensitivity of the frequency doubling technology. More work is needed in population-based studies to further refine the algorithm and more accurately determine the screening effectiveness of the frequency doubling technology.

Our new algorithm interprets the results of the frequency doubling technology on the basis of the location and severity of the detected defects. The algorithm performed better than just counting the number of abnormal points. We chose to weight those points in the center more than peripheral points. This is consistent with what is known about the variability in testing more peripheral locations. Our results support previous reports that the frequency doubling technology has high specificity and sensitivity at appropriate cutoffs.²⁴ In addition, although test time was not a part of our algorithm, we found that longer tests are frequently associated with visual field defects on Swedish interactive threshold algorithm perimetry. Further work is needed to establish the role of frequency doubling technology in population-based screening. Frequency doubling technology seems to perform better than current screening approaches used in routine ophthalmologic practice and might be considered as a useful adjunct to the standard eye examination.

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