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For Healthy Sight
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Visual Field Testing in Glaucoma

It is very difficult to define glaucoma only with the characteristic parameters such as measurement of intraocular pressure (IOP), assessment of chamber angle, optic disc size, nerve fiber layer thickness, visual field testing etc. The disease may be present with abnormalities of only one of the above characteristics or sometimes presence of combination findings.

However, it is evident that glaucoma causes nerve fiber damage. Therefore detection of nerve fiber damage and correlating other clinical findings is better approach to understand and define glaucoma.In this perspective changing definitions of various time have been proposed some of which are mentioned below:

- A multi-factorial optic neuropathy in which there is a characteristic acquired loss of optic nerve fiber.
- Glaucoma describes a group of diseases that kill retinal ganglion cells.
- High IOP is the strongest known risk factor for glaucoma but it is neither necessary nor sufficient to induce the neuropathy.

Recently proposed ones :

- Glaucoma is a progressive neurodegenerative disorder.
- Effects of retinal ganglion cell loss on magno-, parvo-, koniocellular pathways in the geniculate nucleus and visual cortex in glaucoma.

Besides other glaucoma tests it is very important to do visual field test which actually gives information regarding extent, type and depth of visual field defect resulting from nerve fiber damage. In the later stages of glaucoma the visual field provides essential information about whether the glaucoma is stable or is getting worse. But understanding and interpreting visual field often become difficult due to lack of analytical information of visual field parameters found in the print out. In this concern we attempted to elaborate visual field testing for better understanding of the issue.

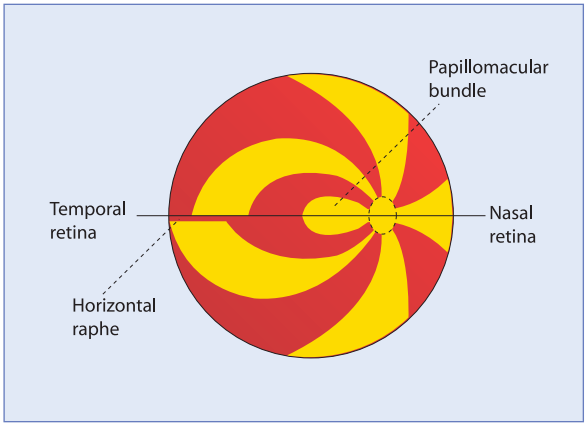

Figure 1 : Nerve fiber disposition

Tests & Examinations for Glaucoma

a. ntraocular pressure (IOP) measurement using Goldmann applanation tonometry (slit lamp mounted), central corneal thickness (CCT) measurement, peripheral anterior chamber configuration and depth assessments using gonioscopy, visual field measurement using standard automated perimetry (central thresholding test), optic nerve assessment with dilatation using stereoscopic slit lamp, and biomicroscopy with fundus examination.

b. Nerve fiber layer analyzers

- GDx, Optical coherence tomography (OCT), Heidelberg tomograph.

c. Others

- Ocular blood flow measurement
- Ultrabiomicroscopy (UBM)

Normal Visual Field

The limit of the normal visual field is 60^0 into the superior field, 75^0 into the inferior field, 110^0 into the temporal field and 60^0 into the nasal field. Traquair, in his classic thesis, described an island of vision in the sea of darkness. The island represents the perceived field of vision and the sea of darkness is the surrounding areas that are not seen. In the light-adapted state, the island of vision has a steep central peak that corresponds to the fovea, the area of greatest retinal sensitivity.

Visual Field Testing (Perimetry)

The retina is composed of receptors, “photoreceptors,” that change light energy into electrical energy. Each photoreceptor's signal is then picked up by a special nerve cell called ganglion cell. Thus, each ganglion cell is responsible for "connecting" a portion of the retina to the brain. There are millions of ganglion cells and any disruption in the function of these cells will block the signal's transmission of portion of the retina, and the accompanying visual field becomes less sensitive to light.The test is to document the level of peripheral vision consists basically of responding every time a flash of light is perceived, all the while looking straight ahead. Understanding the various parts of the print-out of results, is the way of understanding more about visual field testing.

Perimetry is the systematic measurement of visual field function. The two most commonly used types of perimetry are *Goldmann kinetic perimetry* and *threshold static automated perimetry*. With Goldmann or "kinetic" perimetry, a trained perimetrist moves the stimulus; stimulus brightness is held constant. The limits of the visual field are mapped to lights of different sizes and brightness. With threshold static automated perimetry, a computer program is selected. The most commonly used one tests the central 30° of the visual field using a 6° spaced grid. This is accomplished by keeping the size and location of a target constant and varying the brightness until the dimmest target the patient can see at each of the test locations is found. These maps of visual sensitivity, made by either of these methods, are very important in diagnosing diseases of the visual system. Different patterns of visual loss are found with diseases of the eye, optic nerve and central nervous system.

Terminology Related to Perimetry

Hill or island of Vision– Traquair's apt comparison of the visual field to an island or hill of vision surrounded by a sea of blindness, depicts the visual field as a three-dimensional spatial model.

The contour of the island represents various levels of retinal sensitivity, the narrowest peak is the fovea (greatest sensitivity) while the outer borders correspond to the least sensitive areas in the peripheral field.

Threshold : It is defined as the dimmest target perceived by the patient at a given discrete point; psychophysicists define the term as the ability to perceive a stimulus 50% of the time. The sensitivity of the eye varies from moment to moment and from day to day and this needs to be considered in the designing of visual field tests.

Isopter: A line within the visual field which connects points of equal sensitivity or threshold is defined as an isopter.

Brightness: Brightness is defined in terms of decibels (dB) and apostilbs (asb).

Decibels: Decibels can be thought of as a relative, logarithmetic, unit of change in stimulus brightness. A decibel is one-tenth of a log unit i.e. 10.

Basics of Illumination in Preimetry

Illumination intensity, and/or brightness is expressed in apostilbs on the basis of logarithms. The statement $10^2 = 100$, can be expressed in another form by using Logarithms, abbreviated LOG. Instead, of saying that “10 exponent 2 equals 100 we can say the logarithm of 100 to the base 10 equals 2,” (LOG10 100 = 2). Likewise LOG1010,000 = 4, LOG1010,0000 = 5, LOG1010 = 1, LOG101 = 0 and LOG10.0.1 = -1 and so on.

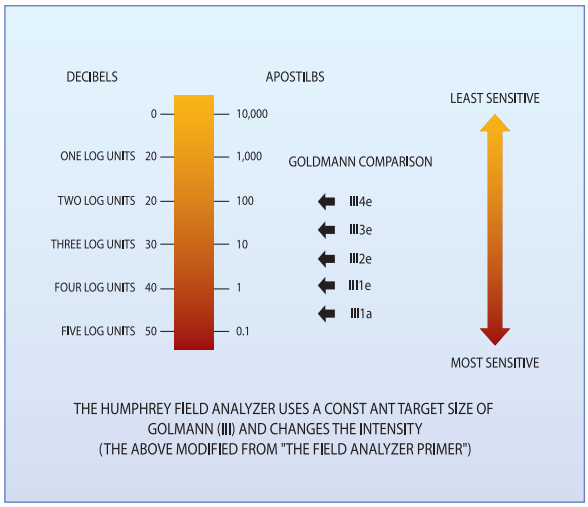

Fig. 2 : Light illumination and intensity

The intensity range of the Humphrey Field Analyzer is from 10,000 to 0.1 apostilbs (asb). The term apostilbs relates to luminance of a given test target being projected on to the interior of the white bowl of the machine.These values in apostilbs are converted to logarithms and then to decibels (dB).The term decibels is a relative value which expresses the attenuation from maximum intensity of 10,000 asb.

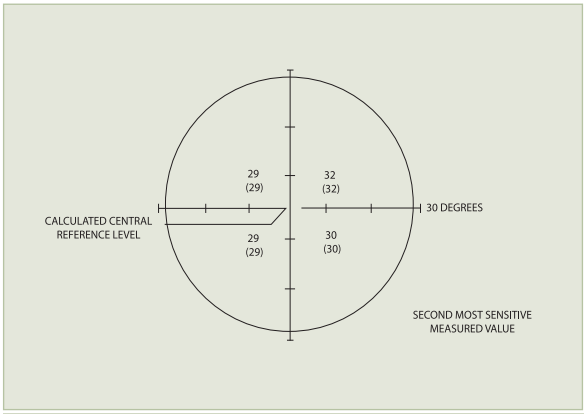

Fig. 3 : Bracketing numerical

Using This Concept
10,000 ASB = 0 dB
1000 ASB = 10 dB
100 ASB = 20 dB
10 ASB = 30 dB
1 ASB = 40 dB
0.1 ASB = 50 dB

That is1dB = 0.1 LOG UNIT and 10dB = 1 LOG UNIT. The graphic (Fig. 2) may further help explain the concept.

The Humphrey Field Analyzer uses a constant target size equal to a Goldmann "III" and varies the target brightness only. The standard field analyzer target size GOLDMANN "III" (4 mm^2) can be changed if a larger, say GOLDMANN "V" (64 mm^2) or smaller GOLDMANN "I" (1/16 mm^2) target size if needed for severely disturbed fields or in clinical research. It compares the patient's test results against this model to determine how their threshold results, for each tested point, compares or falls outside the normal population model.

The values in parentheses (Fig. 3) shows that point has been tested twice and the system uses the average of the two values to make other calculations. The second most sensitive value is used to calculate the expected height of the central hill of vision, known as the central reference level. It is indeed possible that actual values measure might be below the calculated value or expected value. If the value is lower than the expected value for a given patients age this will be expressed in the Total Deviation as a negative number say (-1) showing it is 1 decibel below the expected value. These negative values become diagnostic when they reach (-5) or greater and more so if there are several group together. The parameters for most automated perimeters are loosely based on a hill of vision where the central five (5) degree's sensitivity, in decibels, is in the low to mid 30 decibels, from five (5) to thirty (30) degrees sensitivity is in the mid to upper 20 decibels and beyond thirty (30) degrees the sensitivity is in the teens to low 20 dB

Reliability Factors

Fixation Losses: The Humphrey field analyzer periodically checks the patient's fixation by presenting stimuli within their blind spot (Heijl-Krakau Technique). When the number of fixation losses is greater than 20%, a symbol (XX) will appear next to the fixation losses to alert the doctor there is reason for concern.

False negative errors: A brighter stimulus is presented at a test point in the field that was earlier reported, as being seen, having "Normal Sensitivity" but now the patient does not respond to the bright stimulus. High, false negative scores might indicate fatigue or inattentive patient.

False positive errors: The projector makes a noise when it moves and the patient responds to the sound though no stimulus has been presented. The patient is responding to outside factors or trying to outguess when the stimulus will be presented. A high false positive score indicates that the patient is “Trigger Happy”.

Interpretation

Fluctuation Factors : Short-Term: Relative normality is less than 3dB when the same point is tested twice and is usually between 1dB and 2dB during a given test period. There are two reasons for an abnormal Short-Term Fluctuation (SF) – inattentive patient or a patient with a diseased visual system.

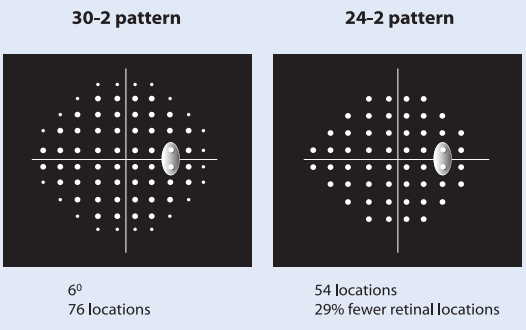

Fig. 4 : 30-2 and 24-2 pattern

Low fluctuation: < 1.5 dB
Normal fluctuation 1.5dB TO 2 dB
Medium fluctuation >2 dB BUT < 3 dB
High fluctuation >3 dB

Grayscale: It is for the patients benefit; for their interpretation or understanding. It represents tested points and non-tested intermediate points, which have been assigned values, interpolated from surrounding points. It tells the doctor nothing about the depth of a scotoma.

Total Deviation: These numeric values represents the difference in decibels between the patient's test results and the expected age-corrected normal values at each test point in the visual field. The plot just below this finding are graytone (symbols) which shows the statistical significance for a given test value. These are based on the deviation from expected normal patient's threshold profiles. The darker the pattern (symbol) the more significant the deviation from the expected threshold.

Pattern Deviation: This plot is similar to the Total Deviation except the STATPAC attempts to adjust the analysis of the test results for any overall changes in the height of the measured hill of vision caused by say cloudy media, cataracts or small pupils. Hence, this numeric pattern deviation plot shows the deviation in decibels from the age-corrected normal values, adjusted for any shifts in overall sensitivity. The plot just below this finding are again graytone (symbols), which show the statistical significance of the results at each point. The darker the pattern (symbol) the more significant the deviation from the expected threshold.

Probability of Abnormality: The P value represents the probability where a patients findings have deviated from the expected normal values. The probability statements is based on the Hill Of Vision distribution seen in the normal population. This P value is computed from the total deviation and the pattern deviation plots. P<1% means that this deviation happens in less than 1% of the normal population and must be considered as highly suspicious.

Global Indices

Mean Deviation or Defect (MD) : The MD is the mean difference in decibels between the "normal" expected hill of vision and the patient's hill of vision. If the deviation is significantly outside the norms, a P value will be given. Example: P< 0.5% means that less than 0.5% of the normal population showed a MD larger than the value found for this test. This index is a measure of overall depression, elevation of the field or significantly deep losses in one part of the field and not in others.

Pattern Standard Deviation (PSD): This is a measurement of the degree which the shape of the patient's measured field or hill of vision departs from the "NORMAL" age-corrected reference field model. The value is expressed in decibels and any value of 2dB or greater will have a (P) value next to it indicating the significance of the deviation.

Corrected Pattern Standard Deviation (CPSD): This is a calculated measurement in decibels of how much the total shape of the patient's hill of vision deviates from the shape of the "NORMAL" hill of vision for the patient's age, after being corrected for intra-test variability. In calculating the CPSD the STATPAC

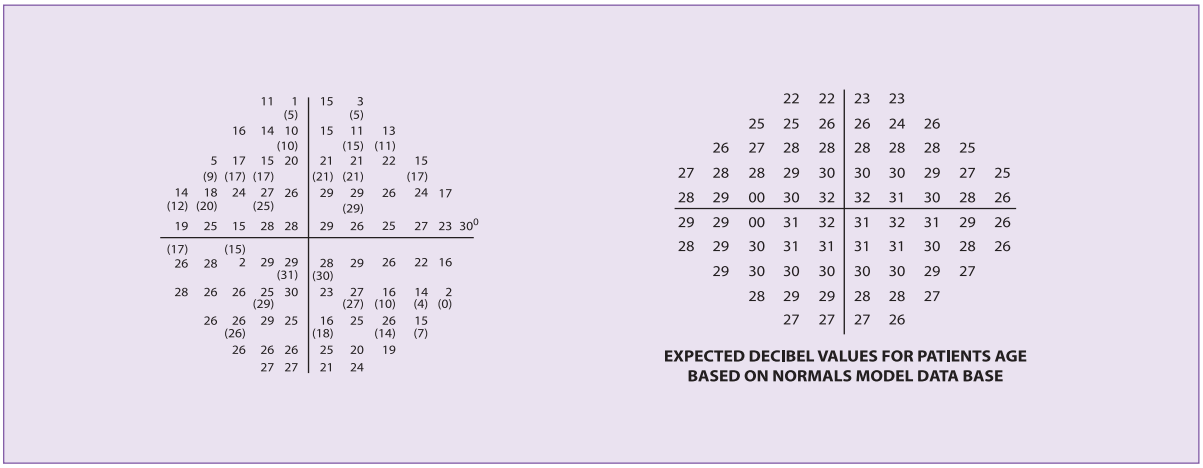

Fig. 5 : Mean deviation or defect

attempts to determine if the irregularities in the hill of vision are real by removing the short-term fluctuation (SF), which may mask a relative scotoma.

Short-Term Fluctuation (SF): This is what the Field Analyzer has been testing all along. It is simply an index of the consistency of the patients responses during the field testing. This value is obtained when ten (10) pre-selected points are tested twice and the difference, in decibels, of the patient's responses are compared.

Screening Test	Extent of Visual Field / Number of Points
Central 40	30 degrees /40 points
Central 76	30 degrees / 76 points
Central Armaly	30 degrees /84 points
Peripheral 60	30 to 60 degrees /60 points
Nasal step	50 degrees /14 points
Armaly full field	50 degrees /98 points
Full field 81	55 degrees /81 points
Full field 120	55 degrees /120 points

Followings are going to be very important in making a diagnosis and determining how to manage a patient.

MD QUESTIONABLE
PSD QUESTIONABLE
SF QUESTIONABLE
CPSD QUESTIONABLE

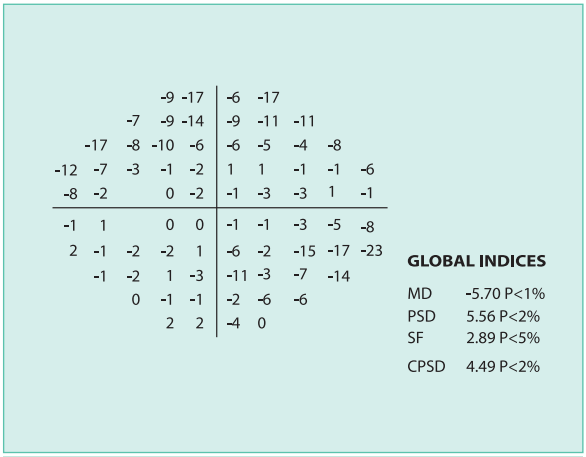

Fig. 6 : Global indices

Humphrey's Visual Field, the Swedish Interactive Threshold Algorithm or (SITA), is much faster than either the 24-2 or 30-2 full threshold fields or the SWAP.The one drawback is it presently does not have a statpack which gives the mean deviation information. The SITA program is newer and is more likely 6 to 7 minutes per eye which cuts down on patient fatigue and improves the reliability.

Both the SWAP and SITA programs run the typical 24-2 and 30-2 fields and the results are in decibels. Therefore, interpreting the results is the same as the standard Humphrey's Visual Fields.

In 30^{o} and 24^{o} test, test locations are separated 6^{0} apart. In 24^{o} pattern, the outermost ring is omitted from the test except the two nasal points, this will reduce tested locations from 76 locations in this 30^{o} test to 54 locations in the 24^{o} test, thus reducing the number of tested locations by 29%, this will shorten the time of the test, and reducing patient's fatigue. These two nasal dots are not omitted from the 24^{o} test being commonly involved in glaucomatous damage .

Numerical values are the estimated sensitivity of each test location. These values are used by the software to make different calculation, and also doctors can use them to estimate the severity of damage and to detect any progressive deterioration of the field of vision.

Normality or Abnormality

A cluster of 2 or more points depressed =5 dB compared with surrounding points is suspicious. A single point depressed >10 dB is very unusual but is of less value on a single visual field than a cluster, because cluster points confirm one another. Corresponding points above and below the horizontal midline should not vary markedly; normally the superior field is depressed 1-2 dB compared with the inferior field. It should be kept in mind that printout of different machines (e.g. Humphrey and Octopus) can not be compared because the test locations are not the same and also because the decibel values used by different manufacturers may not be comparable owning to differences in background luminance and test object intensity.

A *"bracketing"* technique is used to threshold each test point. An initial stimulus is presented at a level the patient is expected to see. If seen, the stimulus intensity is decreased in 4 decibel steps (0.4 log units) until the patient no longer sees the stimulus; if not seen, it is increased in 4 dB steps until seen. The

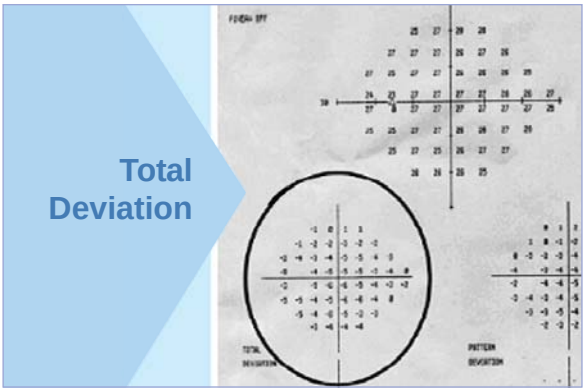

Fig. 7 : Total deviation

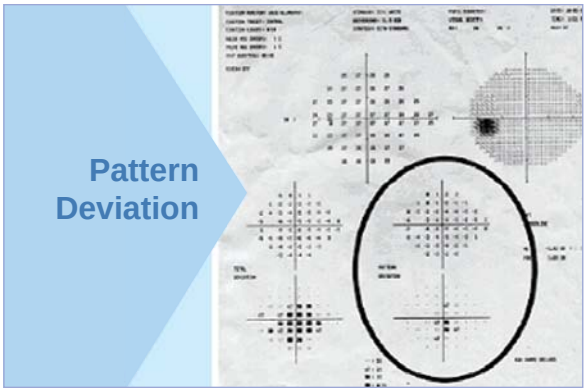

Fig. 8 : Pattern deviation

instrument then changes direction, moving in 2 dB steps until a change in patient response is made. The last stimulus seen by the patient is recognized as the threshold for that point.

Total Deviation

The software start to compare the estimated sensitivity of each test location with that value of the normal population of the same age, and the difference is recorded. So if the printout of total deviation demonstrates a value of -4 this means that the estimated value of a patient is less by 4 db from the normal values of persons of the same age. A recorded value of +2 means that patient showed a higher value of 2 than the normal. A value of zero means that the patient value is the same as the normal population. So we can define the total deviation as the difference between the measured threshold of each individual test location & the age corrected normal value for that location.

Pattern Deviation

It is derived from the total deviation via adjustment of the measured thresholds upward or downward by an amount which reflects any generalized change in the threshold of the least-damaged portion .To understand how that is done shown in the next example (Fig. 8).

So these signs (probability) indicate how frequently a value at a particular test location is found in the normal population. It should be kept in mind that the P value does not signify that the field is pathologic; it indicates how much the field deviates from age-adjusted normal values. When most of the dots are labeled being abnormally low, then it is said that there is a generalized depression of the field of vision. Generalized depression is seen in cases of cataracts and miosis. However, in patients with uniform concentric cupping due to elevated IOP, a generalized loss of retinal sensitivity may be the first sign of glaucomatous visual field loss.

Glaucoma Hemifield Test (GHT)

The upper and lower hemispheres of the visual field are compared to one another. There are 4 possible interpretations of the results that are printed.

- GHT outside normal limits : The upper & lower fields are quite different (found in less than 1% of normals), therefore indicative of glaucoma damage.
- GHT borderline
- General reduction of sensitivity : indicates unreliable fields .
- Within normal limits GHT is a very good way to catch abnormal fields.

Classification of OHTS (Ocular hypertension treatment study) Visual Field Abnormalities

1. A visual field is definitely normal if all locations are within normal limits on the Total Deviation Plot, and is designated as "NL."
2. A visual field is definitely abnormal if any of the conditions below are met:
   (a). The GHT visual field index is abnormal (outside normal limits or general reduction of sensitivity).
   (b). The CPSD/PSD visual field index is abnormal ($p < 5\%$).

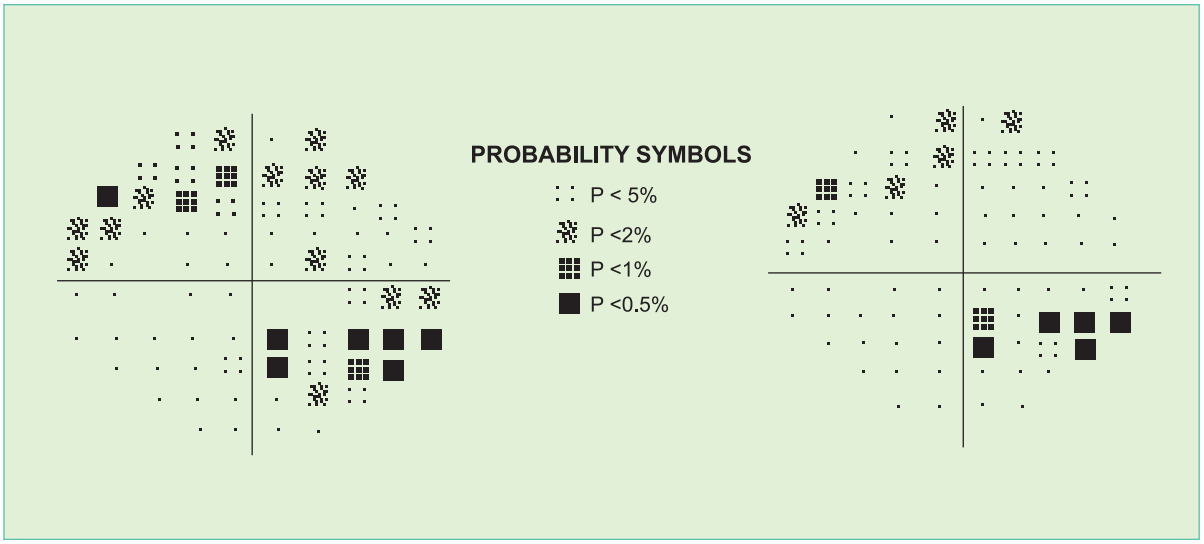

Fig. 9 : Probability symbols

3. A visual field or hemifield may be abnormal if any of the conditions below are met:

   (a). A single point is worse than the 0.5% probability level on the total and/or pattern deviation plot.

   (b). Two clustered points are beyond normal limits ($p < 5\%$), and at least one point is worse than the 1% level on the total and/or pattern deviation plot (a cluster is defined as two or more horizontally or vertically– not diagonally– contiguous abnormal points with $p < 5\%$).

   (c). Three or more clustered points are worse than the 5% level on the total and/or pattern deviation plot.

For all classification evaluations (a, b, and c) the pattern of loss has to be consistent with ocular pathology.

4. In general, the pattern of abnormal points on the deviation plot (total or pattern) showing the greater number of abnormal points should be used to determine the appropriate classification for an abnormality. However, the other deviation plot as well as the gray scale should be evaluated to confirm the appropriateness of the classification. Abnormal points that are extraneous to the salient pattern should be ignored.

5. An abnormal (or possibly abnormal) visual field is given a designation described below.

   (a). The superior and inferior hemifields of an abnormal field are evaluated separately, with the first designation being the superior hemifield and the second designation being the inferior hemifield. Hemifield designations are separated by a slash.

   (b). If a defect straddles the horizontal midline, only a single designation is given and no slash is presented.

Nerve Fiber Bundle Abnormalities (from least severe [1] to most severe [4]).

1. Nasal Step (NS): Limited field loss adjacent to the nasal horizontal meridian with at least one abnormal point ($p < 5\%$) at or outside 15^0 on the meridian. It cannot include more than two significant points (on either plot) in the nerve fiber bundle region on the temporal side.

2. Partial Arcuate (PArc): Visual field loss in the nerve fiber bundle region that extends incompletely from the blind spot to the nasal meridian. The defect is generally contiguous with either the blind spot or the nasal meridian and must include at least one abnormal location in the temporal visual field.

3. Arcuate (Arc): Significant visual field loss in the nerve fiber bundle region, extending across

contiguous abnormal points from the blind spot to at least one point outside 15^0 adjacent to the nasal meridian.

4. Altitudinal (Alt): Severe visual field loss throughout the entire superior or inferior hemifield that respects the horizontal midline, with the majority of points in the hemifield having a $p < 0.5\%$ value on the total deviation plot and the entire horizontal midline demonstrating abnormality.

Other Abnormalities

Paracentral (Pc): A relatively small visual field abnormality (a cluster or a single point) in the nerve fiber bundle region that is generally not contiguous with the blind spot or the nasal meridian. In particular, it does not involve points outside 15^0 that are adjacent to the nasal meridian.

Temporal Wedge (TW): A small visual field defect that is temporal to the blind spot.

Vertical Step (VS): Limited visual field loss that respects the vertical meridian and that includes at least two abnormal points at or outside 15^0 along the vertical meridian.

Quadrant (Q): Significant visual field loss throughout an entire quadrant that respects the vertical midline. Essentially all points must have a $p < 5\%$ value on the total deviation plot.

Hemianopia (H): A visual field defect that respects the vertical meridian and that involves essentially all points in a vertical hemifield.

Partial Hemianopia (PH): A visual field defect that respects the vertical meridian and that is greater than one quadrant but less than a complete vertical hemifield.

Central (C): Visual field loss that is predominantly in the macular region. The foveal threshold must have a $p < 5\%$ value. It can be associated with a single hemifield and paired with another defect.

Peripheral Rim (PR): Generally continuous visual field loss outside 15^0 in all four quadrants, with usually no visual field loss inside 15^0 on either deviation plot. There must be visual field loss temporal to the blind spot.

Partial Peripheral Rim (PPR): Generally continuous field loss outside 15^0, but not in all quadrants and must have some curvature.

Widespread (Wsp): Diffuse visual field loss that includes all four quadrants. The GHT may show a general reduction of sensitivity or the MD must show $p < 5\%$. The CPSD/PSD must not show a $p < 5\%$ value. The majority of abnormal points on the Total Deviation Plot are not abnormal on the Pattern Deviation Plot.

Total Loss (TL): Severe widespread visual field loss (MD = -20.00 dB).

Superior Depression (SD): Two or more abnormal points in the very superior region.

Inferior Depression (ID): Two or more abnormal points in the very inferior region.

Visual field analysis offers the clinician a very valuable tool to correct reference field. A low PSD indicates a smooth detection of glaucomatous and other changes. However, the full hill of vision, a high PSD indicates an irregular hill. PSD benefits both the patient and clinician. It characterizes localized changes in the visual field, provided the various functions and facilities of the software is properly understood and utilized.

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