

# Novel 3D computer-automated threshold Amsler grid visual field testing of scotomas in patients with glaucoma

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**PURPOSE.** *Three-dimensional (3D) computer-automated threshold Amsler grid testing was used to identify and characterize scotomas typical of glaucoma.*

**METHODS.** *The 3D test exhibits a grid on a computer screen at a preselected grayscale and angular resolution, and allows patients to trace those areas on the grid that are missing in their visual field using a touch screen. Eleven eyes in patients with an established diagnosis of glaucoma were examined according to the above protocol. A total of 23 eyes from normal subjects were used as controls. The 5-minute test required that patients repeatedly outline scotomas on a touch screen with varied displays of contrast while maintaining their gaze on a central fixation marker. A 3D depiction of the visual field defects was then obtained that was further characterized by the location, shape, extent, depth, and slope of the scotomas.*

**RESULTS.** *In this pilot study, the 3D depiction of visual field loss demonstrated paracentral, superior and inferior altitudinal, and nasal step defects consistent with glaucomatous damage. The 3D depiction showed a shape, extent, depth, and slope that are consistent with the severity of damage.*

**CONCLUSIONS.** *The 3D test identified and characterized scotomas typical of glaucoma. The test provides several advantages over conventional perimetry including additional information through 3D depiction of scotomas with the addition of contrast sensitivity and a higher angular/spatial resolution. Improved patient compliance and reliability through shorter testing time and potential interactive accessibility and distribution over the Internet further characterize the test. (Eur J Ophthalmol 2009; 19 : )*

**KEY WORDS.** *Glaucoma, Glaucomatous visual field defects, Perimetry, Screening, Visual field*

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## INTRODUCTION

Glaucoma is the second leading treatable cause of blindness in the United States, and one of the top three causes of blindness worldwide. It is estimated that 60.5 million people worldwide will have glaucoma in 2010, with 8.4 million with bilateral blindness (1, 2). In the United States in 2010, an estimated 2.79 million people will have primary open angle glaucoma (POAG) (2). The management of glaucoma lies primarily in early diagnosis and careful monitoring of the condition to prevent further optic neuropathy. Visual field testing has been the mainstay for the diagnosis and monitoring of patients with glaucoma. Although Hum-

phrey visual field (HVF) testing is currently the gold standard for detection of glaucomatous visual field loss as well as monitoring of patients, it has several limitations, such as 1) early and subtle peripheral field defects may not be detected due to testing of the central 24 to 30 degrees of vision, 2) scotomas with small extent may remain undetected due to low spatial resolution, 3) loss of concentration may be induced in the patient due to extended testing time, and 4) accessibility and availability of HVF testing may be lacking.

The Amsler grid was developed by Marc Amsler in the 1940s to test and analyze visual field defects in the central 10 degrees (3, 4) using a suprathreshold target. This test

is good for detecting scotomas and metamorphopsia, but is not as sensitive for the detection of relative scotomas. The development of the threshold Amsler grid using cross-polarizing filters to vary perceived luminance by Wall and Sadun (5) significantly improved the yield of detection of relative scotomas in the central 10 degrees. This test has been found to be much more sensitive for shallow scotoma detection in patients with macular disease and optic neuropathies (6).

With the development of the three-dimensional (3D) computer-automated threshold Amsler grid test (3D-CTAG) by Fink and Sadun (7) (for further information see [http://autonomy.caltech.edu/biomedicine/3d\\_computer\\_automated.html](http://autonomy.caltech.edu/biomedicine/3d_computer_automated.html)), testing of the central 25 degrees or more with an Amsler grid of varying contrast can be accomplished easily and rapidly (7-12). Akin to conventional perimetry, this test adds a third (z) dimension in terms of contrast sensitivity to the (x, y) coordinates (i.e., horizontal and vertical coordinates) of the visual field, and at a much higher spatial resolution of 1 degree or less, both horizontally and vertically. This increases its sensitivity in characterizing and distinguishing optic neuropathies and maculopathies. 3D-CTAG has demonstrated promise as an effective tool in accurately evaluating, characterizing, and monitoring visual field defects in patients with age-related macular degeneration (AMD) (11), with the potential as a screening tool for the early diagnosis of AMD (11). 3D-CTAG has also demonstrated the potential for a sensitive and accurate screening method for glaucoma suspect patients with demonstrated ocular hypertension or physiologic cupping and normal Humphrey visual field tests (12).

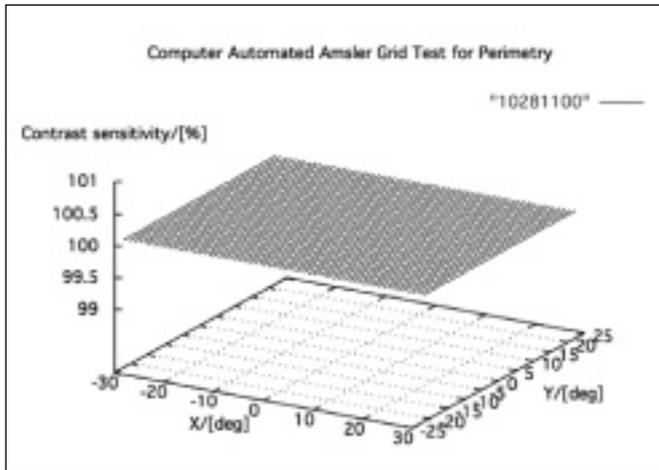
The objective of this pilot study is to establish with 3D-CTAG the location, shape, pattern, slope, and extent of the visual field defects in eyes with an established diagnosis of POAG.

## METHODS

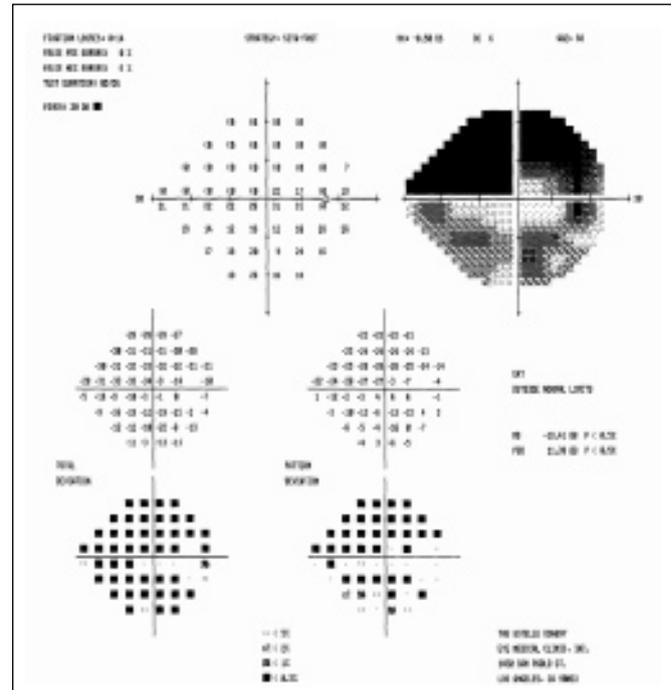
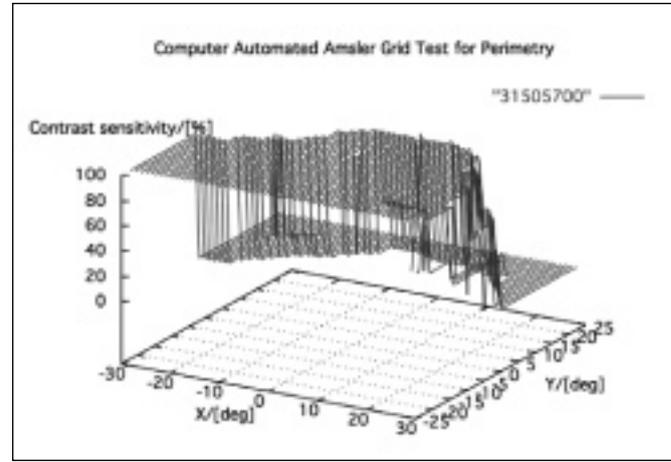
A total of 11 eyes in 11 patients (5 eyes in 5 males and 6 eyes in 6 females) with POAG were examined in the glaucoma clinic at the Doheny Eye Institute, Keck School of Medicine at the University of Southern California. Institutional review board approval and informed consent for voluntary participation was obtained. Glaucoma patients were defined as those with intraocular pressure >21 mmHg or cup to disc ratio of >0.5, and an abnormal achromatic standard or SITA standard 30-2 or 24-2 Humphrey visual field test. The following definition was used to classify an abnormal

achromatic standard test (i.e., glaucomatous visual field loss) (13): a mean deviation probability <0.05, pattern standard deviation probability <0.05, glaucoma hemifield test outside normal limits, or a cluster of three or more adjacent non-edge points in typically glaucomatous locations, all of which were depressed on the pattern deviation plot at a  $p < 0.05$  level and one of which was depressed at a  $p < 0.01$  level. The 11 eyes were subsequently examined using 3D-CTAG. A total of 23 eyes from normal subjects tested at the Doheny Eye Institute were used as historical controls from a concurrent study on glaucoma suspects (12), using the same testing protocol and machine.

Already successfully employed in several clinical pilot studies (8-12), 3D-CTAG exhibits a grid on a black computer screen at a user-defined grayscale (i.e., contrast) and angular resolution (i.e., spatial frequency), and allows patients to trace those areas on the grid that are missing in their visual field using a touch screen. The same cathode ray tube (CRT) touch-sensitive monitor was used without any subsequent changes in the brightness and luminance settings, both throughout each examination and between examinations. The CRT monitor was turned on at least 30 minutes before the testing sessions to ensure brightness and luminance stability. Each patient was positioned in front of the computer monitor at a distance of 30 cm, maintainable by a chin headrest. This distance from the central fixation marker on the computer screen (0 degrees horizontally and 0 degrees vertically from fixation) determined the angle of the visual field tested. An eye cover was used to occlude the fellow eye. When necessary, refractive correction was used with the patient's contact lenses or eyeglasses. After initial testing instructions, the patients were presented with grid lines 1 degree apart akin to a standard Amsler grid. The 5-minute test required that the patients repeatedly outlined scotomas on the touch screen with 5 progressively higher levels of contrast (20%, 40%, 60%, 80%, and 100%) while maintaining their gaze on a central fixation marker. Fixation was monitored by the physician administering the test. Each eye was tested separately. The results of each tested level were recorded, and in combination, resulted in a 3D depiction of the central (25 degrees radially) hill of vision both as topographic contour rings and as 3D wire/shaded diagrams. Areas of 0% contrast sensitivity corresponded to the inability of a patient to recognize an Amsler grid at 100% contrast difference, and areas of 100% contrast sensitivity to the ability to recognize it at the lowest preset contrast, i.e., the darkest grid. The results were subsequently used to establish the location, extent,



**Fig. 1** - Three-dimensional (3D) visual field of a normal eye with no defects obtained with 3D computer-automated threshold Amsler grid testing. The X-axis denotes the horizontal visual field in degrees, the Y-axis denotes the vertical visual field in degrees, and the Z-axis depicts the contrast sensitivity as a function of location (X, Y).



**Fig. 2** - Single three-dimensional (3D) superior arcuate defect obtained with 3D computer-automated threshold Amsler grid testing (top) and corresponding Humphrey 24-2 SITA-fast visual field (bottom).

slope, depth, and shape of the scotomas in the patients with glaucoma.

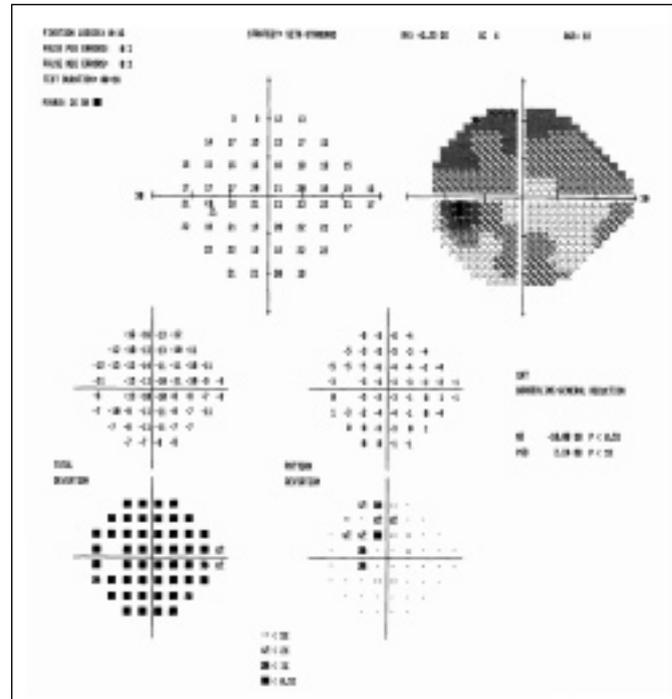
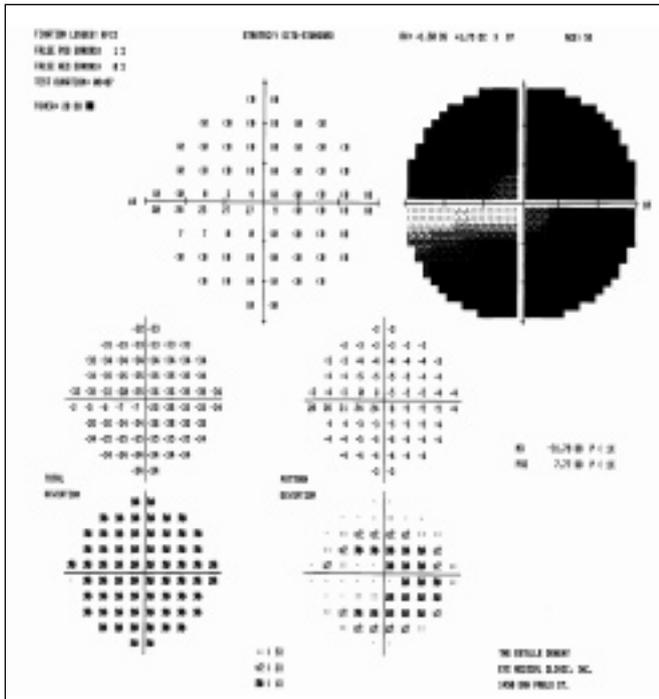
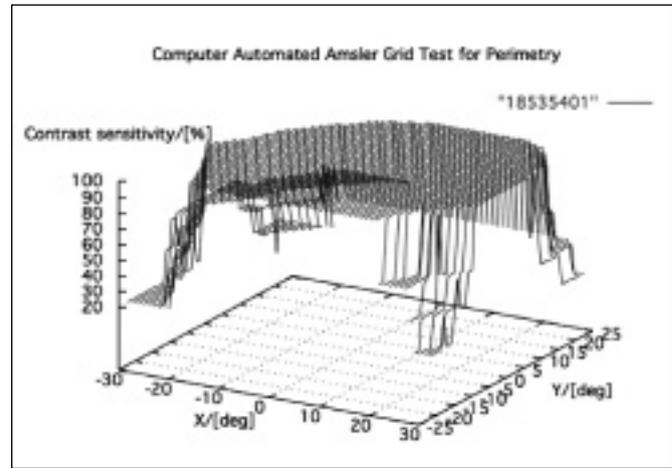
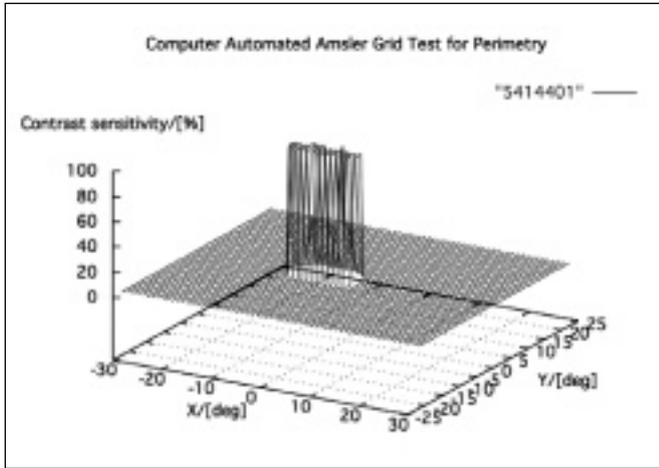
For both the qualitative and quantitative evaluation and characterization of the scotomas obtained with 3D CTAG, the mean and standard deviation of the ratio of the loss of contrast sensitivity over degrees of visual field, expressed as a slope (%/degree) (14), was computed for all occurring horizontal and vertical slopes (with respect to the tested visual field, in our case  $61 \times 45 \text{ deg}^2 = 2745 \text{ deg}^2$ ) within the 3D glaucomatous scotoma of each patient, respectively. The larger the standard deviation of the mean slope, the larger the spread of occurring individual slopes (14): a mean slope of less than 30 %/degree represents shallow slopes, indicative of a relative scotoma, and a mean slope of more than 70%/degree represents steep slopes, indicative of an absolute scotoma.

The visual field data obtained with the 3D CTAG were classified according to the Hodapp-Parrish-Anderson visual field grading scale (13).

## RESULTS

Eleven eyes with POAG were examined with the 3D-CTAG in 3–5 minutes per eye. The age range of the participants in the POAG group was 53 to 81 years. The age range in the control group of 23 eyes was 27 to 74 years. Best-corrected visual acuities in the POAG group ranged from 20/25 to 20/200.

The controls showed normal field (i.e., flat field) with 100% contrast sensitivity (Fig. 1). In the glaucoma group, all patients also demonstrated visual field defects with 3D-CTAG testing (e.g., Figs. 2–4). These visual field defects were characteristic or compatible with glaucomatous visual field loss. Arcuate defects, altitudinal defects, and/or a nasal step were seen in 8/11 (73%) eyes. Five out of 11 eyes (45%) showed arcuate/altitudinal defects alone, with 4/5 (80%) demonstrating superior arcuate/altitudinal defects and 1/5 (20%) showing an inferior arcuate defect. Figure



**Fig. 3** - Three-dimensional (3D) central island of vision obtained with 3D computer-automated threshold Amsler grid testing (top) and corresponding Humphrey visual field using the 10-2 SITA-standard strategy (bottom).

**Fig. 4** - Three-dimensional (3D) early visual field constriction obtained with 3D computer-automated threshold Amsler grid testing (top) and corresponding Humphrey 24-2 SITA-standard visual field (bottom).

2 shows a 3D depiction of a superior arcuate defect as demonstrated by the 3D-CTAG. A superior arcuate defect is also seen in the corresponding HVF test. Nasal defects were seen in 3/11 (27%) eyes, with 1/3 (33%) showing a superior nasal step, 2/3 (67%) showing both superior and inferior nasal scotomas. A constricted visual field was seen in 3/11 (27%) eyes. Figure 3 demonstrates a visual field defect using the 3D-CTAG in a patient with advanced glauco-

ma. This example demonstrates a central island of vision in a severely constricted field, while Figure 4 demonstrates early visual field constriction. All patients demonstrated absolute scotomas or a combination of shallow and absolute defects on the 3D-CTAG. A similar pattern of visual field loss was attained with respect to the location, size, and depth of the scotomas. In areas demonstrating absolute scotomas, the outlined sc-

**TABLE I - AVERAGE VALUES ± STANDARD DEVIATIONS OF OCCURRING SLOPES (%/DEGREE) FOR EACH OF THE 11 EYES IN THE POAG GROUP OBTAINED WITH 3D-CTAG**

Eye no.	Mean slope ± SD (%/deg)	Hodapp-Parrish-Anderson visual field grade*
1	75±35	Severe
2	79±29	Severe
3	46±42	Severe
4	9.7±4.5	Moderate
5	20±20	Severe
6	88±26	Severe
7	95±15	Severe
8	50±35	Severe
9	75±30	Severe
10	78±31	Severe
11	91±19	Severe
Overall average slope ± SD	64±29	

\*Hodapp-Parrish-Anderson visual field grades (13) for the corresponding Humphrey visual field defects.  
 POAG = primary open angle glaucoma; 3D-CTAG = three-dimensional computer-automated threshold Amsler grid test.

otoma boundaries for each tested contrast level (total of 5 grayscale levels) were concentrically arranged, and the lines were overlapping and not crossing. The overall average of the occurring mean slopes for the 11 eyes in the POAG group was 64±29%/degree (range: 9.7%/degree to 95%/degree; Tab. I). The steep slopes determined by 3D-CTAG corresponded to areas of absolute scotomas, indicative of areas of severe glaucomatous visual field deficit (see, e.g., Fig. 3, top: mean slope of 78±31%/degree; the Hodapp-Parrish-Anderson visual field grade for the corresponding HVF defect was severe). A combination of steep and shallow slopes is indicative of moderate glaucomatous visual field deficit (see, e.g., Fig. 2, top: mean slope of 50±35%/degree; the Hodapp-Parrish-Anderson visual field grade for the corresponding HVF defect was severe). The shallow slopes corresponded to areas of relative visual field loss, indicative of areas of mild glaucomatous visual field loss (see, e.g., Fig. 4, top: mean slope of 9.7±4.5%/degree; the Hodapp-Parrish-Anderson visual field grade for the corresponding HVF defect was moderate). Ten out of 11 eyes demonstrated severe visual field deficits, and 1/11 eyes showed a moderate visual field defect on HVF testing according to the Hodapp-Parrish-Anderson visual field grading scale (13). The respective mean slopes for all 11 eyes obtained with the 3D-CTAG and the Hodapp-Parrish-Anderson visual field grades for the corresponding HVF defects are listed in Table I.

## DISCUSSION

In this pilot study, the 3D depiction of visual field loss obtained with the 3D-CTAG demonstrated paracentral, superior and inferior altitudinal, and nasal step defects consistent with glaucomatous damage (e.g., Figs. 2–4). These findings, in addition to the consistent shape, location, and pattern of scotomas on 3D-CTAG, make it unlikely that they were due to other factors. By providing a third dimension of contrast sensitivity information at a higher angular/spatial resolution than standard Humphrey automated perimetry, the 3D depiction shows a slope that is consistent with the severity of damage. Hence a steep slope, as seen in our patient population, is indicative of absolute visual field defects, while a shallower slope signifies a milder gradual shifting zone of relative visual field loss.

One concern in visual field testing in patients with glaucoma is the masking of a defect secondary to the Troxler effect. Since there is no cortical representation of that area, the blind spot is filled in by the visual cortex when presented with a screen wide constant Amsler grid in contrast to standard automated perimetry (i.e., HVF). However, in our study, an enlarged blind spot was detected in a patient with the 3D-CTAG, even though the physiologic blind spot is not detected in this test. Hence, despite the usual problem with Troxler suppression of arcuate scotomas in glaucoma, we are able to consistently find and characterize these visual field defects in the patient population. As with other psychophysical testing, the 3D-CTAG may exhibit false-positive and false-negative results: while the absolute superior defect in the HVF in Figure 2 (bottom) is clearly demonstrated with the 3D-CTAG in Figure 2 (top), the absence of the relative inferior defect on the 3D-CTAG may indicate a false-negative result. In addition, since fixation was monitored by the physician administering the test, future 3D-CTAG modalities may be improved by automated fixation tracking. Psychophysical testing has already been demonstrated to predict the onset of glaucomatous visual field loss in patients with ocular hypertension (15). The effects of glaucoma on contrast sensitivity have been examined (16–19). In contrast to several other retinal diseases, visual field loss from glaucoma first begins as shallow scotomas that then may progress and deepen over time and cause absolute visual field defects. Therefore, early detection of optic nerve damage and visual field loss in glaucoma is of paramount importance. Improvements in resolution and reliability have made computer-based testing increasingly common as a useful diagnostic tool for detecting and monitoring glaucoma (16, 17, 20, 21). For instance, white noise field campimetry, in-

roduced by Aulhorn and Köst (22), has been shown to be a potential fast screening method for detecting glaucomatous visual field defects (23). 3D-CTAG may be a useful addition for the diagnosis and monitoring of glaucoma, as well as for the evaluation and follow-up of glaucoma therapy efficacy. A related pilot study (12) has already shown promise for the early detection of glaucoma in glaucoma suspects using the 3D-CTAG. Since the current study is a pilot study rather than a definitive trial to introduce a new visual field test, additional longitudinal follow-up studies are necessary to establish the relative value and indications for the 3D-CTAG. Quantitative values for visual field characteristics, optic disc characteristics, and other clinical and demographic information were not obtained in this study. The above should be determined through follow-up studies at larger sample sizes. Furthermore, additional independent studies using 3D-CTAG should be conducted and confirmed by multicenter trials. The 3D-CTAG provides high angular resolution, additional information through 3D depiction of scotomas with contrast sensitivity as the third dimension, improved patient compliance through shorter examination time, and potential inter-

active accessibility and distribution over the Internet. It may be used in large community-based screening programs and in the primary care setting for widespread screening of glaucoma and glaucoma suspect patients. Since most patients are evaluated in primary care centers, a potentially larger number of glaucoma and glaucoma suspect patients can be screened and referred for treatment. Furthermore, the potential accessibility over the Internet may enable visual field testing in locations where access to health care centers is not readily available.

*Drs. Fink and Sadun have proprietary interest as patents on the test technology used in this study are issued. Drs. Nguyen, Fahimi, Nazemi, and Kim have no proprietary interest.*

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