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MAJOR REVIEW

Staging Functional Damage in Glaucoma: Review of Different Classification Methods

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Abstract. Classification of glaucomatous visual field defects for different severity levels is important. The reasons for this are numerous, and include: to distinguish between healthy and diseased individuals, to have homogeneous grouping criteria when perimetry is used to define the severity of glaucoma, to adjust therapy on the basis of disease severity, to describe visual field conditions in a short and simple format, to monitor the progression of the disease, and to provide a common language for both clinical and research purposes. Many severity classification methods have been proposed, although none have had widespread use in clinical practice. Other methods, like the cumulative defect curve (Bebie curve), can be used to distinguish the type of visual field loss as diffuse, localized, or mixed. This article provides a review of the main classification methods that have been proposed in the past 40 years. (**Surv Ophthalmol 52**:156–179, 2007. © 2007 Elsevier Inc. All rights reserved.)

Key words. chronic open-angle glaucoma • functional loss classification • perimetry • staging methods • standard automated perimetry • visual field defect • visual field loss characteristics

I. Introduction

Primary open-angle glaucoma (POAG) is a slow, progressive disease for which patients must be monitored throughout their life. The diagnosis of glaucoma is classically based on three criteria: an elevated IOP, typical visual field defects, and characteristic optic disc damage. Unfortunately, the IOP value alone can neither be used to separate healthy from affected individuals nor to stage the disease in different classes of increasing severity, due to its poor sensitivity and specificity. Visual field loss and optic disk damage are thus important, both in the early diagnosis of chronic glaucoma and in the definition of the stage of the disease. Structural alterations can be assessed and recorded manually, using an ophthalmoscopic examination of the optic nerve head with a slit lamp, or by means of various automated image analysis systems (HRT, OCT, etc.). All of the manual-type systems are subjective, poorly reproducible, and require specific clinical experience.[5,13,34,56,67,73,86] Computerized devices are able to analyze the optic disc and nerve fiber layer and to classify the structural damage,[69,82] but are currently under evaluation to determine their clinical utility. The use of these devices in glaucoma management has yet to be widely accepted. Moreover, this type of technology is expensive and is not accessible to many ophthalmologists. Visual field testing with standard automated perimetry (SAP) is currently the most common method used to quantify glaucomatous damage. A standardized staging of glaucomatous functional damage severity, which

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provides a reliable and simple classification of visual field defects, would be very useful both for fields of research and in day-to-day clinical practice for several reasons:

a) To distinguish between healthy and diseased eyes.
b) To use homogeneous criteria for grading severity of disease (which is useful for inclusion criteria in clinical studies in glaucoma, deciding on quantity and type of treatment, etc.).
c) To record and store visual field data in a simple and clear format.
d) To provide better follow-up of the disease.
e) To aid in giving a more reliable prognosis of the disease.
f) For medical-legal purposes.

The method of how visual defects can be classified has been an issue that many have dealt with in past years. One of the simplest and most effective ways to classify defects is to use visual field data obtained by manual kinetic perimetry, SAP, and/or non-conventional testing techniques.

An ideal method for classifying functional damage in glaucoma should be standardized, objective and reproducible, user-friendly, supported by scientific and clinical evidence, adaptable for data obtained from different models of perimeters, supply useful information on the characteristics of visual field defects (shape, type, location, and depth), able to provide a classification which is consistent with structural damage data, widely used and accepted, able to monitor even relatively small changes in functional loss over time, and made available on computer software for easy day-to-day clinical use.

A number of different methods have been proposed in the past for classifying both the severity and characteristic of visual field defects. This article deals with a historical review of the various classification and staging methods of functional damage, which have been used in the field of glaucoma over the past 40 years.

II. Methods for Classifying Visual Field Loss Severity

A. METHODS BASED ON MANUAL PERIMETRY DATA

In 1958, the American Medical Association proposed a scoring system in an article entitled "Guides to the evaluation of permanent impairment. The visual system."[3] The score gives information pertaining to the percentage of retained visual field. This score is obtained by adding the number of degrees of eight principal meridians, and then dividing the total by five. The width of the scotoma is subtracted from the peripheral visual field value in the same meridian. A table was designed that lists the corresponding percentage loss of visual field.

The traditional classification method proposed by Aulhorn and Karmeyer was designed on the basis of a very large sample of glaucomatous patients tested with a manual Tübingen perimeter.[11] Visual field defects are divided in five stages (Table 1). This method has had widespread use in the past, and is still considered to be a fundamental reference point in glaucoma research (Fig. 1).

It is simple, clinically useful, and does not require any statistical or complex analysis. The idea of subdividing visual field loss into five stages has been used in several other modern classification methods. The Aulhorn and Karmeyer method is, however, subjective, dependent on user experience, poorly reproducible, and based on an infrequently used testing procedure. It can be, however, modified,[43] and still used to classify visual field loss severity when the defect morphology is an important parameter. The SAP gray scale printout should be used in the staging of defects with this method.

In 1967, Esterman proposed a grid to be used in the quantitative evaluation of the tangent screen field.[32] The same author then proposed a similar method to score conventional kinetic perimetry.[33] It consisted of 100 units of unequal size, each representing 1%, in which proportionally higher units were assigned to field areas of greater importance (Fig. 2).

The recorded visual field data is superimposed onto the grid and areas within the patient's visual field limits are then counted. This permits the score to be expressed as a percentage. The Esterman monocular and binocular grids were later integrated with Humphrey perimeters. Automated functional scoring is based on the percentage of points seen.

This system, which was originally designed to quantify visual disability and not to specifically stage

TABLE 1

Aulhorn and Karmeyer's classification

Stage I: Only relative defects.
Stage II: Spot-like, stroke-like, or arcuate absolute defects, having no connection to the blind spot.
Stage III: Arcuate absolute defects already connected to the blind spot, with or without a nasal break-through into the periphery.
Stage IV: Extensive ring-shaped or half ring-shaped defects, with a central island of sensitivity maintained.
Stage V: Central island collapse, with only the temporal visual field area remaining.

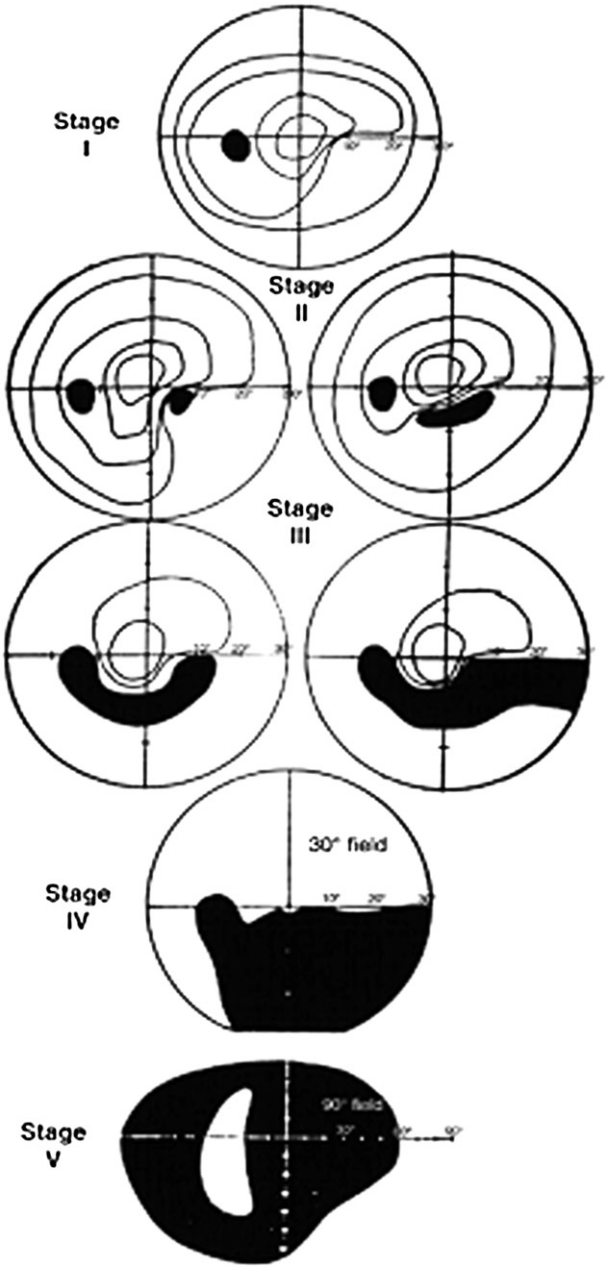


Fig. 1. Aulhorn and Karmeyer's classification. Reprinted from Aulhorn[11] with permission of *Documenta Ophthalmologica.*

glaucomatous defects, was a step forward in the standardization of visual loss assessment. It has some inconsistencies, however, which include: an identical score assigned to different portions of visual field tested with Goldmann and tangent screen instruments, too much weight is given to both the Bjerrum area and the far periphery,[28] and not enough importance is given to the differentiation of very narrow fields or paracentral losses.[28] Esterman's binocular test has been shown to provide poor sensitivity in differentiating the amount of visual loss

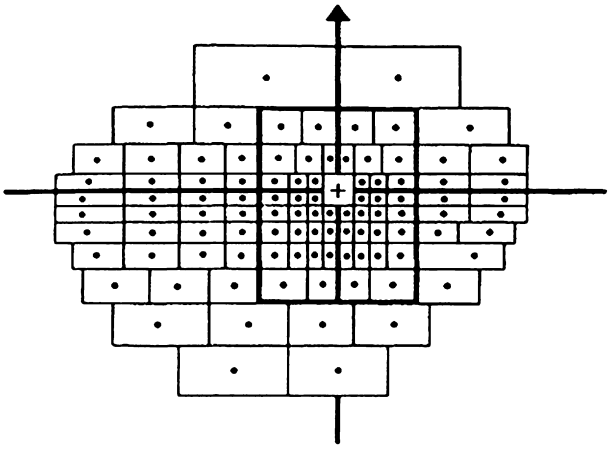


Fig. 2. Esterman's monocular grid. Reprinted from Esterman[33] with permission of *Archives of Ophthalmology.*

in severe glaucomatous patients.[45] The Esterman grid continues to be an interesting method to quantify functional visual field loss due to various ophthalmologic diseases including glaucoma, and can occasionally be used to assess visual disability in forensic medicine.

Other historic methods for quantifying visual field loss assessed by manual perimetry were proposed by Drasdo and Peaston,[31] Hamada et al,[44] Suzumura et al,[90] and Jay and Murray.[54]

B. METHODS BASED ON NUMBER AND DEPTH OF DEFECTIVE POINTS

SAP is the most commonly used method to assess glaucomatous functional loss. It is still considered the "gold standard," although many studies have shown that it does not provide high sensitivity in the detection of very early alterations in chronic glaucoma.[46,78,79] SAP supplies numerical data, which can be used in the statistical analysis and staging of visual field loss. A number of methods have been proposed for such purposes.

In 1982, Greve published a six-stage classification system derived from Aulhorn and Karmeyer's method[43] which can be used with automated visual field testing.

In 1988, Langerhorst used data obtained from an experimental perimeter (scoperimeter) in a four-stage classification method based on the number and depth of depressed points.[65] This method, which is currently no longer used, also took defect location into consideration.

Gandolfo et al attempted to quantify the amount of visual field loss for medical–legal and insurance purposes.[39] The method uses 100 points, in which the areas located centrally and inferiorly are given greater importance. A special custom test was

specifically designed for this purpose using the Perikon PCL 90 automated perimeter. The perimetric results are converted into a score up to 10, giving rise to residual visual field classified in six different global disability zones. The same authors also proposed different methods for calculating the percent of loss.[40,41] For one specific method, the foveal threshold sensitivity is combined with a score obtained from static suprathreshold testing of 100 points in the 60° central area, and with another score, which takes into account the mean eccentricity of 16 perceived kinetic stimuli. Binocular visual fields can be scored and quantified with a custom test ("Visual field percent" or VF%) using Humphrey perimeters.[71] The score is based on one hundred tested points within 60° of the visual field using a three-zone screening strategy. The total number of points with a relative or absolute defect are considered in the final score calculation. This method is currently being used in Italy to assess disability caused by visual field constrictions.

In 1993, Colenbrander et al proposed the "Functional Vision Score System" based on a similar principle, in which an external PC with a customized program linked to a Humphrey Field Analyzer perimeter was used.[28] Fifty points are tested in the 10° central field, and 56 points in the peripheral field. Visual defects, represented as a score, are divided in seven classes, ranging from normal to no remaining visual field. This method seems to overcome some of the limits found in the Esterman grid, however, it is presently only of historical interest.

In 1996, Quigley et al used a nine-level grading scale obtained from the results of both the Humphrey 120 suprathreshold screening test and static and kinetic manual testing on the Goldmann perimeter (Table 2).[80]

TABLE 2

Quigley's Grading Scale

Grade 0: Less than 17 relative or absolute defects
Grade 1: 17 or more defects and a normal Goldmann visual field
Grade 2: Early visual field defects on Goldmann perimetry
Grade 3: Definite visual field defects on Goldmann
Grade 4: Visual field defects in both upper and lower visual fields
Grade 5: Visual field with an absolute loss of one full quadrant (to V_4e target)
Grade 6: Absolute loss in one hemifield, or complete loss of one quadrant and a grade 3 level defect in the other hemifield
Grade 7: Damage worse than grade 6 but not classifiable as grade 8
Grade 8: Blindness (visual acuity of 20/200 or worse, caused by glaucoma or a central island of remaining field smaller than 10° to the target V_4e)

This analytical scale provides a precise subdivision of defect severity. This method is unfortunately based on an infrequently used testing technique (kinetic perimetry) and on automated screening tests, which are both hardly ever used.

In 1993, Hodapp, Parrish, and Anderson proposed an interesting classification based on two criteria:[52] the first criterion considers the overall extent of damage, which is calculated by using both the MD value and the number of defective points in the Humphrey Statpac-2 pattern deviation probability map of the 30-2 full threshold test; the second criterion is based on the defect proximity to the fixation point. The minimum criteria for diagnosing glaucomatous damage and the criteria used to divide defect severity in three classes are reported in Table 3. This is a clinically useful method, and is currently the classification system most commonly used in clinical studies. The main advantage of this method is that in addition to providing information on overall visual field loss based on both MD and number of defective points, visual field defects close to the fixation point that can severely threaten patient vision are also considered. This classification can be of great use in deciding when to start treatment once glaucoma has been diagnosed and how aggressive therapy should be, which is usually based on individual visual defect severity. The disadvantages include the fact that this three-stage subdivision is too simplified, and thus may make it inappropriate for a fine categorization of visual field defects. Moreover, it requires an accurate and time-consuming analysis of every single visual field test result.

Mills et al recently proposed a new classification method, which can be considered an enhanced version of the Hodapp-Parrish-Anderson (H-P-A) classification.[70] This staging system is made up of six stages, as shown in Table 4, which ranges from stage 0 (ocular hypertension/very early glaucoma) to stage 5 (end-stage damage).

In order to avoid any possible confusion, it should be noted that this new method has been named the Glaucoma Staging System (GSS), which is similar to the one introduced by Brusini in 1996.[20]

The staging system proposed by Mills differs from the H-P-A method in that an increased number of stages are used (six instead of three), glaucomatous disease severity of any type is given a precise stage, and there is a good standardization of all parameters. It has been used in recent clinical studies that looked at the cost breakdown associated with different stages of glaucoma.[66,92] The main disadvantages of this system (as pointed out by Mills)[70] include the fact that, like most classification methods that use visual field test outcomes, it does

TABLE 3

Hodapp, Parrish and Anderson's Classification

Minimum criteria for diagnosing acquired glaucomatous damage
- A Glaucoma Hemifield Test outside normal limits on at least two fields; OR
- A cluster of three or more non-edge points in a location typical for glaucoma, all of which are depressed on the pattern deviation plot at a $p<5\%$ level and one of which is depressed at a $p<1\%$ level on two consecutive fields; OR
- A corrected pattern standard deviation that occurs in less than 5% of normal fields on two consecutive fields

Classification of defects

Early defect:
- ○ MD less than –6 dB
- ○ Less than 25% of the points (18) are depressed below the 5% level and less than 10 points are depressed below the 1% level on the pattern deviation plot
- ○ All point in the central 5° must have a sensitivity of at least 15 dB

Moderate defect:
- ○ MD less than –12 dB
- ○ Less than 50% of the points (37) are depressed below the 5% level and less than 20 points are depressed below the 1% level on the pattern deviation plot,
- ○ No points in the central 5° can have a sensitivity of 0 dB
- ○ Only one hemifield may have a point with sensitivity of <15 dB within 5° of fixation

Severe defect (any of the following results):
- ○ MD greater than –12 dB
- ○ More than 50% of the points (37) are depressed below the 5% level or more than 20 points are depressed below the 1% level on the pattern deviation plot
- ○ At least one point in the central 5° has a sensitivity of 0 dB
- ○ Points within the central 5° with sensitivity <15 dB in both hemifields

not consider other clinical factors that can be useful in assessing the amount of glaucomatous damage and progression, the system exclusively works with Humphrey visual field results, and, the various stages probably do not represent equal intervals of glaucomatous progression. Moreover, this system appears to be less user-friendly than the H-P-A, and it does require an analytical and time consuming

TABLE 4

Mills et al Staging System

Stage	Humphrey Mean Deviation (dB)	Probability Plot/Pattern Deviation	dB Plot (Stages 2–4) or CPSD/PSD (Stage 1)	dB Plot (Stages 2–4) or Glaucoma Hemifield Test (GHT) (Stage 1)
Stage 0—Ocular hypertension/earliest glaucoma	>0.00	—	Does not meet any criteria for Stage 1	—
Stage 1—Early glaucoma	−0.01 to −6.00	>3 contiguous points at P<.05 and >1 of the points at P<.01	CPSD/PSD significant (P <.05)	GHT "outside normal limits"
Stage 2—Moderate glaucoma	−6.01 to −12.00 And ⇒	Points below 5%: 19-36 and points below 1%: 12–18 Or ⇒	>1 point(s) with sensitivity of <15 dB and no point with sensitivity of <0 dB within the central 5° Or ⇒	1 or 2 points with sensitivity <15 dB within 5° of fixation in only 1 hemifield
Stage 3—Advanced glaucoma	−12.01 to −20.00	Points below 5%: 37-55 and points below 1%: 19–36	Only 1 point with sensitivity of <0 dB within the central 5°	At least 1 point with sensitivity of <15 dB within the central 5° in both hemifields
Stage 4—Severe glaucoma	−20.01 or worse	Points below 5%: 56-74 and points below 1%: 37–74	2 to 4 points with sensitivity of <0 dB within the central 5°	At least 2 points with sensitivity of <15 dB within the central 5° in both hemifields
Stage 5—End-stage	No visual field in worst eye	No visual field attributable to central scotoma Or ⇒	Worst eye visual acuity of 20/200 or worse attributable to glaucoma	Best eye may fall into any of above stages

TABLE 5

The AGIS Scoring Method

The AGIS score ranges from 0 to 20, and it is obtained as follows:

A cluster of three or more adjacent depressed test locations among the six test sites in the nasal field constitutes a *nasal defect*. The cluster may cross the horizontal midline.

One or more depressed test locations in the nasal field, either above or below the horizontal midline, in the absence of depression of any of the three test locations on the opposite side of the horizontal midline, constitutes a *nasal step*.

A cluster of three or more depressed sites in a hemifield constitutes a *hemifield defect*. More than one cluster of depressed sites may occur in a hemifield.

Points are awarded to the score as follows:

- For a nasal defect or nasal step, add one to the score, and if four or more of the six nasal test locations are depressed 12 dB or more, add one more to the score.
- In each hemifield with one or more clusters of three or more adjacent depressed test locations (hemifield defects), add one to the score if there are 3 to 5 depressed test sites in the clusters; add two if there are 6 to 12; add three if there are 13 to 20; and add four if there are more than 20.
- If half or more of the adjacent defective locations in a hemifield are depressed 28 dB or more, add five to the score; if half or more are depressed 24 dB or more, add four; if half or more are depressed 20 dB or more, add three; if half or more are depressed 16 dB or more, add two; or if half or more are depressed 12 dB or more, add one. This series of steps may add as much as five to the score for each hemifield containing a deep defect.
- If a hemifield lacks a cluster of three adjacent depressed test sites, but contains at least two adjacent depressed sites of which one is depressed 12 dB or more, add one to the score.

assessment of several visual field parameters (such as the global indices, number of depressed points at two probability levels in the pattern deviation probability plot, number of points with either a very low or no sensitivity within the central 5°, etc). It thus appears applicable for clinical research studies, yet not ideal for day-to-day clinical use.

The Advanced Glaucoma Intervention Study (AGIS)[1] began as a multicenter randomized clinical trial designed to determine whether laser trabeculoplasty or trabeculectomy could be a better treatment for glaucoma patients in which medical treatment alone is no longer adequate. The study was also directed at analyzing the clinical course and prognosis of open-angle glaucoma after surgery. With this in mind, the investigators developed quantitative methods to assess test reliability and to measure visual field defect severity using the Humphrey 24-2 threshold test. The AGIS visual field defect score is based on both the number and depth of adjacent depressed test locations in the nasal area, upper hemifield, and lower hemifield (Table 5).

This score is obtained from the total deviation plot of the Statpac 2 single field analysis. A point is considered to be defective when a minimum amount of sensitivity depression is reached (Fig. 3).

Scores for each hemifield and for the nasal area are summed. The maximum possible score is 20 (two for the nasal field and nine for each hemifield). Test results may be scored manually and/or by computer using special software. Transparent plastic templates were created in order to assist in the manual scoring.

Visual field scores are divided in five stages (categories): Score 0 = normal visual field; Score 1–5 = mild damage; Score 6–11 = moderate damage; Score 12–17 = severe damage; Score 18–20 = end-stage.

This scoring system was specifically designed for the AGIS studies, especially in monitoring visual field follow-up tests in glaucomatous patients over time, and was not originally intended for clinical application. Although it is analytical and accurate, it is time-consuming and difficult to use, especially for beginners. The use of a specific PC program can simplify the calculation of the score. The AGIS system does provide a standardized classification of visual field loss severity that can be useful in scientific and clinical studies, however, it is not a practical method for day-to-day clinical use.

In the Collaborative Initial Glaucoma Treatment Study (CIGTS), a similar classification method was used.[72] A weight is given, based on the minimum

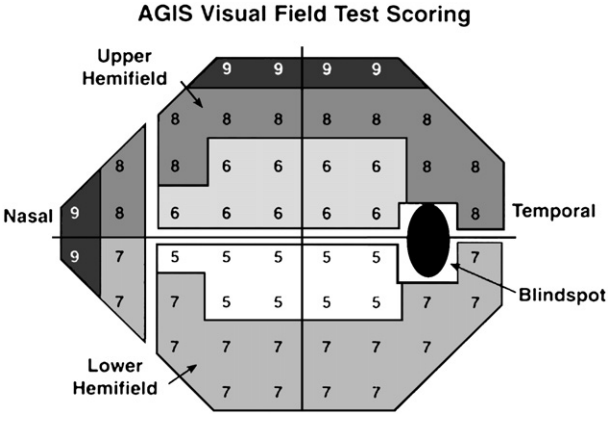


Fig. 3. Different areas taken into consideration in the AGIS classification with minimum deviation from normal considered as significant. Reprinted with permission from the Advanced Glaucoma Intervention Study. 2. Visual field test scoring and reliability. Ophthalmology, 1994.[1]

depth of the defect at any given point in addition to its two most defective neighboring points in the total deviation probability plot of the Humphrey 24-2 threshold test. A defect of 0.05 on the total deviation probability plot is given a weight of 1; a defect of 0.02 is given a weight of 2; a defect of 0.01 is given a weight of 3; and, a defect of 0.005 is given a weight of 4. A point without two neighboring points all depressed to at least $p \leq 0.05$ is given a weight 0. The score obtained for all 52 points in the field are summed, giving a total ranging from 0 to 208. This sum (divided by 10.4) is then transformed to a numerical scale, which ranges from 0 (no defect) to 20 (all points showing a defect at the $p < 0.005$ level).

It is important to note that the H-P-A, AGIS, and CIGTS methods have all been specifically designed for results obtained from the full-threshold 30-2 and 24-2 programs of the early 600-series Humphrey perimeters (now Carl Zeiss Meditec, Dublin, California).

These methods are accurate with regards to localized defects, however, they fail to take into consideration slight diffuse sensitivity depressions, which may at times be due to early glaucomatous damage.[50]

C. METHODS BASED ON PATTERNS OF VISUAL FIELD LOSS

The Optic Neuritis Treatment Trial (ONTT) and the Longitudinal Optic Neuritis Study (LONS) consisted of a long-term multicenter evaluation of several forms of treatment for patients with optic neuritis. Details concerning the study have been previously published.[2] Automated static perimetry was a primary outcome measure in this investigation. Among other activities, the Visual Field Reading Center (VFRC) for the ONTT study classified all visual field properties into 14 different categories of visual field loss (based on shape) while also determining the severity and interocular characteristics (monocular, binocular, etc) of visual field losses.[60] It was found that a classification system of visual field loss for optic neuritis could be achieved, allowing multiple readers to perform the assessments consistently, and that the use of such a system was beneficial.

A similar approach was undertaken for the Ocular Hypertension Treatment Study (OHTS).[59] In that study, the VFRC found that a total of 17 different classifications were needed to be able to specify the shape of all visual field deficits in the OHTS (glaucomatous and non-glaucomatous visual field deficits). The severity of visual field loss associated with each shape category was also published. This system provided a reliable and consistent method of characterizing visual field abnormalities. Additionally, it was determined that there was 97% agreement among two out of three visual field readers, and that the test–retest agreement for individual assessments was approximately 88%. These results indicate that it is possible to implement a visual field classification system that is consistent and reliable. Although this procedure may be too complicated for routine clinical use, it should be of great value for clinical research purposes.

D. METHODS BASED ON SAP VISUAL FIELD INDICES

Visual field indices, initially reported by Flammer and co-workers,[35] summarize the distribution of sensitivity within the visual field, and give useful information regarding functional loss. The results are expressed in the form of a few simple numbers, which can also be used in the staging of visual field defects.

In 1988, Gollamudi et al proposed a simple classification system based on the so-called "difference index" ($\sqrt{}$CLV-MD).[42] Early damage is indicated as a positive difference index; mid-stage damage is indicated in a difference index of about zero or slightly negative; and advanced damage is depicted as a negative difference index value (Fig. 4).

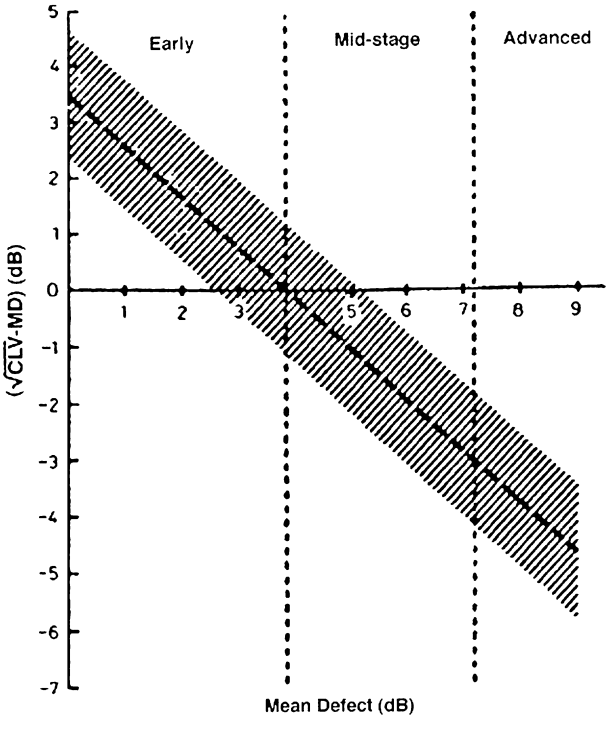


Fig. 4. Gollamudi et al classification diagram. Reprinted from Gollamudi [42] with permission of *Ophthalmologica*.

The intervals between stages, as stated by the authors, are only suggested, and are not mandatory. These authors were the first to notice that the combination of the two main visual field indices (MD and CLV for Octopus perimeters) could provide greater information than what is originally represented if these indices are separately considered: the CLV (or CPSD) index appears to be sensitive to early localized glaucomatous loss, but seems to remain stable over time, whereas the MD appears to be more representative of overall widespread visual field loss. Taken together, these indices can provide a better comprehension of the glaucomatous functional damage from perimetric test results. The Gollamudi et al classification is a good example of how visual field indices can be used in the quantification of visual defect severity. To the best of our knowledge, however, it has never been used in any clinical study.

In 1990, Pearson et al published an interesting paper which similarly concluded that "since the MD and CLV covary so well over most of the range of field deficit in glaucoma, the product function (MD x CLV) might be a valuable measure of overall damage."[77]

In 1994, Brusini et al (Brusini P, Tosoni C, Miani F: Suddivisione in stadi del glaucoma cronico semplice: utilità di un linguaggio comune nella clinica e nella ricerca. Minerva Oftalmol 36:347–50, 1994) used a new five-stage classification method based on the use of both the MD and CPSD values (Table 6).

This was one of the first attempts in which visual field indices were used to obtain information pertaining not only to the severity of defects, but also on the type of damage. Stage 1a, for example, incorporates results that show diffuse depressions of sensitivity; stage 1b describes results with localized defects; and stage 1c contains mixed defect results. These concepts have further been developed and used to create subsequent staging methods.

TABLE 6

Classification Based on MD and CPSD Values by Brusini et al

Stage 0: both MD and CPSD within normal limits
Stage 1:
• MD between −3 and −5 dB and CPSD ≤3 dB, OR
• MD < −3 dB and CPSD between 3 and 5 dB, OR
• both MD and CPSD between −3 and −5 dB
Stage 2: MD >−5 and <−8 dB and CPSD <8 dB, OR MD <−3 dB and CPSD >5 and <8 dB
Stage 3: MD between −8 and −12 dB, OR CPSD ≥8 dB
Stage 4: MD ≥−12 dB and <−20 dB
Stage 5: MD ≥−20 dB

The Glaucoma Staging System (GSS) is a classification method introduced by Brusini[20] in 1995 which uses MD and CPSD/CLV values (from either the 30-2/24-2 Zeiss-Humphrey tests or the G1/G1X/G2 Octopus programs) on a Cartesian coordinate diagram (Fig. 5).

This nomogram allows the user to quickly determine the disease stage, which is defined by the intersection of the two values. The visual fields are divided in six different stages by curvilinear lines from stage 0 (normal visual fields) to stage 5 (low threshold readings, with only small remnants of sensitivity remaining). Moreover, visual field defects are subdivided in 3 groups by two oblique straight lines: generalized visual field defects are found in the upper area; mixed defects in the central area; and, localized defects in the lower left area.

The GSS has proven to be very useful in both staging the damage severity and in separating the different components of visual field loss (generalized, localized, and mixed).[17,21,61,62,81,83,84] It has also shown to be useful in estimating the amount of structural damage in glaucoma[19] and to monitor defect progression over time.[63] In 2005, a new GSS 2 was proposed with the intent of providing an improved modified version of the former system (Fig. 6).[23]

In this current version, the lines that separate the different stages and defect types were mathematically determined. A new borderline stage was created, positioned between stage 0 and stage 1 in which borderline defects could be found. Two new scales, which incorporate both the PSD and LV values respectively, were added to the old scales, in

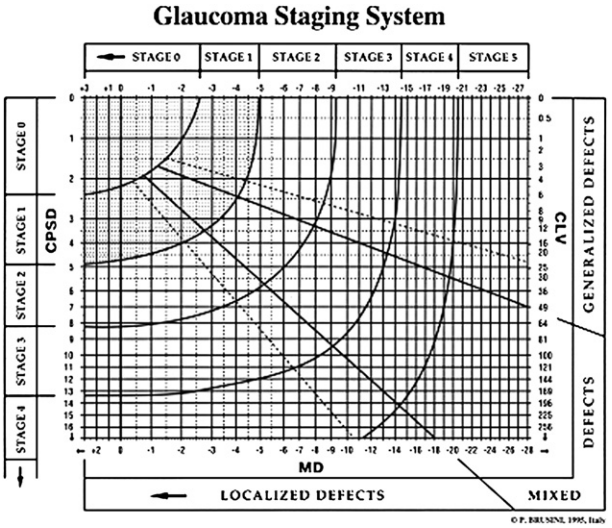


Fig. 5. Brusini's Glaucoma Staging System. Reprinted from Brusini[20] with permission of the *European Journal of Ophthalmology*.

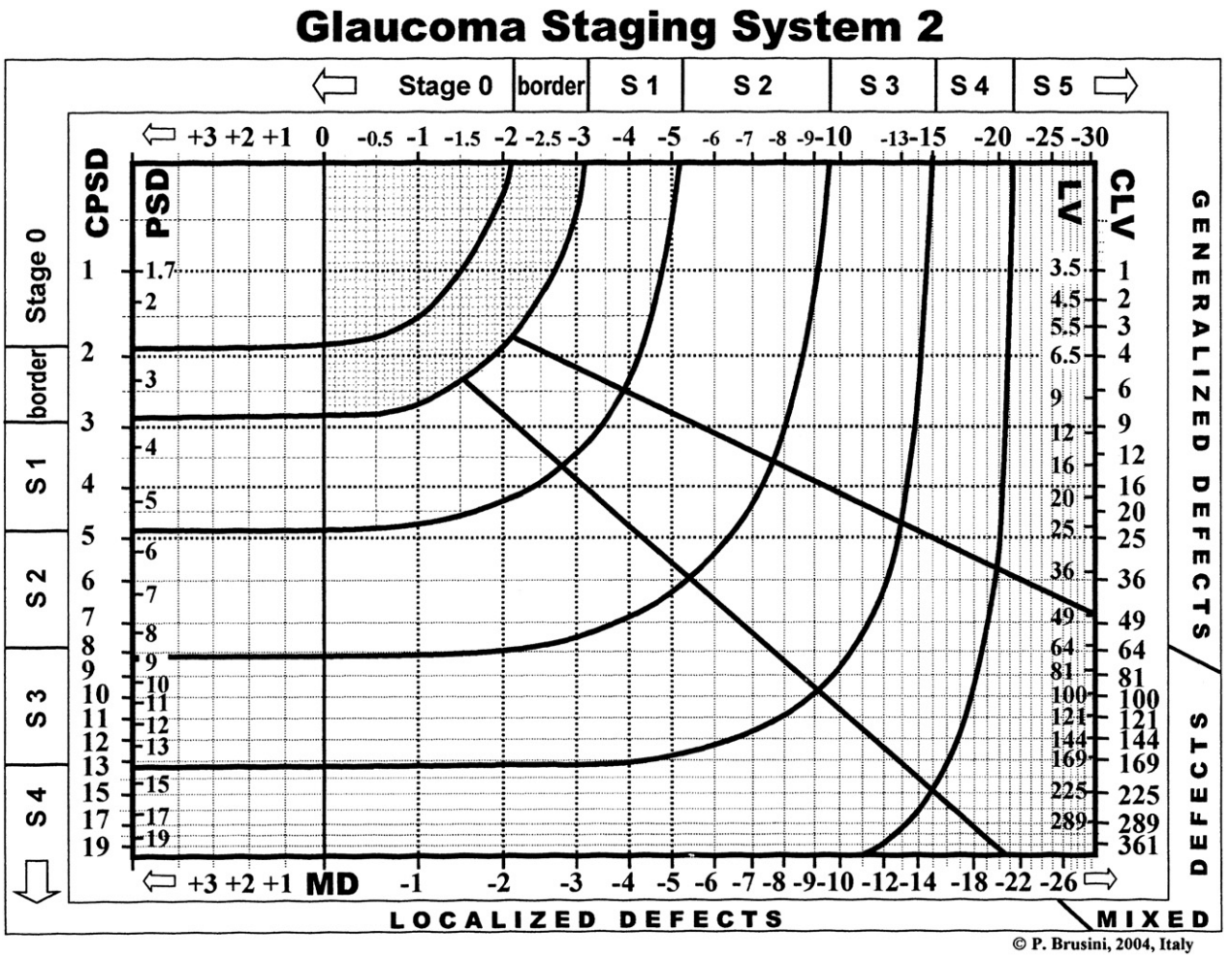


Fig. 6. Glaucoma Staging System 2. Reprinted from Brusini and Filacordia[23] with permission of the *Journal of Glaucoma.*

order to precisely classify cases in which the SF is not calculated (SF off, SITA strategy, G1-G2 program with only the first phase performed), or when a very high short-term fluctuation is present. The classification of visual field loss severity with this method is comparable to other classification systems, such as the H-P-A and the AGIS[23] methods. Both of these, however, are more time-consuming. The GSS and the GSS 2 are limited due to the fact that they are strictly based on two global indices, and thus can be affected by artifacts, and short- and long-term fluctuation. Moreover, they were not designed to supply any information on location, shape, or morphology of visual field defects. Different defects at times can thus be classified in the same manner.

The Functional Score (FS) is a perimetric index created by Weber in 1993,[12] which estimates the percentage of retinal ganglion cell loss from the HFA 30-2/24-2 threshold tests. The FS is obtained exclusively through the Peridata software (DOS version 6.3 β or higher). This index was used in 1997 (Brusini P: Classificazione del danno funzionale per mezzo del "Functional Score". Proc. 5ft Congress Italian Society of Perimetry, 1997, 86–87) to create a classification system, which appeared to give information on both the severity of visual field loss and on the structural damage in glaucoma. No other reports confirmed the clinical usefulness of this potentially interesting classification. Moreover, the FS index is no longer available in the new Peridata for Windows software.

E. METHODS BASED ON SAP BOX PLOTS

The box plot is a modified histogram that summarizes the visual field status in five numbers. This concept was proposed by Heijl et al in 1987,[49] and was then inserted in the Change Analysis printout of the Humphrey Statpac and in the Peridata software. The maximum negative deviation ("minimum"), the lower limit of the box, and the median value were used by Shin et al to create a five-stage classification method of visual field defect severity (Table 7).[85]

TABLE 7

Shin et al Classification Based on Box Plot Data

Stage 1: minimum –7 dB or better
Stage 2: minimum –8 dB or worse and lower limit of box –7 dB or better
Stage 3: lower limit of the box depressed from –8 to –21 dB
• Subgroup "a": median –4 dB or better
• Subgroup "b": median –5 dB or worse
Stage 4: lower limit of the box depressed to –22 dB or worse
• Subgroup "a": median –8 dB or better
• Subgroup "b": median from –9 to –15 dB
• Subgroup "c": median –16 dB or worse
Stage 5: median reaches –22 dB or worse

This system is objective and standardized—however, it is not very easy to use; it is time consuming, information on the morphology and location of a defect is not provided, and very different defects may result to be classified in the same stage. Moreover, an additional page with a box plot representation needs to be printed out. The box plot method has not attained widespread use, which is probably due to these limitations.

F. METHODS BASED ON CUMULATIVE DEFECT CURVE (BEBIE CURVE) PARAMETERS

The cumulative defect curve, better known as the Bebie curve,[15] provides an easy and reliable "at a glance" assessment of the local and diffuse components of the visual field loss. A cumulative defect curve has also been proposed for Frequency Doubling Technology (FDT) perimetry.[55]

Quantitative information regarding the severity and location of a defect, however, is very difficult to obtain with this method, because the curve was not created with this intention. In 1994 and 1995, Brusini et al (Brusini P, Tosoni C: Use of Bebie curve for perimetric damage staging in glaucoma. Octopus Users' Meeting, Lucerna, 22–24 March 1994; Brusini P, Barea P, Tosoni C: Nuovi metodi di classificazione del danno funzionale glaucomatoso per mezzo della perimetria. Boll Ocul 74, Suppl 2:231–8, 1995) described a complex classification method based on Bebie curve data, which offered a very precise differentiation of visual field defects in five classes, each of them subdivided into stages of different severity. This method has the disadvantage of being complex, time-consuming, and not suitable for a day-to-day use.

G. AUTOMATIC BUILT-IN CLASSIFICATION METHODS

Octopus Intelligent Box Plot (Octosmart-Octosoft –2EZ program, Interzeag, Octosoft-2EZ Operator Manual, 1988) is a bar graph, continuously displayed throughout the examination, which classifies visual field loss into five different levels, including a borderline stage. The defect levels correlate to both the MD and LV (or CLV) indices. A vertical bar, representing the MD value, indicates the defect severity, and the horizontal bar is an indicator of the confidence interval which is calculated from the LV value and number of test points measured. This bar become narrower as LV values become smaller and as the number of test points increase. Based on this continuous indicator, the perimetrist can decide whether or not further testing is needed. The Defect Level Indicator, in a similar semi-quantitative manner, is used to divide the visual field status into four severity levels. It was initially designed for the Octopus 1-2-3 perimeter (Octopus 1-2-3 Perimeter Digest, Interzeag AG, Schlieren, Switzerland, 1991, pp 22–23), and is now currently available on the Octopus model 101 & 301/311 (Fig. 7). This easy classification method can provide a quick and general glance of the visual field status.

A simplified qualitative classification of visual field status is also available for other automatic perimeters (Henson-Hamblin and Henson Pro:[51] normal, suspect, defect; Humphrey Statpac for Windows:[27] within normal limits, borderline, outside normal limits).

The formulas used in the GSS 2[23] have recently been added to the Oculus Easyfield perimeter software (Oculus Optikgeräte GmbH, Wetzlar, Germany), thus providing visual field defect information pertaining to both severity and type on the printout.

The Statpac Humphrey Glaucoma Hemifield Test (GHT) is a knowledge-based system which takes the pattern deviation probability scores of five zones in the upper field into consideration, and compares them to their corresponding mirror-image scores in the lower field.[48] The GHT classifies the threshold test results in five categories (Table 8).

The GHT was not created to stage visual field loss severity, but to detect the first signs of functional damage in glaucomatous patients, thus aiding ophthalmologists in the diagnosis. It has actually proven to be very sensitive in detecting early glaucomatous field loss, which is usually characterized by shallow localized defects.[7,8,58,89] It has become a widely used method for classifying a visual field as abnormal.[52] It does not, however, take into consideration slight diffuse sensitivity depression, which sometimes can be an early sign of glaucomatous

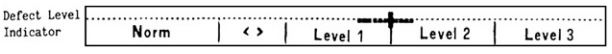


Fig. 7. Octopus Defect Level Indicator.

TABLE 8

Glaucoma Hemifield Test Classification

- Outside Normal Limits: Sensitivities in one or more of the five zones in the upper half of the field are significantly different ($p < 0.01$) from the sensitivities measured in the corresponding zones in the lower half of the field.
- Borderline: the sensitivity differences between zone pairs are greater than those seen in most normal subjects ($p < 0.03$), but do not reach the level required for the previous message.
- General Depression of Sensitivity: The point with the seventh highest deviation from normal is under the 0.5% probability level.
- Abnormally High Sensitivity: The best point locations are over the 0.5% probability level.
- Within Normal Limits: None of the above significance limits are reached.
- The dual statement "Borderline + General Reduction of Sensitivity" appears when a significant diffuse sensitivity depression is combined with an up-down difference at the $p < 0.03$ level.

damage. Moreover, the GHT does not differentiate between purely localized and mixed defects, which are both included under the "Outside Normal Limits" message.[21]

H. METHODS BASED ON NON-CONVENTIONAL PERIMETRY DATA

Frisén's High-pass Resolution Perimetry (HRP) is a non-conventional visual field testing technique, which appears to preferentially evaluate the parvocellular pathway. It determines spatial resolution thresholds with the use of ring-shaped, high pass, spatially filtered targets.[36] Several visual field indices are calculated in HRP. The "Neural Capacity" (NC) index, expressed as a percentage in relation to normal, is quite interesting because it appears to provide pertinent information on the functional retino-cortical neural channels that are still active in the tested eye. This information can aid in quantifying the extent of the structural damage. In 1993, Brusini and Miani (Brusini P, Miani F: Impiego della stima dei canali neurali retino-corticali per la stadiazione del glaucoma cronico ad angolo aperto. Boll Ocul 72, Suppl 2:159–68, 1993) proposed a five-stage classification based on the values of this index, which gives information on the structural status of the affected eye. The instrument (Ring perimeter), however, has not been of common use and is no longer commercially available.

FDT is one of the most interesting and widely used non-conventional methods of visual field testing currently available.[4,22,53,68,81,91,93] This technique selectively analyzes retinal ganglion cells of the magnocellular system, which have a very low redundancy. The test uses stimulus patterns of low spatial frequency sinusoid gratings (alternate vertical dark and light bars) and high temporal frequency counterphase flicker. FDT has been used by various authors, in the classification of visual field loss severity.

Patel designed an algorithm based on FDT data,[76] using the C-20 screening test: a value of 1 is assigned to the outside 12 points; a value of 3 to the inner four loci; and a value of 5 to the fixation (weighing factor). Each point is graded from 0 to 3 on the basis of the depth of the defect. Normal areas are assigned a 0 value, mild defects are graded as 1, moderate as 2, and severe as 3, on the basis of the gray-scale printout. This score is then multiplied by the weighing factor. A final score is determined by summing all abnormal points. Scores range from 0, for a completely normal test, to 87, for a test in which all points are missed at the maximum threshold. A similar "Abnormality score" was proposed by Brusini and Tosoni in 2003.[25] All these scores, however, tend to be time-consuming and not quite applicable in a clinical setting.

A clinical classification using the FDT probability map of the N-30 threshold test was also proposed by the same authors.[25] This method subdivides visual fields into four categories (normal test, early defect, moderate defect, severe defect), based on the number and location of statistically abnormal points. This classification is also quite time-consuming, requiring an analytical assessment of the numerical maps.

A new two-axis diagram, called the FDT Staging System, reporting FDT MD and PSD indices on the *x* and *y* axis, respectively (Fig. 8) has recently been proposed by Brusini.[18,25,26]

This system, which was originally designed for the N-30 threshold test, classifies defects into six stages (ranging from stage 0, for completely normal tests, to stage 5, representing very advanced damage) and in three types (generalized, mixed, and localized). The cut-off lines that divide the defect in stages, along with those that divide the defect in three different types, have all been designed along the same lines as those used in the GSS. The FDT Staging System is a quick method to quantify functional loss severity with FDT in a routine clinical setting. FDT indices generally show some variability, which can affect both the precision and the reproducibility of classification methods like this one, especially in cases of early damage. A new improved version of this system, which can also be used with the current Humphrey Matrix N-30-F, 30-2, and 24-2 threshold tests, has been recently published.[24]

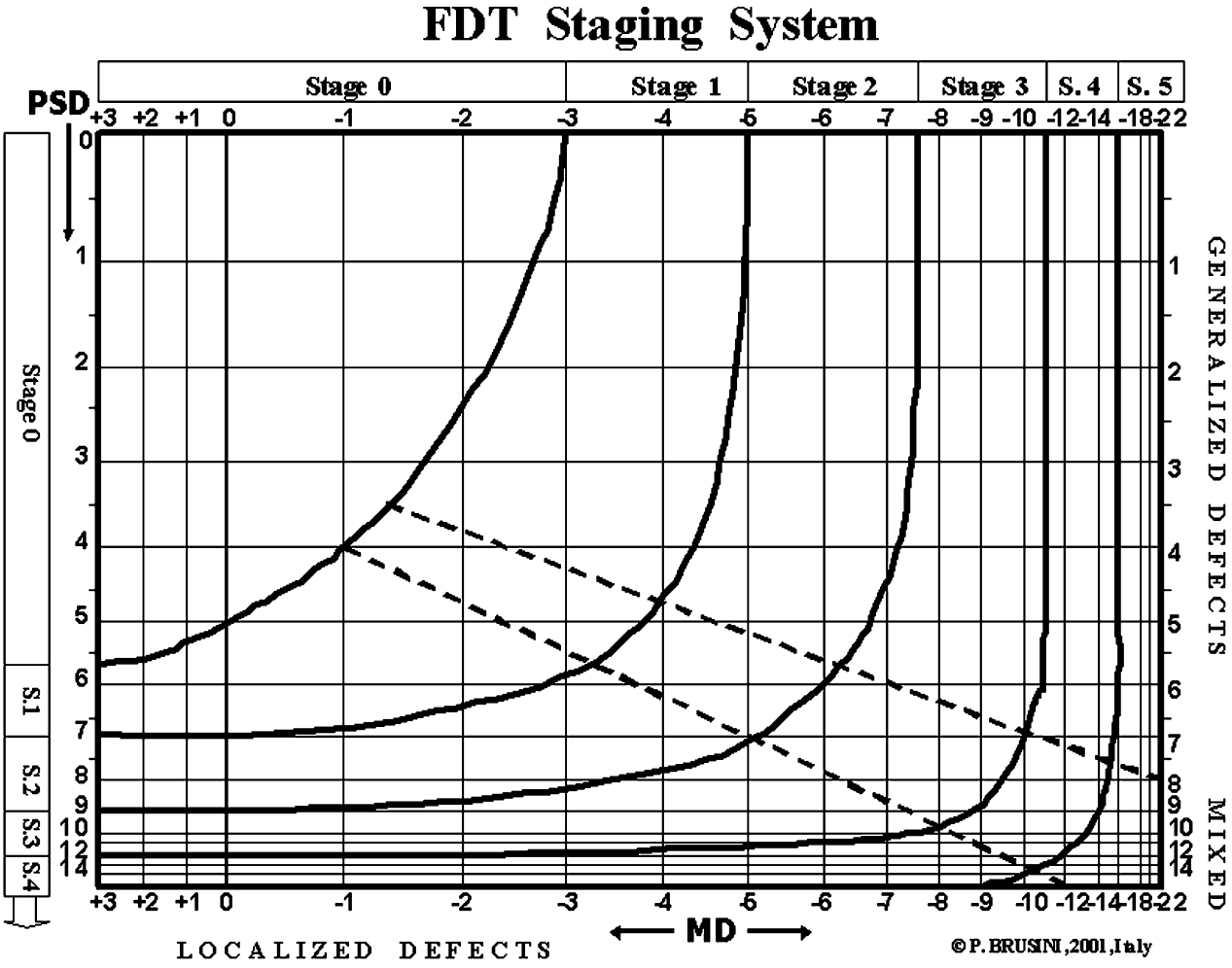


Fig. 8. FDT Staging System. Reprinted from Brusini and Tosoni[25] with permission of the *Journal of Glaucoma.*

In 1998, Sponsel et al used the FDT C-20 threshold test data to differentiate defects into three severity classes:[87]

1) Early visual field loss: more than 4 abnormal sectors at 1% to 5%
2) Moderate visual field loss: either 1 abnormal sector at 0.5% or more than 13 sectors at 1% to 5%
3) Severe visual field loss: more than 1 abnormal sector at 0.5%

This algorithm demonstrated a good correlation (73% precise parity; 93% parity within one grade) with the H-P-A classification for SAP data (HFA 30-2 test). Very early defects, however, can be missed.

There are currently no methods available for staging FDT defects that have had widespread or international acceptance. This issue has not attained great interest yet, probably because FDT, like short wavelength automated perimetry (SWAP), is primarily used in the early detection of glaucomatous loss and SAP is still considered the gold standard in visual field testing.

III. Classification of Characteristics of Visual Field Loss

The separation of local and diffuse components of visual field loss is an important step in the assessment of glaucomatous patients, seeing that different defects may result from different pathogenic mechanisms. While localized defects are considered a typical sign of perimetric glaucoma damage, a generalized sensitivity depression is a non-specific finding, and may arise from clouded media and/or miosis. The presence of a generalized depression has been considered by some in the past to be a clear sign of glaucoma,[29,30,50] although others have recently contested this finding.[6,47] Different methods can be used to differentiate the type of visual field defect.

A. VISUAL FIELD INDICES

It is known that uniform generalized defects have a specific effect on the MD index, and localized defects affect the PSD (or LV).[14] An increased MD value with a normal PSD (or LV) is usually an indication of a diffuse loss, whereas a high PSD value associated with a normal or only slightly increased MD is indicative of a localized defect. If both these indices are abnormal, the results may be due to one of two situations: a) a generalized but non-homogeneous defect; or b) a large localized defect. A careful assessment of the other visual field data is of course mandatory, as these visual field indices at times may prove to be misleading due to artifacts or other conditions.

Other experimental visual field indices have been proposed in the past for the same goal (Langerhorst's General Reduction of Sensitivity index[65] or the Diffuse Loss index of Funkhouser[37,38]), however, these have not shown widespread use in the field of glaucoma assessment.

As previously mentioned, the GSS is a diagram in which MD and CPSD (or CLV) values are plotted.[20] Studies have shown that it provides a correct classification regarding the characteristic of visual field defects (generalized, localized, and mixed) in comparison with other classification methods.[21,23] Similar to the Bebie curve, however, it is not specific for glaucoma damage and does not take spatial information into consideration.

B. PROBABILITY MAPS

The Total Deviation and Pattern Deviation Probability Maps of the Humphrey Statpac 2 program (similar to those used in the Octopus seven-in-one representation of G1/G2 test results) are very useful in providing a precise differentiation of the characteristic of a defect (Fig. 9).[48,74]

The first map shows the statistical significance of all the differences between the actual point-by-point sensitivities and the normative age-corrected values. The second map shows the same data corrected for the individual sensitivity, calculated on the basis of the seventh most sensitive value in the Total Deviation Map, which is taken as the new base at a value of zero. In this representation, localized defects are strictly shown. The following three situations are possible:

1) An extensively altered Total Deviation map associated with a normal Pattern Deviation map: this condition is indicative of a purely generalized defect
2) The same points appear to be abnormal in both maps: in this case, a localized defect is most likely present
3) Both maps are altered but the Total Deviation map appears to be more affected than the Pattern Deviation map: this condition can be found when both the components of the visual field defects are present (mixed defect, see Fig. 9)

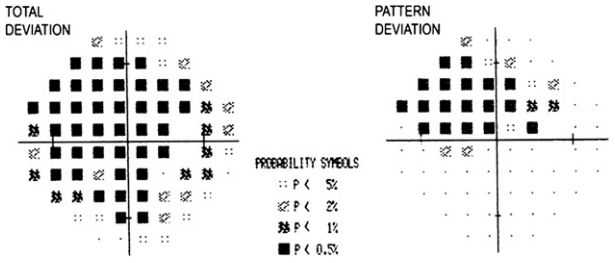


Fig. 9. Statpac Humphrey Total and Pattern Deviation Probability maps (mixed defect).

An extremely informative and useful method for both detecting the presence of visual field defects and distinguishing the characteristic of the loss, involves the assessment of the two probability maps. It is important to note here the Total Deviation map may be affected by all possible causes that can cause visual field defects (i.e., cataract), and thus should be considered as a non specific indicator of functional loss. The Pattern Deviation map, on the other hand, is very sensitive to artifacts (i.e., peripheral rim lens defects), which should always be considered when interpreting visual field printouts.

New color-coded probability maps, similar to the standard total deviation probability map, have been proposed by Åsman.[10] The symbols are plotted in four different colors based on specific criteria that could be useful, for example, in highlighting the effect of a cataract on the visual field status. Further research is needed to determine if and how this method of representing visual field can truly be useful in a clinical setting.

C. BOX PLOT

The box plot can be used to distinguish visual field defect characteristics. Based on the position, shape, and tail of the box plot, the defect can be classified into three types:[48]

1) Generalized defect: the box plot has a lower position in the graph, but its shape is unchanged (Fig. 10B)
2) Localized defect: a long negative tail is present, but the box is in its normal position (Fig. 10C)
3) Mixed defect: a long tail is associated with a depression of the whole symbol and/or with

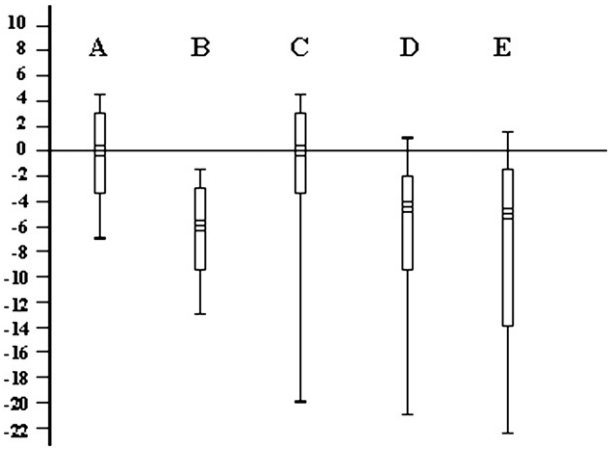


Fig. 10. Box plots representation of different types of defects. *A:* normal visual field; *B:* generalized defect; *C:* small localized defect; *D and E:* mixed defects.

a depression of the lower limit of the box (Figs. 10D and E)

Although this system seems to offer a precise and reliable differentiation of the characteristics of a defect, it is not commonly used, due to the scarce general knowledge of box plot philosophy. Other limitations include the fact that an additional page of data needs to be printed, information regarding the location of defects is not provided, different defects can have the same representation, and it is only available on Humphrey-Zeiss instruments or on Peridata software. These limitations may explain why it has not had great use in both clinical and scientific settings.

D. BEBIE CURVE

The Bebie curve represents the cumulative distribution of the local deviations from normal values.[15] All tested points are arranged according to the defect depth, beginning with the best points located in the left side of the graph, and gradually moving down the graph to the right as defects become worse. This type of representation is particularly helpful for a quick and immediate classification of the type of defect, specifically in differentiating a diffuse loss from a localized one (Fig. 11).

Other authors have proposed criteria that are slightly different. Funkhouser et al used different lengths and slopes of the depressed curve in defining diffuse loss.[37] Lachenmayr et al, on the other hand, characterized a diffuse loss when the curve falls below the 84th percentile in at least 80% of the values.[64] The intention behind all these methods was to provide standardized criteria based on the Bebie curve, which may prove to be useful in research. The shape of the curve, however, can supply rapid information as to the type of defect, which can be useful in a day-to-day clinical setting. A specific classification of defect characteristics, based on the Bebie curve data, was used by Brusini[21] (Table 9).

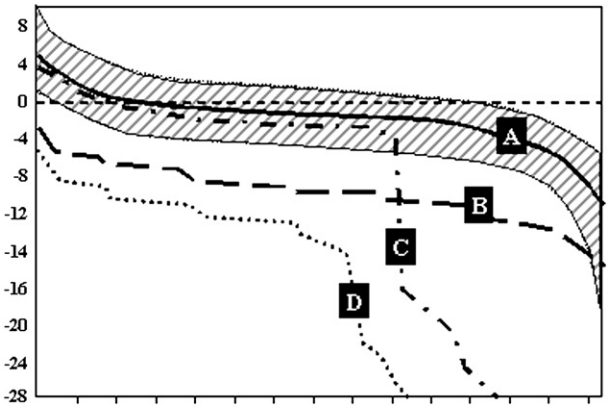


Fig. 11. *A:* normal visual field; *B:* diffuse loss; *C:* localized defect; *D:* mixed defect.

The Bebie curve can still be considered a smart, easy, and useful method for quick classification of visual field results. Misclassification can at times occur when using this curve, for example: visual fields having only a few points depressed are usually considered as normals, and a mixed defect may at times be classified as a diffuse loss when the right end of the curve falls within the 95th percentile

TABLE 9

Classification of Defect Characteristics Based on the Bebie Curve

1) Diffuse Loss:
   a) more than 60% of points under the 95th percentile
   b) the slope should be parallel to the normal curve (a departure from parallel less than 0.2 dB per location was retained as the maximum permissible)
   c) the plateau of depressed points start within the first 10 ranked locations
   c) no abrupt fall on the right side of the curve under the 95th percentile
2) Localized Defect:
   a) at least 40% of points are within normal limits
   b) the slope abruptly falls on the right side (these points must be under the 99th percentile)
3) Mixed Defect: the two components of visual field damage appear to be present:
   a) more than 20 locations have a diffuse defect, as previously described in the section mark 1, points b and c
   b) the right segment of the curve has a steeper gradient (a difference >5 dB between the mean point of this depression and the right end of the diffuse defect segment is required)
   d) cases that cannot be classified in the other two classes

Based on Brusini.[21]

limits. This is due to the loss of spatial information, as correctly pointed out by Åsman and Olsson.[9] The Bebie curve normative limits are based on values obtained in mid-peripheral areas, and thus significantly depressed points in the central field may fail to reach the 95% significance limit, which is very low at the right side of the curve.[9] Moreover, a cluster of clinically significant depressed points is considered in the same way as if the same group of depressed points were isolated and dispersed in the visual field.

Cumulative defect curves have recently been developed by Johnson and Spry to characterize visual field defects assessed by means of the FDT N-30 full threshold test.[55] These curves, based on a large normative database, are remarkably similar to those available on Octopus perimeters, and may be a helpful tool for distinguishing between diffuse and localized loss using FDT perimetry.

E. VISUAL FIELD PROGRESSION

As stated earlier, the ability to monitor small changes in functional loss over time is another important area in which staging of functional glaucomatous damage could be quite useful. Most of the investigations in this area have found that the ability to detect small pathology-related visual field changes in the presence of high inter- and intra-test variability is a major challenge, yet this decision remains as one of the most important aspects of patient management. A number of investigators have evaluated and compared many different procedures for monitoring glaucomatous visual field progression.[16,57,74,75,88,94] Readers who are interested in detailed information concerning visual field progression should consult these references. A brief overview of this clinical problem has been dealt with in a descriptive review.[88] Several common attributes have been noted by these investigators: 1) every longitudinal multicenter clinical trial has a different criterion concerning the definition of progressive glaucomatous visual field loss; 2) there are large differences in the clinical performance (sensitivity and specificity) of these analysis procedures; 3) suspected progressive changes must be confirmed by additional test results to maintain good performance; 4) the various methods of determining glaucomatous visual field progression agree with each other about 50–60% of the time; 5) variability is a major difficulty in being able to differentiate pathologic visual field progression from test–retest variability; and, 6) there is no consensus among investigators as to the best method of determining glaucomatous visual field progression at the present time. A glaucomatous visual field classification and staging system may be

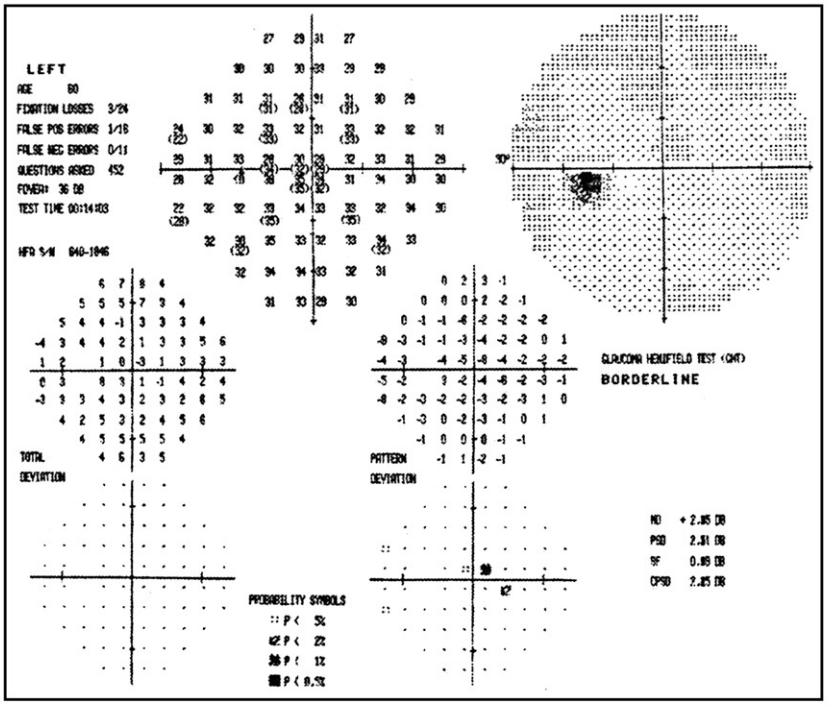
TABLE 10

*Characteristics Found in Various Classification Methods**

SYSTEM	No. of stages	Diagnostic ability	Ability in staging defect severity	Ability in distinguishing defect type	Ability in monitoring progression	Visual disability grading	User friendly	Standardized	Clinically tested	Widely used
Aulhom and Karmeyer	5	–	+++	–	+/–	–	+++	–	++	++
Esterman grid	Score 0–100	–	++	–	+/–	++	++	+++	+++	+
VF%	Score 0–100	–	++	–	+/–	+++	++	+++	++	– (++ in Italy)
Glaucoma Hemifield Test	No (5 VF categ)	+++	–	–	–	–	+++	+++	+++	+++
Hodapp-Parrish-Anderson	3	++	++	–	–	–	+	+++	+++	++
AGIS and similar	5 (score 0–20)	+	++	–	++	–	–	+++	+++	+/–
Bebie curve	No	–	+/–	+++	+/–	–	+++	+/–	+++	+++
TD-TP Probility maps	No	+++	+	++	+	–	++	- (for staging)	++	+++
GSS-GSS2	5 (6 in GSS2)	–	+++	+++	+	+/–	+++	+++	++	+/– (+++ in Italy)

VF% = visual field percent, VF categ = visual field categories, AGIS = Advanced Glaucoma Intervention Study, TD-PD = Total and Pattern Deviation, GSS= Glaucoma Staging System.

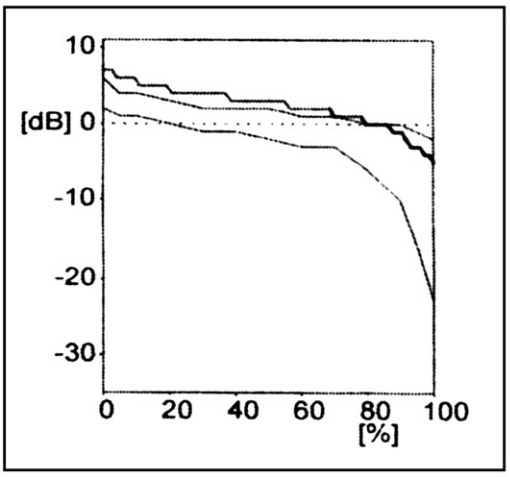
*Qualitative scores, ranging from – (bad) to +++ (very good), are based on both published literature and personal experience.



Aulhorn and Karmeyer: normal visual field

H-P-A: normal visual field

AGIS: score=0: normal visual field



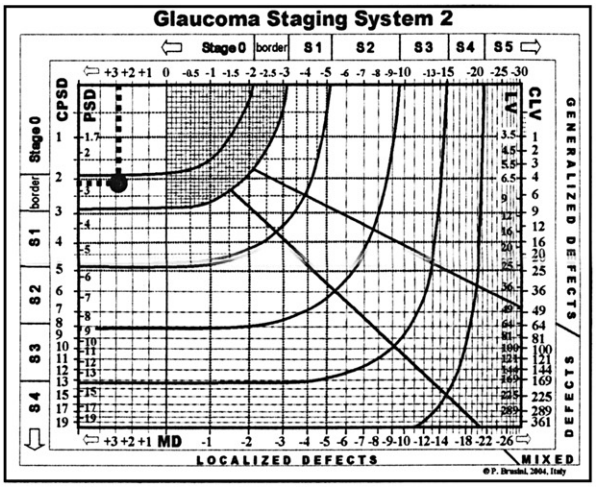
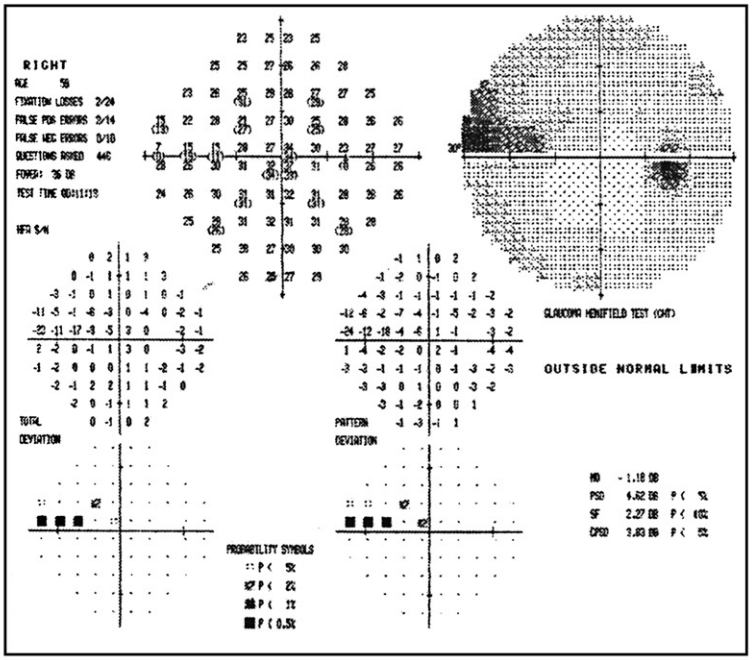
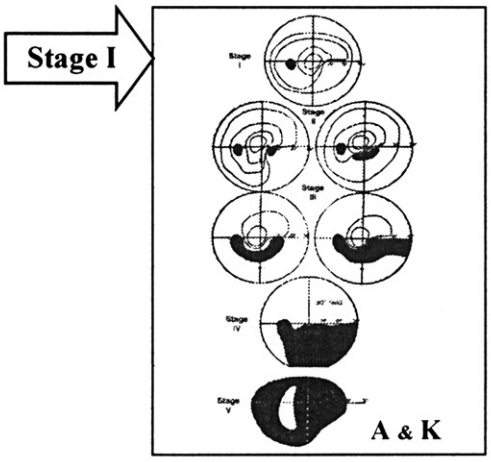


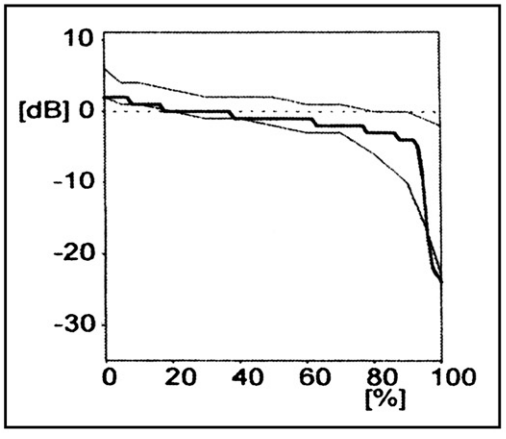
Fig. 12. Visual field with a subtle paracentral defect. GHT is "borderline". Visual field indices are all normal, and sensitivity is slightly above normal (MD = +2.95 dB). Total Deviation map is completely normal, whereas the Pattern Deviation map shows two significantly abnormal paracentral points in the superior hemifield and one abnormal point in the inferior nasal quadrant. A & K, H-P-A (cluster of only two points in the superior hemifield; third point crosses the horizontal meridian and is thus not part of the cluster), and AGIS methods all classify this visual field as normal. Bebie curve is almost completely over the 5° percentile, apart from the right side of the curve. GGS 2 indicates a "borderline defect".





H-P-A: Early defect (MD better than -6 dB; less than 18 points p<5% and 10 points p<1% in the Pattern Deviation map; all points in the central 5° have a sensitivity of at least 15 dB)

AGIS: score=3: mild damage (For a nasal defect or nasal step, add one to the score; add one to the score if there are 3 to 5 depressed test sites in the clusters; add one if half or more are depressed 12 dB or more)



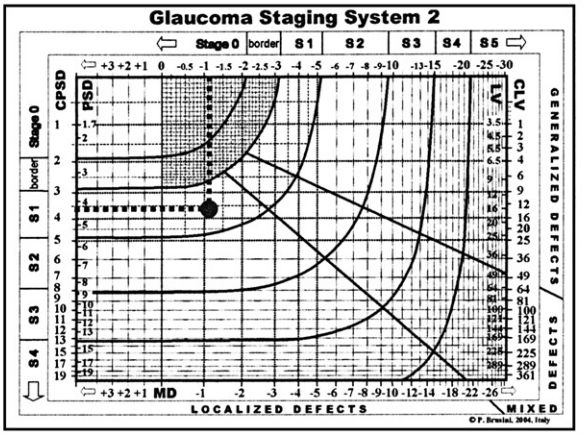
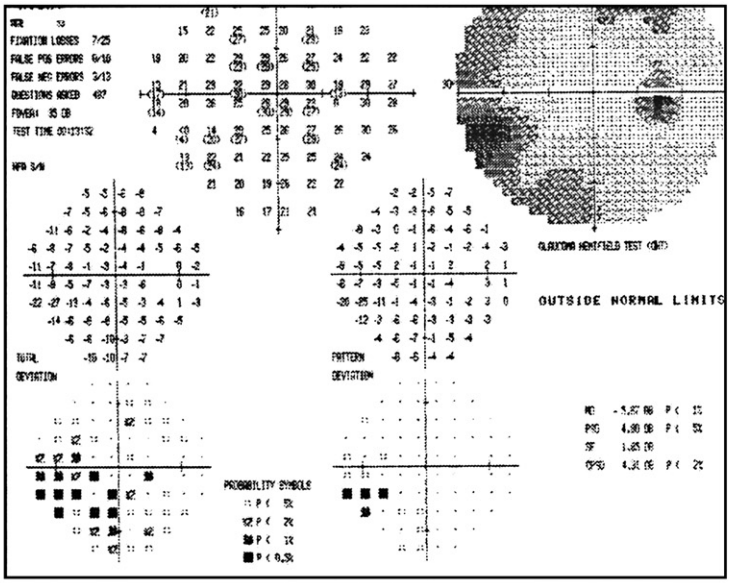
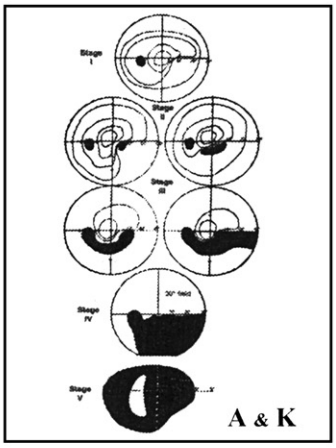


Fig. 13. Peripheral superior nasal step. GHT is "outside normal limits". MD is within normal limits, whereas PSD and CPSD are significantly abnormal, suggesting the presence of a small localized defect. Probability maps are pretty much identical, indicating a purely localized defect. A & K method classifies this visual field as Stage I. H-P-A method classifies the defect as "early defect", and AGIS method considers it as "mild damage". Bebie curve clearly shows an abrupt falling on the right, indicating a small localized defect. GSS 2 classifies the defect as "localized defect - Stage 1".

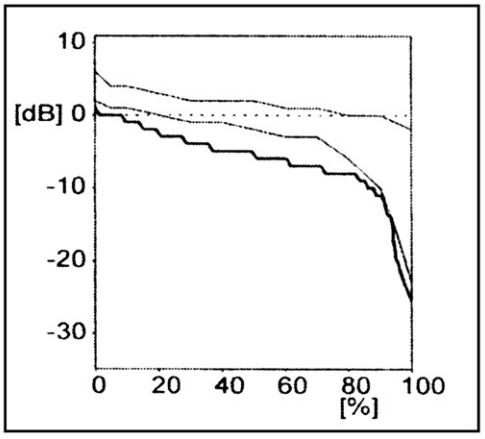


Stage II



H-P-A: Early defect (MD better than -6 dB; less than 18 points p<5% and 10 points p<1% in the Pattern Deviation map; all points in the central 5° have a sensitivity of at least 15 dB)

AGIS: score=4:mild damage (For a nasal defect or nasal step, add one to the score; add three if there are 13 to 20 depressed test sites in the clusters)



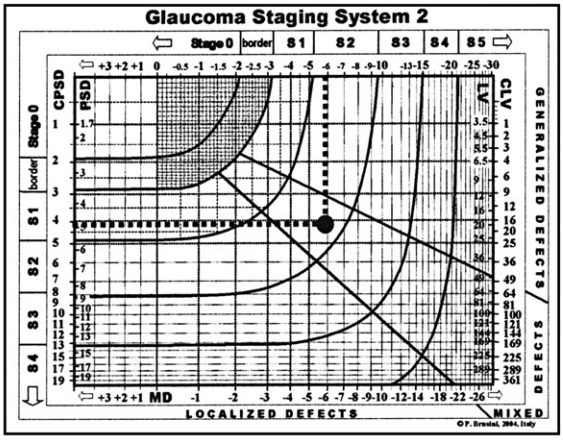
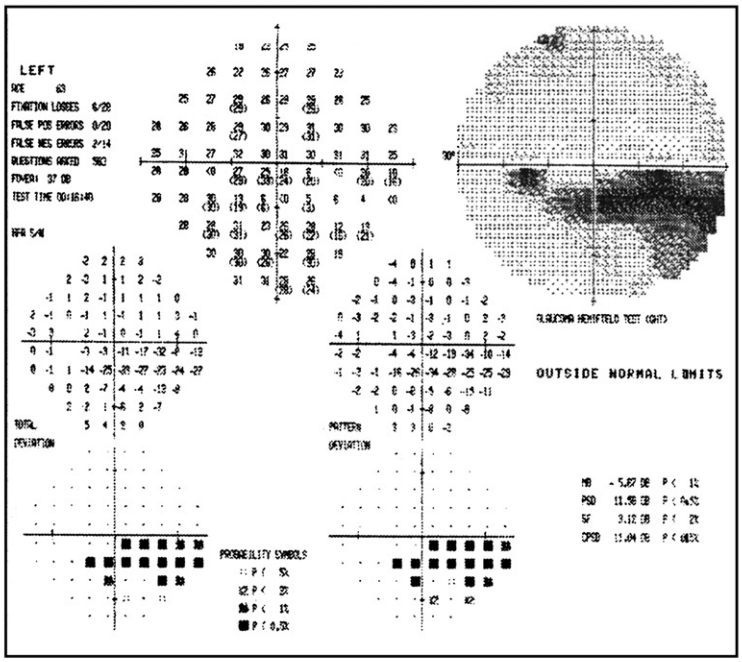
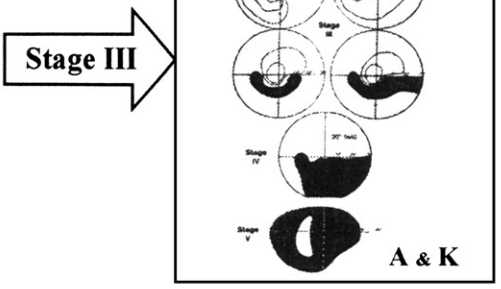


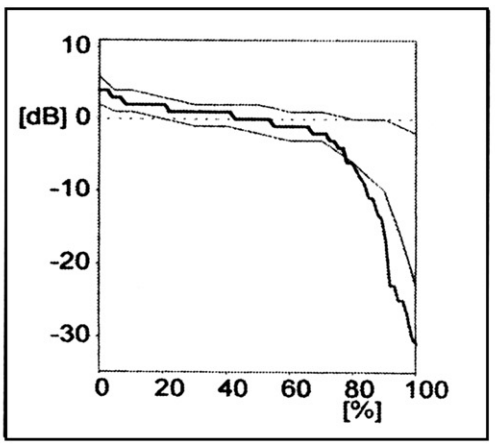
Fig. 14. Visual field with an inferior nasal defect and a widespread diffuse sensitivity depression. GHT is "outside normal limits". Both MD and PSD/CPSD indices are significantly abnormal, suggesting a mixed defect. Total Deviation map shows a larger defect than the Pattern Deviation map, thus suggesting a mixed defect. A & K method classifies this visual field as "Stage II". H-P-A method classifies this as an "early defect", and AGIS method considers it as "mild damage". Bebie curve shows a depression in the first part of the curve and a fall on the right (mixed defect). GSS 2 classifies the defect as "mixed defect - Stage 2".





H-P-A: Moderate defect (more than 10 points p<1% in the Pattern Deviation map)

AGIS: score=7:moderate damage (For a nasal defect or nasal step, add one to the score; if four or more of the six nasal test locations are depressed 12 dB or more, add one; add three if there are 13 to 20 depressed test sites in the clusters; if half or more of the adjacent defective locations in a hemifield are depressed 16 dB or more, add two.



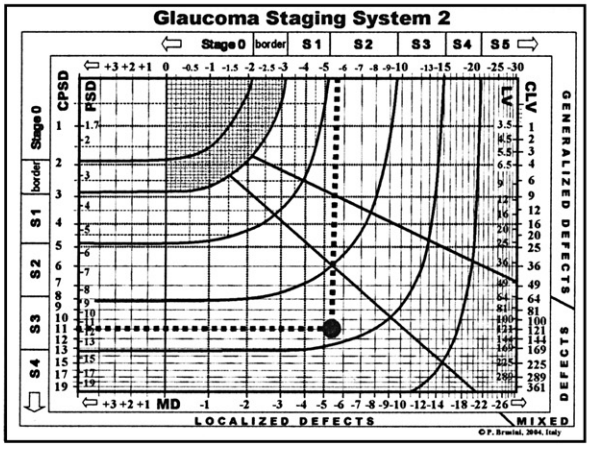
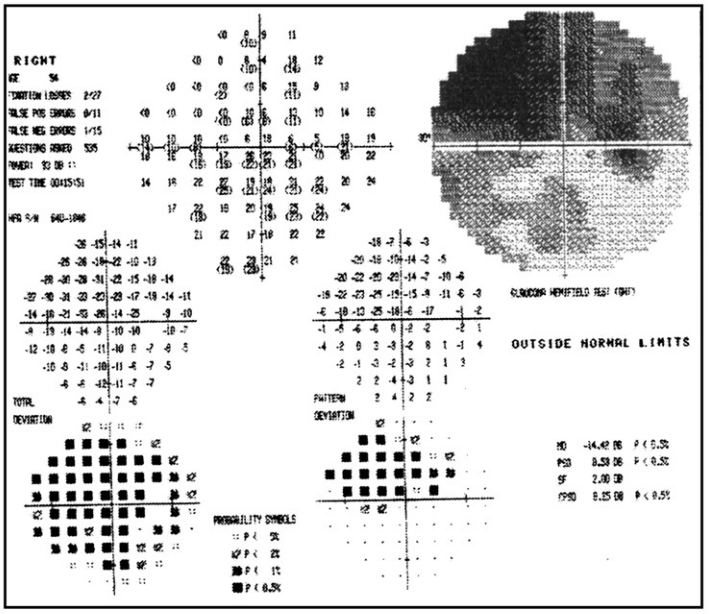
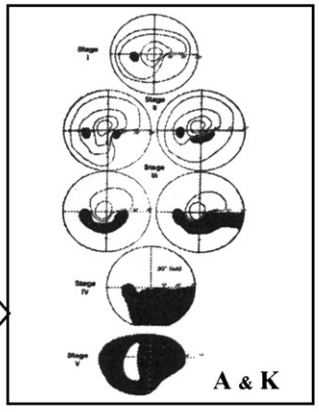


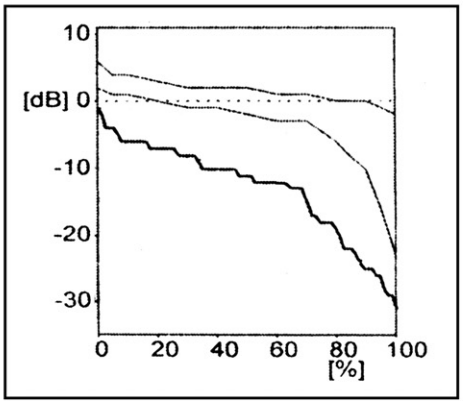
Fig. 15. Deep inferior arcuate scotoma. GHT is "outside normal limits". All visual field indices are significantly abnormal, especially PSD/CPSD, suggesting a large visual field defect. Probability maps both show a highly significant defect, indicating a localized loss. A & K method classifies this visual field as "Stage III". H-P-A method rates the defect as a "moderate defect", similar to AGIS method that considers it as "moderate damage". Bebie curve shows a deep fall on the right (large localized defect). GSS 2 classifies the defect as "localized defect - Stage 3".





H-P-A: Severe defect (MD greater than -12 dB)

AGIS: score=13: severe damage (For a nasal defect or nasal step, add one to the score; if four or more of the six nasal test locations are depressed 12 dB or more, add one; in any hemifield, add four if there are more than 20 depressed test sites in the clusters; if half or more are depressed 20 dB or more, add three)



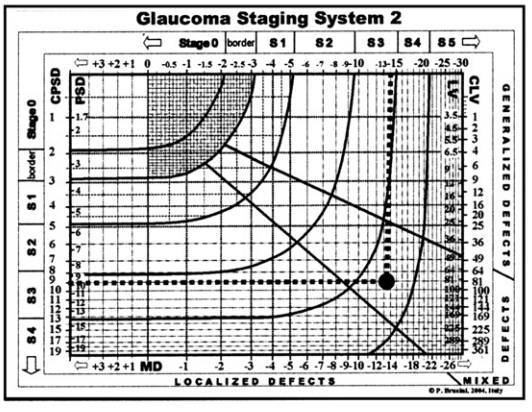


Fig. 16. Large and deep superior defect with a sensitivity depression that affects the entire visual field. GHT is "outside normal limits". All visual field indices are significantly abnormal, suggesting a severe visual field defect. Probability maps both show a highly significant defect, but Total Deviation map defects are greater than Pattern Deviation map, indicating a mixed loss. A & K method classifies this visual field as "Stage IV". Both H-P-A and AGIS methods rate the defect as "severe". Bebie curve shows that the entire curve is affected, and the shape suggests a large mixed defect. GSS 2 classifies this defect as "mixed defect - Stage 4".

quite helpful in deriving a useful and simple method of addressing this problem.

IV. Conclusions

In dealing with primary open angle glaucoma, it is helpful to have a reliable staging of visual field defect severity. An accurate separation among various defect types can also be useful. An analytic method of classification could also be very useful in following the progression of functional damage over time. Most methods of classification have little, if any, clinical usefulness. Two case scenarios can be useful to explain why any one method has failed to have a widespread acceptance: 1) the method is simple and easy, however, it is subjective, not standardized, and has a poor reproducibility; or, 2) the method is accurate and standardized, but is too time-consuming, and requires complicated calculations or software which is either rarely used or not easily available. The choice regarding what method is best naturally depends on the purpose it intends to serve, which needs to be quick and easy in a routine clinical setting, yet standardized and precise in scientific research studies. No method currently used is perfect. Moreover, one must also keep in mind that perimetry, in itself, is a subjective psychophysical testing method, and thus any classification system that is based on this type of data can never be completely accurate and reproducible.

It can be difficult to choose the appropriate classification method from so many that have been proposed over the past years. Table 10 has been added to serve as a practical and easy guide to help in the decision-making process as to what method is best suited for different needs. The table ranks some of the currently used methods according to the following headings: stage system and number of stages utilized; glaucoma diagnostic ability; defect severity staging; defect type characterization; progression monitoring; disability severity assessment; user friendliness; standardization; clinically tested; and, widespread use. The table lists classification methods that specifically use SAP results, which continues to be considered as the gold standard in POAG management. It is important to note that the Aulhorn and Karmeyer method uses the SAP gray scale plot (Table 10).

V. Summary

Primary open-angle glaucoma severity loss must be taken into consideration when taking both prognostic and therapeutic decisions. Glaucomatous damage can presently be quantified using either structural or functional loss criteria, or a combination of both. An accurate structural assessment of both the optic disk and retinal nerve fiber layers usually requires sophisticated and expensive technology. Standard automated perimetry currently tends to be used as the gold standard for the quantification of glaucomatous functional loss. It would be very useful in glaucoma research and in the clinic to have a common standardized method that not only stages visual field defect severity, but also provides information on defect type. Although visual field testing is computer-assisted, it still remains to be a subjective procedure, with a physiological variability component that is usually unavoidable. A perfectly standardized and reproducible staging method is thus not possible. Many staging systems have been proposed in the past 40 years. Some of them are based on the number of depressed points either in the total or pattern deviation maps of SAP; others use visual field indices; whereas others utilize different parameters or non-conventional visual field testing techniques. A widespread standardized classification method to stage glaucomatous severity and defect type could be advantageous in both the field of research and in daily clinical practice, and thus emphasis should be placed in achieving this goal and standardizing these procedures on an international level.

VI. Method of Literature Search

This review was based in part upon articles published in peer-reviewed journals indexed in PubMed. Searches include various combinations of the following terms: *visual field classification, perimetry, automated perimetry, non-conventional perimetry, open-angle glaucoma, glaucomatous functional loss, and functional defect classification in glaucoma.*

Dates of articles retrieved from PubMed ranged from 1975 to 2006. Some older key references were also cited in this paper. Additional articles came from the proceedings from the International Perimetric Society. Some books, which specifically deal with the topic of perimetry, were also considered. Non-English articles were also included, based on the authors' discretion. These studies were translated and thoroughly analyzed.

VII. Appendix

Five visual field results (ranging in defect severity) have been taken as examples to classify the same defects by different methods, in order to give a clearer practical explanation of the various

methods (Figs. 12–16). The GHT test results have been included, in addition to comments regarding the visual field indices and the Total and Pattern Deviation probability maps. The defects have been classified according to the following methods: 1) Aulhorn and Karmeyer (A & K), based on the gray scale plots; 2) Hodapp-Parrish-Anderson (H-P-A); 3) AGIS score; 4) Bebie curve, obtained from PeriData Windows data (PeriData Software GmgH version 2.0, Huerth, Germany); and 5) Glaucoma Staging System 2 (GSS 2).

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