FROM DARKNESS TO LIGHT

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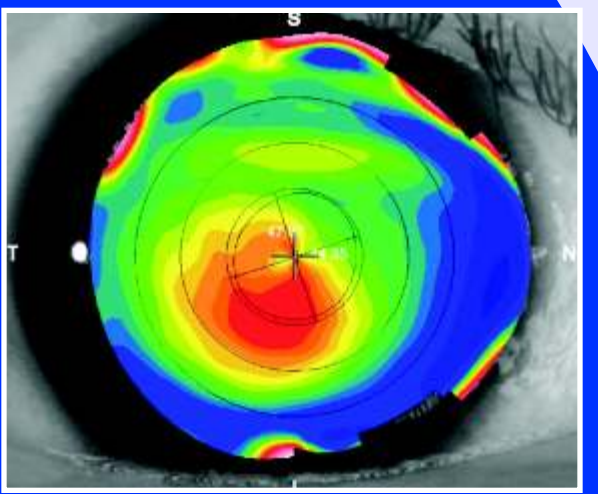
Rajasthan Ophthalmological Society

CME Series No. 2

Investigations in Ophthalmology

Methodology & Interpretation



Visual Fields

Corneal Topography

Optical Coherence Tomography

Edited by :

Dr. PAVAN SHOREY

Hony. General Secretary

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In this issue

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Investigations in Ophthalmology : Methodology & Interpretation

Rapid advances in the field of ophthalmology have led to innumerable investigations, some crucial in diagnosis, some not so. Many times these investigations are brought to you by the patient and we mostly do not know how to interpret them.

We have taken up three investigations: Visual Fields, Corneal Topography and Optical Coherence Tomography. These are the most commonly seen investigations.

Visual Fields, though an old investigation cannot be interpreted by many. We have included both the Humprey and the Octopus print outs.

Corneal Topography is fairly common and is very important in diagnosing early keratoconus besides other indications.

Optical Coherence Tomography has revolutionized the understanding of macular disease. It is like in Vivo histopathological section and gives a wealth of information about macular oedma, macular hole, epiretinal membrane etc.

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Dr. Pavan Shorey
Hony. General Secretary

Corneal Topography : Methodology and Interpretation

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Introduction: Cornea air interface is the first point where the light enters the eye and around 80% of refraction occurs at this point. Hence the corneal surface plays a critical role in the quality of optics of the eye. A small amount of distortion of this surface can lead to marked deterioration in the quality of image forming at the retina. The typical cornea is responsible for 43 of 60 diopters (D) of refraction of the eye. The average radius of curvature, 7.8mm, generates the majority of refractive power of the cornea (about +48.00 D). The posterior surface, with its concave shape and stromal index similar to that of the aqueous, contributes about – 5.00 D. In addition, the majority of astigmatism originates from the corneal shape. It is not surprising that great effort has been put forth to measure this surface of the eye.

Reflection techniques such as Placido disc, keratometry, photokeratoscopy and videokeratography have been developed to study corneal topography. It was the last development that is videokeratography that helped the clinicians to understand corneal curvature in a better way and correlate it with potential visual acuity, thereby allowing the clinician to evaluate the whole of the cornea qualitatively and quantitatively.

Methods of topography analysis :

1. Keratometry
2. Keratoscopy
3. Photokeratoscopy
4. Videokeratography

1. **Keratometry :** For ages keratometry has been standard method of measuring corneal curvature. Keratometer projects single mire on to the cornea. Separations of points on the cornea are determined to calculate the curvature of cornea. Keratometry has certain limitations. It measures only a small region of the cornea. It assumes the cornea is symmetrical and it is not accurate for very steep or very flat cornea.
2. **Keratoscopy :** It is the qualitative method of analyzing corneal curvature. Keratoscope like Placido disc, projects an illuminated target consisting of concentric circles on to the corneal surface. The viewer visualizes the image of circles thus formed on cornea. A keratoscope gives qualitative information only. It can miss subtle changes and it fails to pick up astigmatism of less than 3 D
3. **Photo Keratoscope :** In Photo Keratoscope one can capture the image on the film and can have a permanent record of the image. However, low amplitude images and complicated pictures of the cornea cannot be detected by this analysis.
4. **Video Keratography :** This technique is also known as Computerized Corneal Topography. In this technique a video keratoscope also known as Corneal Topographer is used to capture the image of mires, which is analyzed by computer to give us the quantitative description of the corneal topography in the form of color-

coded maps. It is the process for mapping the surface curvature of the cornea, similar to making a contour map of land

Computerized Corneal Topography:

Corneal topography instruments used in clinical practice most often are based on Placido reflective image analysis. This method of imaging of the anterior corneal surface uses the analysis of reflected images of multiple concentric rings projected on the cornea. The purpose of corneal topography is to produce a detailed description of the shape and power of the cornea. Using computerized imaging technology, the 3-dimensional map produced by the corneal topographer aids an ophthalmologist in the diagnosis, monitoring, and treatment of various visual conditions.

The corneal topographer is made up of a computer linked to a lighted bowl that contains a pattern of concentric rings. The patient is seated in front of the bowl with his or her head pressed against a bar while a series of data points are generated on a placido disk, which has been projected on the cornea. Computer software digitizes these data points to produce a printout of the corneal shape, using different colors to identify different elevations.

The procedure itself is painless and brief. It is a noncontact examination that photographs the surface of the eye using ordinary light. The greatest advantage of corneal topography is its ability to detect conditions invisible to most conventional testing.

Components of Topographer

A. Video Keratoscope : It uses 25 or 32 rings Coliminated and illuminated video keratoscope with a fixation point and to project mires on to the cornea. Video image is captured on to the video monitor. On each ring, 256 points are evaluated and therefore the analysis evolves evaluating thousands of points covering whole of the cornea. Most corneal topographers evaluate 8,000 to 10,000 specific points across the entire corneal surface. By contrast, keratometers measure only four data points within the cornea's central 3-4mm; the small size of this area can lead to errors in determining precise toricity.

B. Computer and a Monitor : CPU of a computer does the analysis of all the points evaluated on the cornea. Analyzed data is displayed on computer monitor in color-coded maps and other formats.

Video Keratoscopy: The first step is to fill in all the patient details into the computer including the refraction of the patient. Next the patient is made to sit in front of corneal topographer. The eye is aligned to the topographer. The patient is asked to look into the fixation point situated in the center of the illuminated cone. By pressing the button, image is captured. Multiple images are captured and the best one is selected. A drop of tear substitute can be instilled which helps in giving a better picture. The patient should be instructed to look steadily at a fixation point with the eyelids fully open.

A good corneal topography should have minimum lid and eye lashes shadow with no dry spots. There should be no pooling of tears (Fig. 1). The rings should be thin and continuous and should not be touching each other (fig. 2).

Digitization or processing : Once keratograph is captured, computer digitizes the image of all mires in order to record the relative position of all 256 points on each keratograph ring from the center of central mire. Then it uses certain algorithms to convert the digitized information into corneal curvature data.

Display Modes : the processed information is next displayed on the system monitor in various color coded maps, numerical maps or astigmatic maps.

Fig. 1

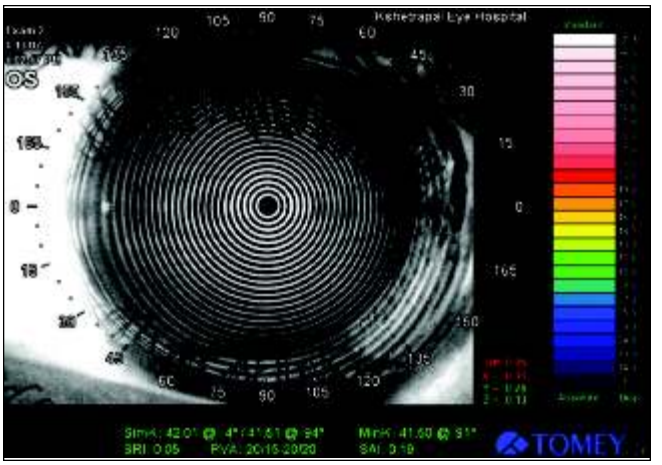

Fig. 2

Color Coded Maps : They are the most popular and useful way of depicting the information in which color is assigned a defined range of surface power. The advantage is that we get an idea about topography of the cornea at a glance. The color coded maps give information regarding the patient details, the type of map and various quantitative values e.g. Sim K etc. (Fig. 3)

Scales for color coded maps: Corneal topographer uses various color coded scales to represent the various curvatures on the cornea. The various scales used are *absolute scale, Normalized scale* and *adjustable scale*

In Absolute Scale each color denotes a fixed range of power. This scale remains the same

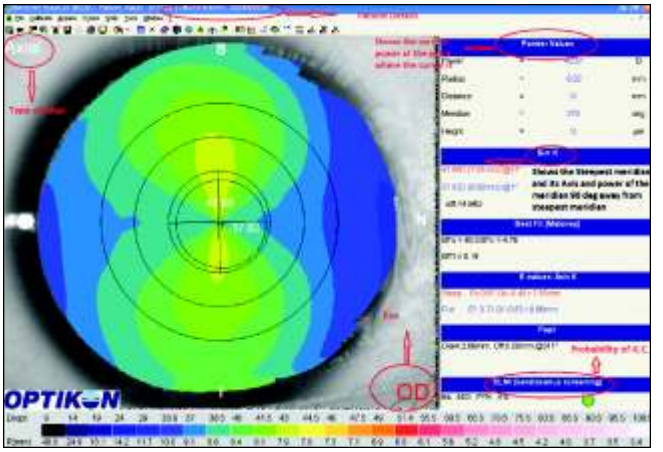

Fig. 3

for all graphs and is universal. This scale is composed of 11, 1.5 D steps in diaptoric range of 35.5 to 50.5 D. Above and below this range 5D steps are used (Fig 3). Kindly note the color coded absolute scale at the bottom of the figure. While in normalized scale the range of power in a given map is divided into 14 equal steps. The minimum step size is limited to 0.4 D (Fig. 4). This type of scale is more sensitive to pick up smaller fluctuation in corneal power. In adjustable scale diaptoric range can be adjusted to view subtle changes in curvature of the cornea (Fig. 5).

Numerical Display : In this type of display the corneal power is numerically displayed at various points.

Astigmatic Map : this type of map displays the steepest and the flattest meridians with the help of color-coded lines on the topography map.

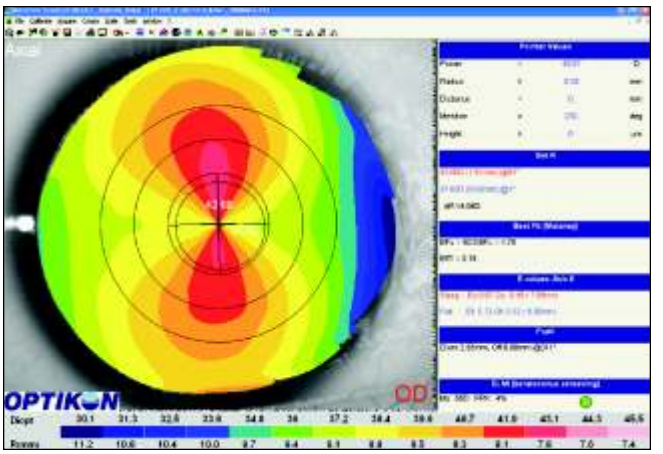

Fig. 4 : Same Map as in Fig. 3 but with normalized scale.

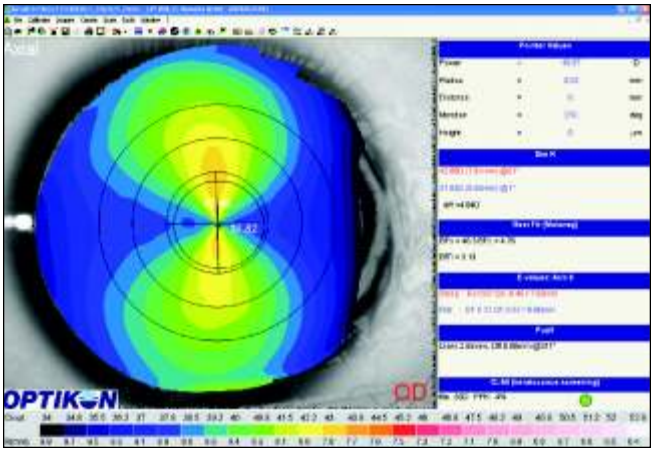

Fig 5 : In this adjustable scale each color represents a difference of 0.75 D. It can be adjusted as desired

Other features: Multiple map option where we can view 2 or more maps simultaneously for comparison between various maps.

Subtraction Maps : It tells us the difference in corneal power in 2 given maps it is extremely useful in assessing the effect of refractive surgical procedure.

Quantitative Indices:

Corneal Statistics data are presented in map information window of the system monitor in the form of parametric or qualitative discretion of corneal topography.

Parametric descriptors of corneal topography : These descriptors, which augment the information provided by color-coded corneal topography maps, are

- Surface Asymmetry Index (SAI)
- Surface Regularity Index (SRI)
- Simulated Keratometery value (SIM K)
- Potential Visual acuity (PVA)

Surface asymmetry Index : Measure of the Central Corneal asymmetry. It is quantified as difference in power between corresponding pairs of points, which are 180^0 apart on 4 central mires on 128 equally spaced meridians.

SAI approaches Zero for a perfectly radially symmetric surface and increases as the corneal shape becomes more asymmetric within specific meridians. Since the normal cornea usually has a high degree of central radial symmetry the SAI is a useful quantitative parameter for monitoring changes that occur in patients following refractive surgery, with C.L. induced cornea warpage, following P.K. and in other corneal disorders that causes alteration of corneal symmetry as happens with off center keratoconus.

Surface Regularity Index : SRI is a measure of central optical quality and correlates very well with best corrected spectacle visual acuity. SRI is calculated from summation of local power fluctuation along 256 equally spaced semi meridians on the 10 central mires. SRI approaches zero for a normally smooth corneal surface and increases directly with increasing irregular astigmatism SRI value can be used to predict the optical performance that might be expected in a particular patient based on corneal topography, if the other function of visual system such as lens and macula are functioning properly.

Simulated Keratometry Value : Sim K. value provides the power and the location of steepest meridian and the meridian 90^0 away. These orthogonal simulated keratometric values are good predictors of Keratometric readings. These values are obtained by calculating average power on 12 points on photo keratoscope ring 7, 8 and 9 representing positions on a cornea that would be similar to those of keratometer mires on the same cornea, a separation distance of 3 to 4 mm.

Potential visual Acuity : Using SRI and its correlation with P.V.A a range of visual acuity expected, based on corneal topography alone is provided. Based on these indices the system gives an estimate of potential visual acuity of the eye assuming that the eye does not have any other abnormality.

Pointer Values : Power of the corneal can be determined on any point by just clicking with mouse on that point on the cornea. It determines the power on that particular point on the cornea. The power is displayed both in refractive power and radius of curvature. It

also determines how far and in which meridian is that particular point from the center reference point on cornea.

Application of Video keratography : Computerized Video Keratography has helped us to understand the cornea. It is useful in following ways.

- Normal topography
- Diagnoses of curvatural disorders.
- Pre operative assessment of kerato refractive surgery.
- Evaluation of results of refractive surgery.
- Management of astigmatism following intra ocular surgery.
- Contact lens fitting.

Normal topography: Until very recently it was assumed that the cornea has very well defined central sphero cylindrical optical zone, Surrounded by distorted peripheral cornea. However video keratography has shown that such a well-demarcated area does not exist. It has been found that central corneal blends with the peripheral cornea without any demarcation line. It has been noted that the degree of flattening that occurs in paracentral and peripheral cornea is asymmetrical and that the cornea flattens close to the center in nasal hemi meridian. It has also been noted that there is mirror image symmetry between right and left cornea in most of the cases.

Patterns of normal topography: Five types of normal topographic patterns have been detected

- Spherical (Fig. 6)
- Oval
- Symmetrical bow tie (Fig. 7)
- Asymmetrical bow tie
- Irregular

Corneas that have astigmatism of more than 1.5 D exhibits bow tie pattern, where as corneas with less than 1.5 D astigmatism may exhibit only oval pattern.

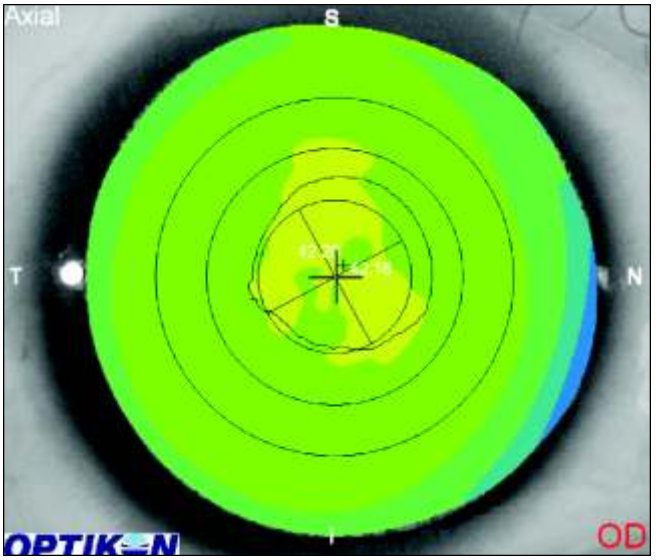

Fig. 6 : Note the spherical cornea with hardly any difference in power in steep and flat axis.

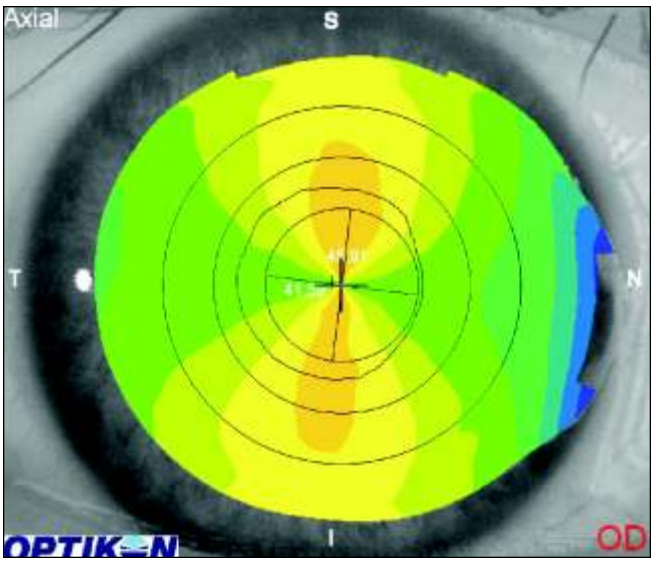

Fig. 7 : Symmetrical Bow tie pattern. The upper and lower halves of the cornea are symmetrical.

Interpretation of print out :

In most cases the physician will get the report in the form of a color coded print out. Those who own the machine can directly view the report on the computer screen that can display many more parameters than those can be viewed on printed report. The first thing to see on a printed report is the patient's name, age and sex is correct and it matches with the patient. If we wish to view the corneal wave front then the refraction should be added verified and should be noted that it has been entered correctly.

The first thing to look for in a report is the Sim K values. As mentioned earlier the sim K displays the maximum power of the cornea and the power of the cornea 90^0 away from it. Then the observer should look at the color coded map. This will display the curvature and pattern of curvature of the cornea. One should note by looking at the color map if the cornea is symmetrical or asymmetrical. Once the symmetry of the cornea is noted then one should look for the steepest corneal point. Usually the steepest corneal point will lie either in the center or close to the center of cornea. The steepest corneal point will be denoted by hottest color on the color scale. One must also look at the type of the color scale. One should take into account if the color code or scale is absolute or normalized or customized. Remember that in myopes who have undergone corneal refractive surgery, the central part of the cornea may be flatter than the periphery.

Diagnoses of curvatural disorders :

- Keratoconus
- Keratoglobus
- Pellucid Marginal degeneration
- Contact lens warpage

1. **Keratoconus:** It is possible to detect keratoconus (Fig 8)with video keratography even in sub clinical stage when it is not apparent on slit lamp examination or keratometery. Detection of keratoconus in sub clinical stage is important in potential candidates for refractive surgery as we know that these patients are unfit to undergo refractive surgery. Features that indicate that keratoconus is present include
   1. Central power more than 47 D
   2. Inferior superior index –3 D, 3 m inferior to cornea
   3. Difference more than. > 1 D in central power of fellow eye.

   Corneal topography has also helped us to understand the genetics of keratoconus. For e.g. 50 % of family members of patients with keratoconus have shown topographic evidence of keratoconus.

   Corneal Topography is also helpful in monitoring the progression of keratoconus and detecting unusual forms of keratoconus.

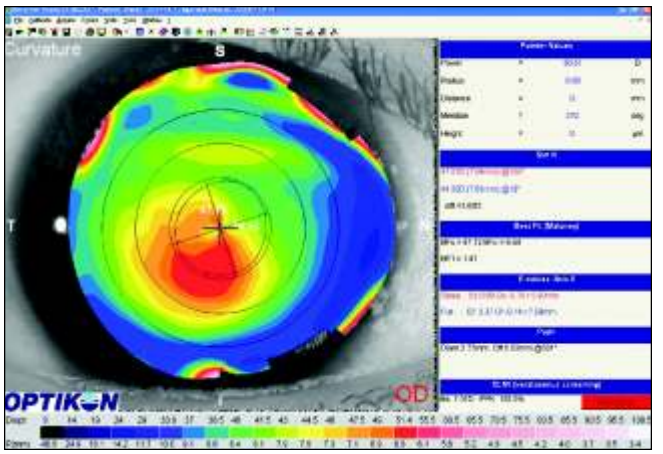

Fig. 8

Diagnoses of curvatural disorders :

- Keratoconus
- Keratoglobus
- Pellucid Marginal degeneration.
- Contact lens warpage

2. **Keratoglobus:** On topography it is characterized by over all steep curvature. For example the entire corneal curvature may be above range of absolute scale with negligible flattening towards the periphery.
3. **Pellucid Marginal degeneration:** It is characterized by corneal ectasia in the inferior peripheral cornea just superior to a narrow band of non-vascular corneal thinning, 1-2 mm central to the limbus. Topography shows marked flattening of the central and para-central cornea along the vertical hemi meridian and steepening in inferior oblique hemi meridian.
4. **Contact Lens Warpage:** Warpage refers to topographic changes in cornea due to C.L. wear. Warpage will produce regular or irregular astigmatism and is like a keratoconus like pattern. When C.L. wear is discontinued, the corneal curvature

comes back to normal over a variable period of time. It is important to demonstrate stable topography before undertaking any refractive procedure on a C.L. wearer

Pre operative assessment in kerato refractive surgery : Corneal Topography is extremely useful in many ways in pre operative assessment prior to surgery.

1. Ruling out presence of keratoconus
2. Confirming the axis of astigmatism
3. Asymmetric astigmatism
4. Misleading keratometry

Evaluation of results of refractive surger:

1. Topography after LASIK
2. Decentration
3. Regression
4. Planning of re-treatment
5. IOL Power calculation

Post PRK : Varity of patterns have been described post LASIK. One such study describes topographic patterns - uniform, keyhole, semicircular and central island. It has been found out that central island has been associated with some loss of best visual acuity. It is defined as well circumscribed central circular or oval area of corneal power of > 3 D of ablated area. It also causes visual disturbance such as diplopia. Fortunately most of central island show resolution spontaneously.

Decenteration : Patient post LASIK may present with troublesome night vision like glare and hallo. One reason for this could be de-centered ablation which could be appreciated on corneal topography .Only decenteration of more than 1 mm causes visual symptoms. Fortunately most of the times the decenteration is less than 1 mm

Regression : It is Vital in documenting the post operative course of refractive surgery. Regression can clearly be documented using subtraction maps. Similarly it can also record the asymmetric healing response.

Planing retreatment : It is must to have topographic picture to know which area require retreatment.

IOL Power Calculation : For IOL power calculation post refractive surgery the keratometry is fallacious because of central corneal flattening. For this purpose central corneal power as depicted by corneal topography is more reliable.

Management of astigmatism following Intra ocular surgery : Video keratography is an invaluable tool in the management of postoperative astigmatism after keratoplasty. It helps in identifying sutures responsible, which can then be removed. Again topography has shown that astigmatism following keratoplasty is non-symmetrical and non-orthogonal and astigmatic keratotomy done using corneal topography picture is better. Corneal topography is a useful tool in cataract surgery also. It helps in easy localizing of steep meridian. Placing suture on steep meridian can help in reducing the preexisting astigmatism.

C.L. fitting : Usually keratometric measures are sufficient for contact lens fitting. Most cases of keratoconus and post P.K. astigmatism, having keratometric measurement are not sufficient. In many such cases C.L. fitting is done with trial and error method often resulting in failure. Recently information obtained from topography analysis about these corneas is used to design rigid C.L. allowing placement of multiple spherical or aspherical curves on the posterior surface of cornea. •

Interpretation of Visual Fields

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Why perform visual fields at all??

Why should a patient have his visual fields performed? Isn't it enough to just monitor his IOP regularly and treat him (keeping his pressures, say less than 22mm).

NO!

The basic aim of glaucoma treatment is to halt further optic nerve damage. This can only be achieved if his IOP is maintained below the level at which his optic nerve is susceptible to damage. This IOP level varies with each individual depending upon the extent of glaucomatous atrophy and on individual variations in optic nerve vulnerability. If the visual fields are not performed periodically there is no way to assess quantitatively whether the optic nerve has been damaged further at the existing IOP.

Therefore visual fields are *absolutely essential* as a documentation of optic nerve damage and preservation of vision.

Basis of Quantitative Perimetry

The visual fields have certain characteristics -

1. Boundary- The farthest points at which an object is visible - when the eye is fixed. (this is elucidated by kinetic perimetry)
2. Every point within this boundary can be defined in terms of the visual acuity, minimum size of object visible and minimum brightness visible. (assessed by static perimetry)

In quantitative perimetry special attention is paid to three factors that affect the visibility of a white spot-

1. Size
2. Brightness
3. Background illumination- the darker the background illumination the easier it is to perceive a stimulus of fixed intensity.

Units of Light Intensity

For every perimeter a value of zero decibels is allotted to the maximum intensity stimulus. A 10dB stimulus is one log unit less intense than the maximal intensity (or 1/10 of max). A 20dB stimulus is two log units less intense (1/100 of max). A 30dB stimulus is three log units less intense (1/1000 of max). Hence, the larger the dB unit the less intense or bright is the light perceived, or more sensitive is the area tested.

A 3 dB decrease in measured threshold always means that the eye has lost about half of its sensitivity (3dB decrease means the intensity of light had to be doubled to be seen by the patient).

Threshold Sensitivity

Every point in the visual field has threshold sensitivity. A stimulus cannot be seen if it's weaker than the threshold sensitivity. All stimuli brighter than threshold are visible.

Selection of test

The 30-2 test tests the central 30 degrees of the field, 76 points are tested with a gap of 6 degrees between points. The 24-2 test tests the central 24 degrees .Since fewer pints are tested, the test takes less time and there is less chance of patient fatigue. The fields are therefore more reliable .The 10-2 test is done for patients with advanced field visual field loss.

INTERPRETATION OF A SINGLE FIELD

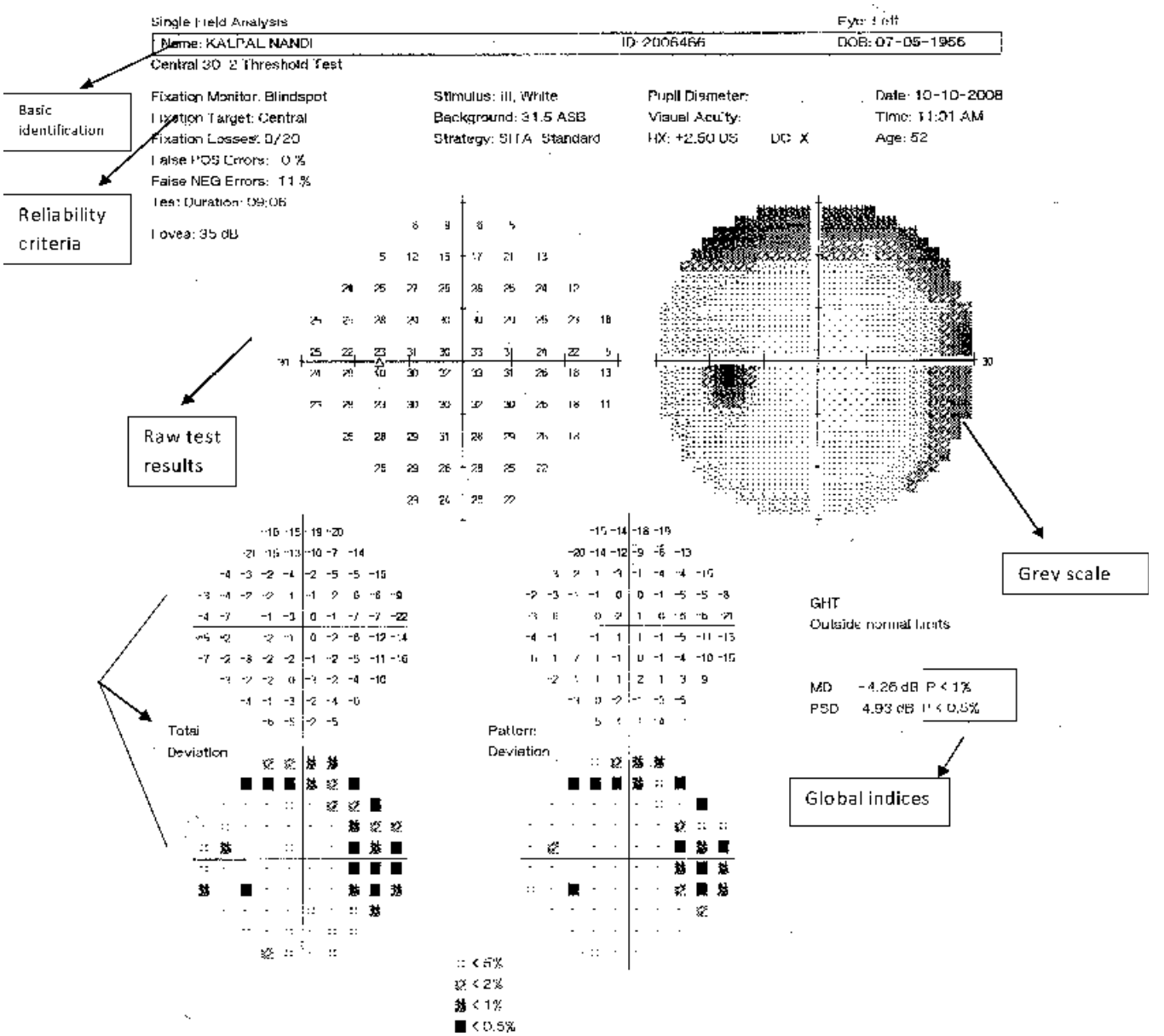
There are seven different packets of information in each print-out.

1. Patient Identification and Test Type.
2. Indicators of reliability of the test.
3. Raw unprocessed threshold sensitivity measurements.
4. Deviation of sensitivities from normal for that age (total deviation).
5. Deviation from normal after adjustment for the patient's overall sensitivity (pattern deviation).
6. Overall indices of normality (global indices)
7. Plain - language analysis (glaucoma hemifield test

1. Basic Identification

Very 'basic' but MUST be confirmed.

The name of the patient must be spelt correctly. This avoids problems with data retrieval at subsequent visits. Erroneously entered birth dates can cause diagnostic dilemmas because the total deviation plot is adjusted for patient's age (with increasing age, threshold sensitivities drop because of age-related ganglion cell death). 10-2 fields test the central 10 degrees, 24-the central 24 degrees and 30-2 tests the central 30 degrees of the visual fields.



2. Reliability Parameters

There are three parameters which tell us whether the fields plotted are reliable or not.

a. Fixation Losses

b. False Positives

c. False Negatives

a. Fixation Losses: This tells us whether the patient fixed his eyes straight ahead or moved it during testing. This is done by presenting stimuli at the blind spot periodically (Heijl-Krakau method) and noting whether the patient perceived it. The patient obviously should never see any stimulus shown at the blind spot. The fixation loss rate is recorded on the printer as the number of times the patient responded to the blind spot stimulus divided by the total number of presentations at the blind spot. The letter X appears next to the FL rate when the ratio exceeds 20%.

b. False Positives: This records the number of times the patient presses the button during pauses in the test, when no stimulus was actually shown. Some patients are 'trigger-happy' and press the button at regular intervals regardless of whether the stimulus was seen or not. The letter X is printed next to the FP ratio whenever it exceeds 33%.

c. False Negatives: This denotes the frequency with which the patient fails to press the button at a location where the stimulus was *previously* visible. This shows inconsistent responsiveness or inattentiveness. FN responses are also higher in patients with scotomas and therefore in patients with established glaucomas. XX appears in front of the FN ratio when FN responses exceed 33%.

High Fixation Loss rates are often due to patient misalignment rather than unsteady fixation and may not indicate unreliability. High False Positive rates on the other hand almost always indicate an unreliable test.

High False Negatives rates in *normal* fields indicate an inattentive patient. But high FN rates are common in *reliable glaucomatous fields*.

3. RAW TEST RESULTS

These are presented at the top of the printouts. The threshold sensitivity values are displayed as decibels. The numbers in the brackets show the thresholds perceived on repeat testing of these points.

4. GREY SCALE

It is very tempting to look at the grey scale and interpret the fields but this is ERRONEOUS for several reasons.

1. To develop a grey scale printout sensitivities are assigned to locations between test points that were *not actually tested.*
2. It is NOT a statistical or normative analysis (no corrections are made for the age of the patient or for any generalized depression which could be due to media opacities like corneal opacity, cataract etc and NOT due to glaucoma.
3. Some parts of the visual fields may appear dark and yet not be associated with disease (e.g. due to eye-lid artifacts, spectacle rim artifacts etc.).

5. TOTAL DEVIATION (Deviation from normal values for that age)

The total deviation is the difference of threshold sensitivity of each test point from the median normal threshold for that age. The total deviation display has two parts :

1. *Numeric values* which represent the actual decibel deviation from age normal.
2. *Probability plot* showing symbols that indicate the statistical probabilityof deviation being abnormal. The symbols

become darker as the deviation from normal becomes more significant. A symbol for p<1% means that <1% of *normal* fields have a sensitivity that low.(there is a 99%chance that the point is abnormal.)

6. PATTERN DEVIATION

If a patient has a cataract, a corneal opacity or any other cause for media haze, then all the points tested may be depressed so that the entire field appears abnormal. Now, if within this field there are areas that are damaged due to glaucoma, these areas will not be apparent because of the overall depression.

The pattern deviation plot makes an adjustment for the overall depression. The adjustment is based on a representative point in the least affected part of the field .The deviation of this point from the normal is computed. Now this difference is subtracted from all the points tested- to get the pattern deviation plot.

The pattern deviation plot thus unmasks glaucomatous field losses.

So when assessing a visual field greatest emphasis must be placed on the pattern deviation plot.

7. GLOBAL INDICIES

In contrast to the total deviation and pattern deviation plots, the global indices summarize the entire field and assign a *single* value to *one* of the tests. The global indices are :

1. Mean Deviation
2. Pattern Standard Deviation
3. Short-Term Fluctuation
4. Corrected Pattern Standard Deviation

1. Mean Deviation-(MD) this indicates the *average overall severity of field loss*. It is the average of all points in the total deviation plot. This is affected by

i. Degree of loss

ii. Number of abnormal locations

A positive number for MD indicates that the average sensitivity is better than normal. If MD is lower than that found in 10% of normal individuals then a significance level is printed (p<10%, p<5% etc).

2. Pattern Standard Deviation(PSD) this indicates the degree to which the sensitivities are different from their neighbors'. PSD is small in a normal field or one in which all points are equally abnormal. When some points are affected more than others then PSD is high. Therefore PSD is an index of unequalness or unevenness of the visual field. PSD quantifies localized loss as a single value and is most useful in identifying early defects. Significance limits are displayed if PSD exceeds that found in 90% of normals.

***Abnormal PSD is suggestive of glaucoma*.**

3. **Short term fluctuation** (SF)

It is an index of intra-test variability. It is the difference between the patient's responses at the same location during the same session. The machine retests 10 locations for thresholds. The variability in thresholds measured is greater in abnormal locations but this variability may also be due to inconsistent responses by the patient. Hence, it could also be an index of reliability.

4. **Corrected pattern standard deviation** (CPSD)

As we have seen with SF, the threshold determined may not be consistent and therefore it becomes more difficult to eliminate the "unevenness" of the visual field. In order to account for this variability the SF is deducted from the PSD to produce CPSD.

CPSD however may not be very reliable because :

1. SF value is estimated from only 10 duplicate measurements from the 76 points tested in the fields.
2. CPSD is calculated to remove patient unreliability and inconsistency. However, SF *need not* be an indicator of patient unreliability. Abnormal fields do show variable responses.

8. GLAUCOMA HEMIFIELD TEST (GHT)

This test is based on the fact that glaucoma affects the upper and lower halves of the field differently. This takes into account points along the nerve fibre bundle which are *selectively involved in glaucoma*. In GHT 5 zones in the upper fields are compared with 5 zones in mirror-image locations in the lower fields. GHT is primarily directed for diagnosis of glaucoma and not other diseases. Each of the 5 upper zones is compared with the corresponding lower zones and the difference is then compared with significance limits in normal individuals.

5 messages may appear in the GHT :

a. Outside normal limits - this means either
   i. That when scores in the upper zones are compared with that of the lower zones at least one pair of score differences exceed that found in 99% of normal population.
   ii. Or the individual scores in both members of a pair exceed that found in 99.5% of normals.

b. Borderline - at least one zone pair difference exceeds that found in 97% of normals.

c. General reduction of sensitivity - neither of the above criteria is met but the best part of the field is depressed to a degree that occurs in less than that found in 0.5% of normals.

d. Abnormally high sensitivity - overall sensitivity in the best part of the field is higher than that found in 99.5% of normals.

e. Within normal limits - if none of the preceding criteria is met then this message appears.

IS THE FIELD ABNORMAL?

When we have confirmed that:

1. the fields belong to the patient in question
2. his date of birth is correctly entered,
3. and that the fields are reliable (minimal fixation losses/false positives and false negatives)

Then we can go on to analyze the fields.

As previously mentioned the grey scale only deserves a passing glance- to identify any gross defects. DO NOT base a diagnosis on a grey scale.

One should then turn to the total and pattern deviation plots. The pattern deviation plot shows up focal losses in the visual fields. The global indices will tell us if there is overall loss of sensitivity (MD) or focal losses (PSD). The GHT also provides valuable information on whether the losses are more likely to be due to glaucoma (GHT outside normal limits).

How can we identify early focal defects?

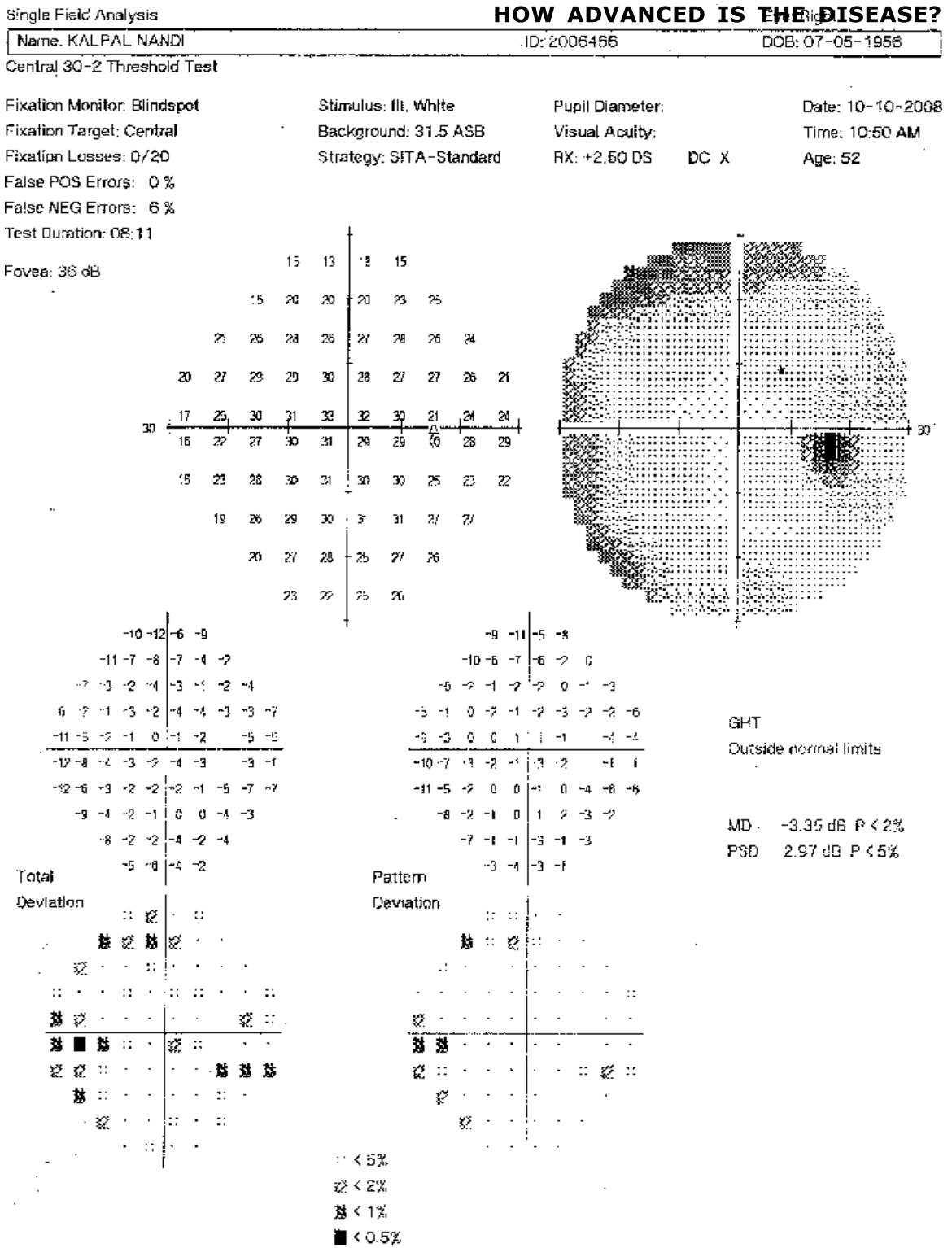
This can be done with ***Anderson's three criteria*** so that a visual field is less likely to be falsely labeled as either glaucomatous or normal. Glaucoma does not cause depression (decreased sensitivity) of the entire field without causing some focal defects. Hence, in glaucoma the pattern deviation will show some losses.

ANDERSON'S CRITERIA-(for recognition of early localized glaucomatous defects)

Reliable fields can be said to have a localized glaucomatous defect if:

1. PD plot shows a cluster of three or more non-edge points (in 30-2 fields) that have sensitivities that occur in less than 5% of the normal population and one point has a sensitivity seen in less than 1% of normal population. Edge points are not included in 30-2 tests because of artifacts in these locations. Edge points are included in 24-2 fields.
2. PSD has a value seen in less than 5% of normals.
3. GHT is outside normal limits.

HOW ADVANCED IS THE DISEASE?

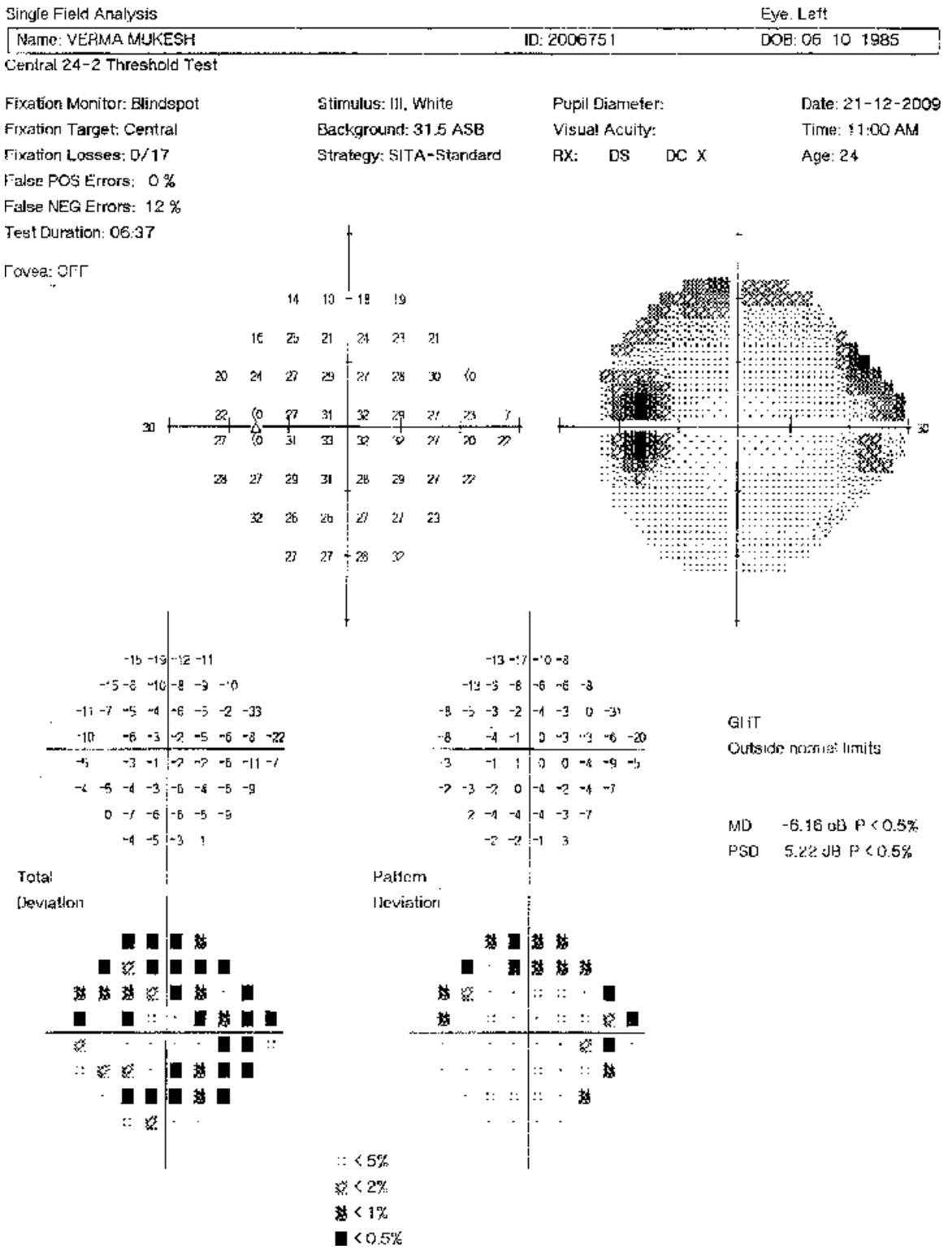


Hodapp classified defects as early, moderate or severe. This classification is useful in establishing a target IOP.

HODAPP'S CLASSIFICATION

Early defect: if the field meets ALL the following requirements :

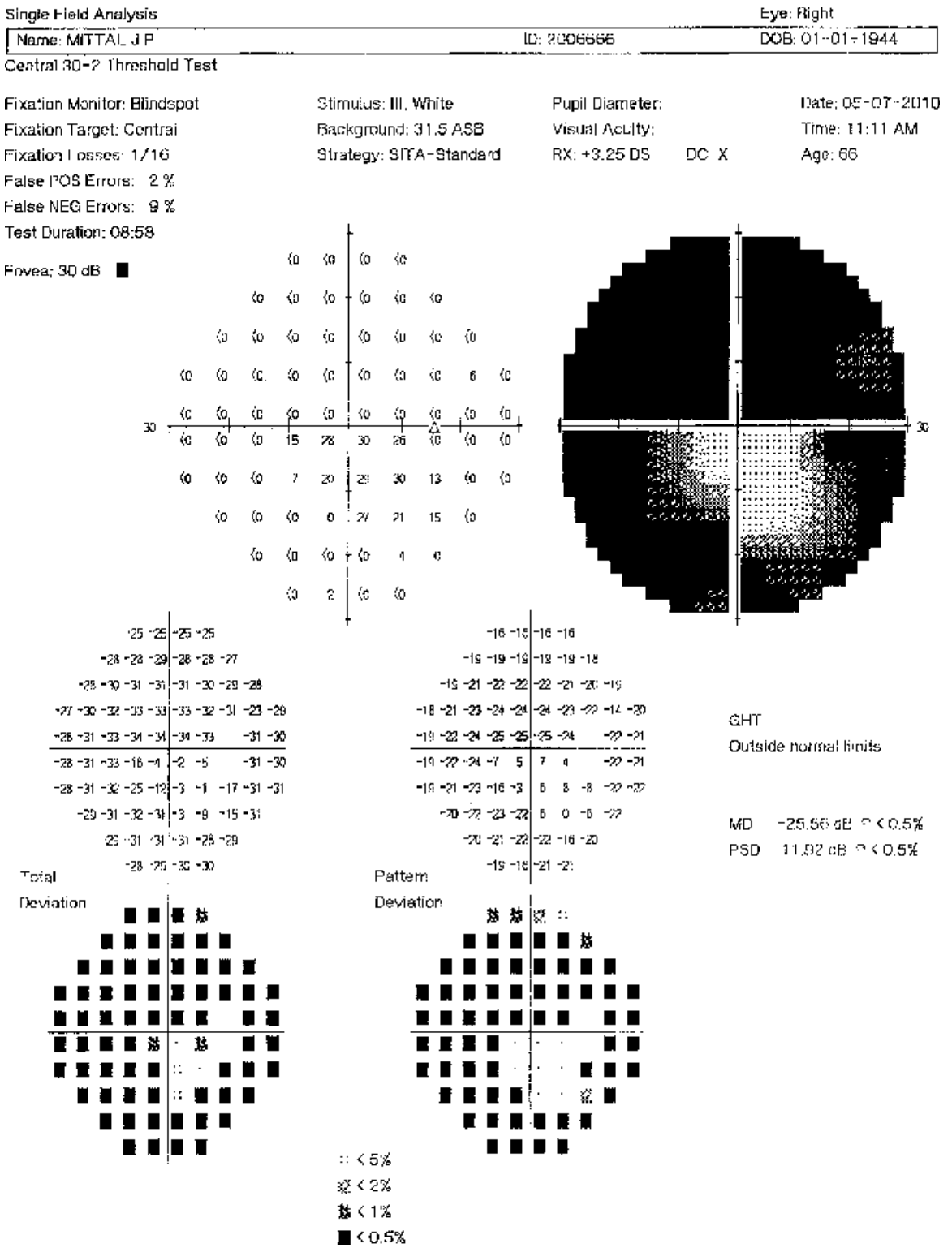
1. MD better than 6dB
2. Fewer than 18 of the 76 points in 30-2 field (25%) are defective in the total deviation plot at the 5% level
3. Fewer than 10 points are defective at the 1% level and



4. No point in the central 5 degrees has sensitivity less than 15 dB

Given below is an example of an early defect- Here the MD d" 6dB,less than 18 points are defective at 5% in the TD plot, less than 10 points are defective at 1 %and no point in the central 5degrees has sensitivity less than 15 dB.

Moderate defect exceeds one or more criteria in the early defect category but does not meet the criterion to be severe.



In the following example it can be seen that the MD is more than 6 dB, more than 18 points are defective at 5% level, less than 20 points are depressed at 1% level

Severe defect: has ANY of the following:

1. MD worse than -12dB
2. More than 37 (50%) of the points depressed at 5% level
3. More than 20 points depressed < 1% level
4. A point in the central 5 degrees with 0 dB sensitivity
5. Points closer than 5 degrees has less than 15 dB sensitivity in BOTH upper and lower hemi fields

The following is an example of a field with severe defect

Why is it necessary to score the field?

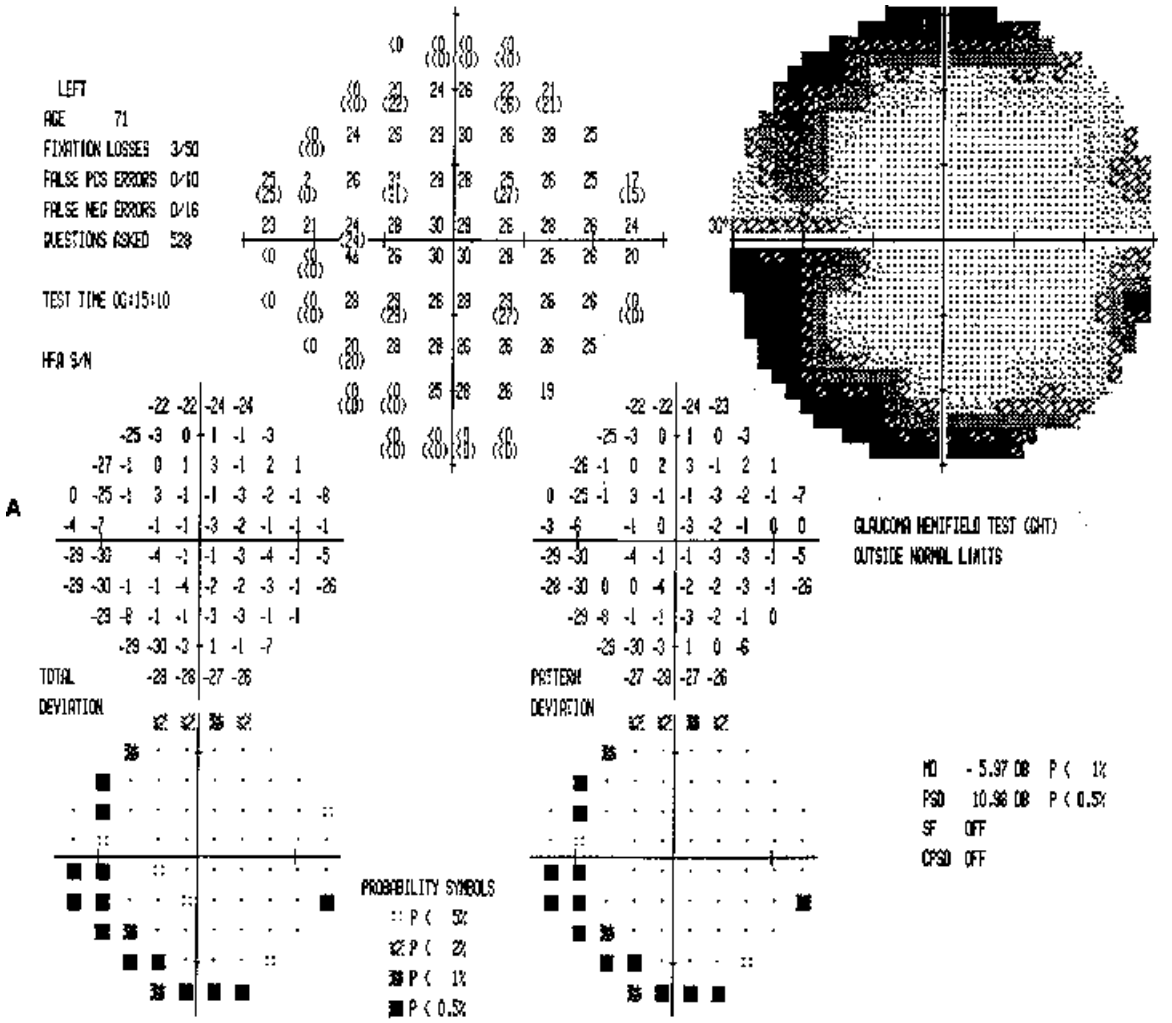
This scoring gives us an objective assessment of the degree of optic nerve damage which can help us set a target IOP so as to prevent further deterioration of the VF.

ARTIFACTS

Are depressed sensitivities that can be erroneously interpreted a VF losses.

1. EDGE ARTIFACTS -

   Edge points are susceptible to artificial low sensitivity by an overhanging eyebrow or the rim of the lens (when it is placed too far from the eyes.)



Typical Lens Rim Artifacts. A, When the lens is too far from the eye or not properly centered, its rim can produce a sharply demarcated absolute (0-dB stimulus not seen) defect. As in this example, it need not extend around the entire circumference.

2. REFRACTION SCOTOMAS

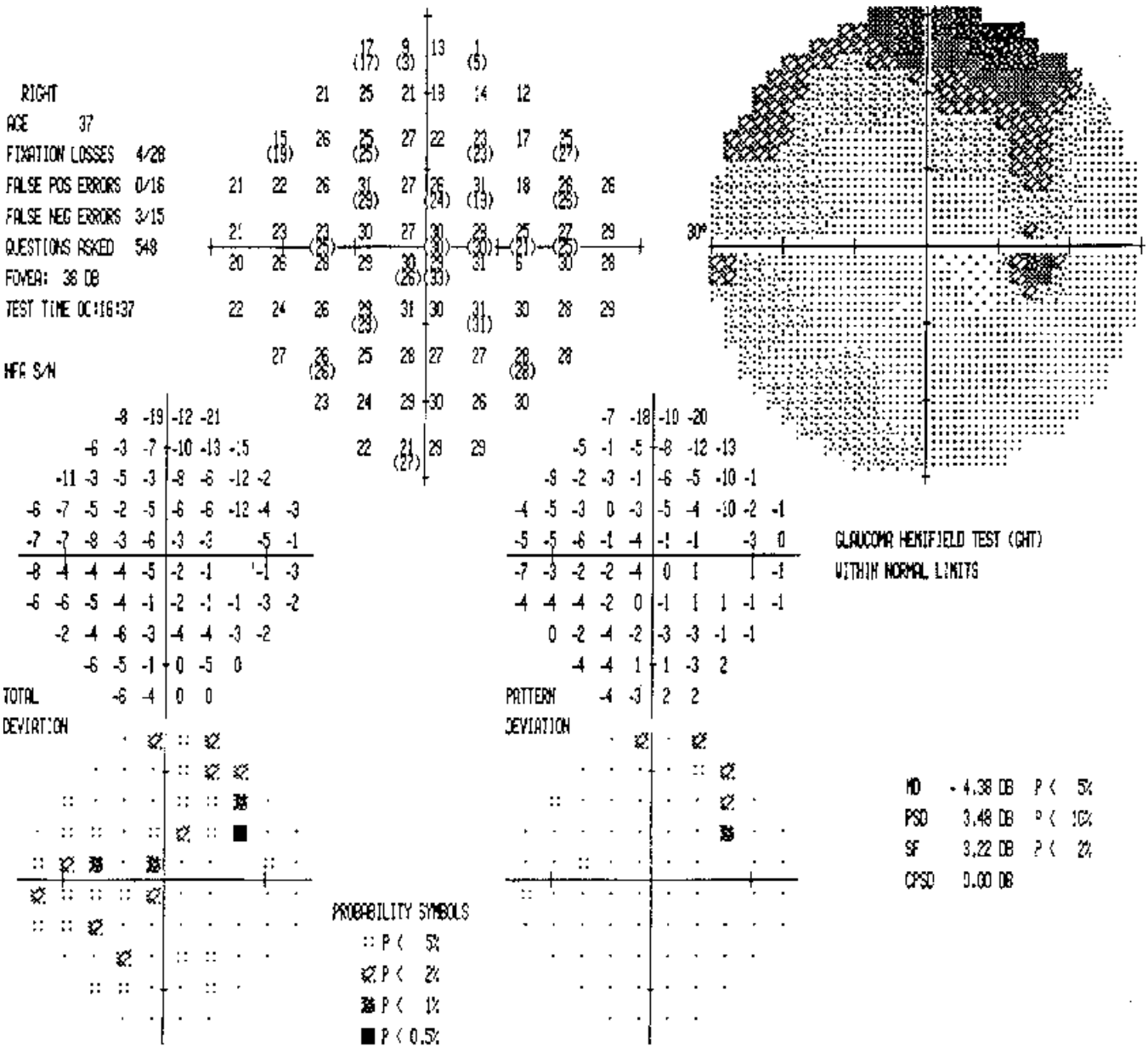
This also called the tilted disc syndrome. It can be mistaken for an arcuate scotoma or an upper temporal hemianopia. This usually occurs with some degree of astigmatism or myopia when the back of the eye is asymmetric and the stimulus focuses in one part of the retina but not in the other. The unfocussed stimulus is less perceived and may cause an "arcuate" scotoma.

3. INCORRECT POSITIONING

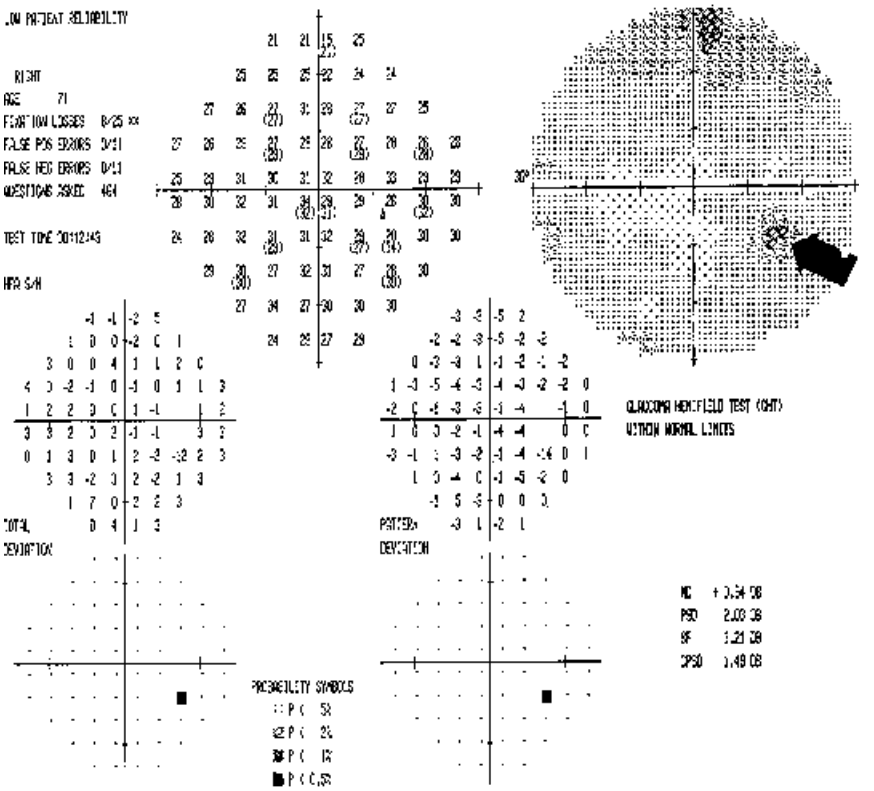
If the patient fixation is not central but slightly off- centre due to incorrect fixing of the head then the blind spot is also shifted and falsely high fixation losses may be seen.

4. INEXPERIENCED PATIENT

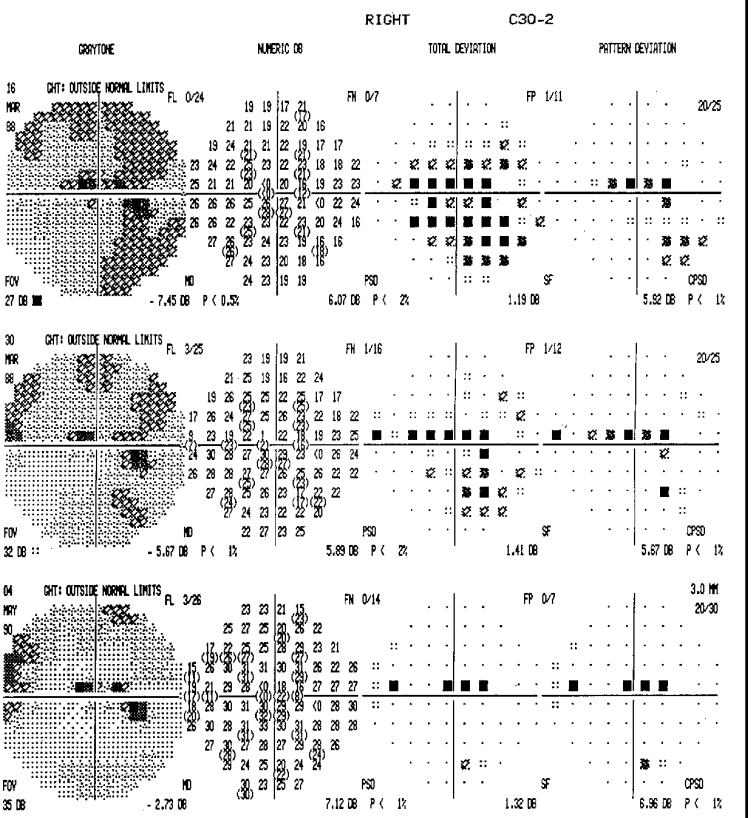
The 1st visual field test performed by the patient should be interpreted with caution. There is a learning curve for perimetry.



Field defect with the features of a typical refraction scotoma.



Incorrect Fixation. Because the patient maintained fixation on the inferior fixation target, the physiologic blind spot is represented as a scotoma in the lower temporal region (*arrow*). The upper field is more depressed than is usual, and a high FL is reported.



Overview Of Fields With Gradual Improvement. These are three of the four fields represented in Figure 7-47. As overall sensitivity improves, especially in the outer portions, the narrow upper arcuate field defect hugging fixation becomes more crisply defined.

Octopus Perimetery

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RamAvtar Eye Hospital & Glaucoma Pavilion, Jaipur
e-mail : sunisha26@gmail.com

Salient features & Points to remember for OCTOPUS Perimetry

- Always the correction is done for distance, using rimles trial lenses only
- Proper explanation is very important as the TOP finishes in about 3 minutes. If the patient has not understood it initially, reliability would be poor.
- The area seen by a steady fixating eye defines the visual field.

DISPLAY, PRINTOUT FORMATS & THEIR INTERPRETATION

The results from a perimetric examination are limited to the values of the local sensitivities & from this set of "raw data" all other statistical calculations are made. In Glaucoma management, the focus is on testing the central 30 degree visual field.

For ease of interpretation, an OCTOPUS visual field printout(the standard 7-in-1 printout) is divided into 9 parts. Each part has it's own significance.

Part 1 - PATIENT DATA

Verify the name, Date of birth, age of the patient. Confirm that the refraction corresponds to the latest test. IOP to be entered .At the end location of the file on PC is displayed.

Part 2 - EXAMINATION DATA

This shows the examined eye & pupil size at the top. Pupil size is very important in order

To compare with the previous data or with normal data.

It also lists Examination date, time, test duration & the actual test parameters like selected Perimetry method, examination program & strategy.

The total number of questions & repetitions also are displayed .Repetitions occur because of the blinking or lost fixation by the patient. Though repetitions do not affect the test result

Lastly it reports the number of missed or presented trials. This is important for the reliability of the test. From this the Reliability Factor(one of the indices) is derived.

Part 3 - VALUE (VA)TABLE

Value Table displays all the information about the patient's visual field as the actual measured values of Retinal sensitivity in decibels(dB).The other graphs & data are derived from this.

Part 4 - COMPARISON(CO)TABLE

This shows the numerical value presented by the difference(comparison) between the are-corrected normal data & the actual measured results. These numbers are defects if they are significantly higher than the variation. This table is designed to use just a simple "+" symbol to avoid overcrowding in the graph.

Part 5 - GREYSCALE

Greyscale provides a quick review & first assessment of the visual field in one quick glance. The lightere the colors, the higher or better is the sensitivity. The darker areas

Indicate depression. Black depicts an absolute defect.

OCTOPUS offers two greyscale options:

1. The standard greyscale is based on the actual measured (VA) values

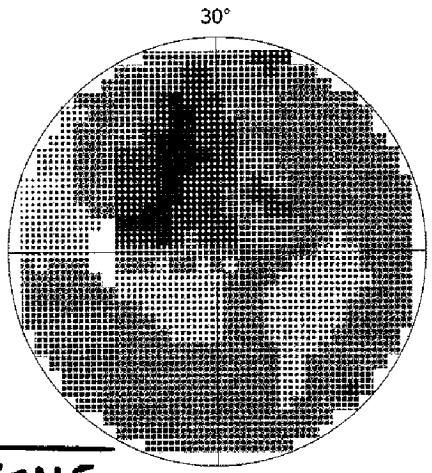
Name, first name	AGARWAL JAGDISH PD
ID	005790
Date of birth	01/01/1940
Gender	male
Refraction S/C/A	/ /
Acuity	
IOP	22 mmHg
Notes	

① PATIENT DATA

② EXAMINATION DATA

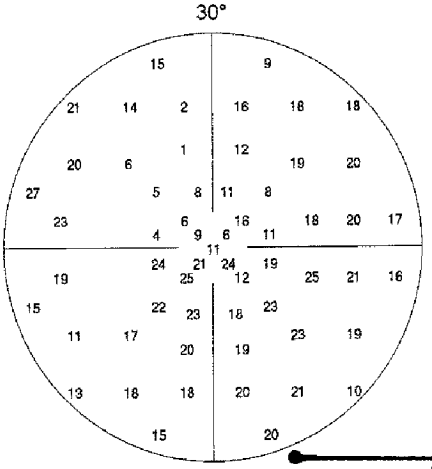
Eye/Pupil	Left eye (OS) / 3.0
Date/Time	28/08/2010 / 11:59 a.m.
Test duration	02:32
Program/Strategy	G1 / TOP
# Stages/Phases	4 / 1
Method	Standard / White/White
Stimulus/Duration	III / 100
Background [cd/m2]	10
# Questions/Repetitions	71 / 2
# Catch trials	pos 1 / 3, neg 0 / 4

⑤ GREY SCALE



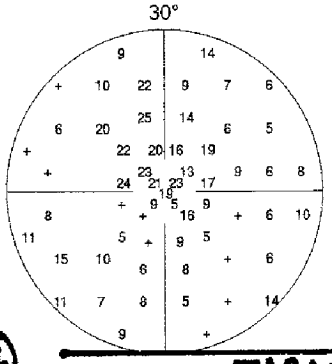
Greyscale (VA)

③ VALUE TABLE

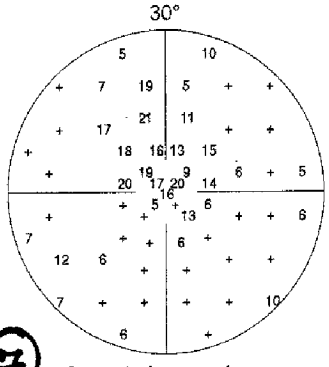


Values

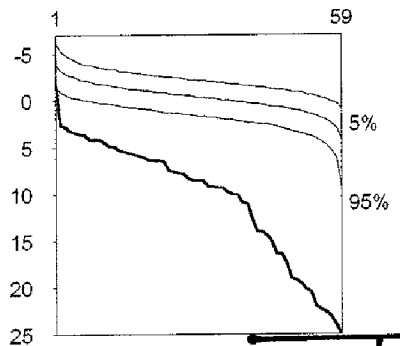
④ Comparison TABLE



⑦ Corrected comparison



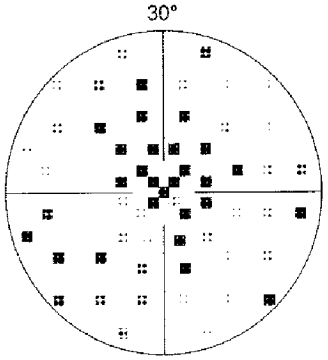
BEBIE'S CURVE ⑥



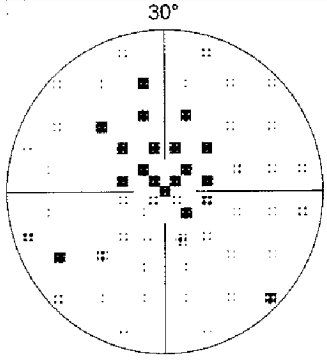
Deviation [dB] 3.6

P > 5
P < 5
P < 2
P < 1
P < 0,5

⑧ PROBABILITY PLOTS



Probability



Corrected probability

⑨ VISUAL FIELD INDICES.

	Phase 1	Phase 2	Mean
#	59		
MS	15.9		
MD	10.4		
LV	43.4		
CLV			
SF			
RF			14.2

2. Greyscale of the CO values(CS).This represents the deviation from the age-corrected normal value in a range of 100% for normal sensitivity to 0% for absolute defect

Part 6 - CUMULATIVE DEFECT CURVE(CD)/ BEBIE CURVE

This shows all defects sorted in the order of increasing depth from Left to Right. It is useful in clearly & quickly assessing the characters & the depth of the defects.

The number 59 represents the total number of locations tested. For an examination with

Program 32,the number would be 74.

Part 7 - CORRECTED COMPARISON TABLE

It can be explained as the result of the values in the CO-table minus the deviation.

The corrected CO-table depicts local defects relative to the mean diffuse depression to show a much clearer picture of the true defects in sensitivity behind a possible cataract.

This is specially of value in co-existing cataract & Glaucoma.

Part 8 - PROBABILITY PLOT & CORRECTED PROBABILITY PLOT

It is calculated from the comparison values in the CO table & is graphically displayed. In this, the statistical significance of the local defects is indicated as a symbol in different shades. The darker the symbol ,the more significant the defect.

The most significant values are tagged with P< 0.5% meaning that less than 0.5% of the subjects within a normal population may show such a defect. But with 60 test locations the probability to find one such defect in a perfectly normal visual field is 30%.Hence,care should be taken while interpreting.

The lowest has the symbol P>5% ,indicating that 5% or more of the population may have the same value.

The Corrected Probability Plot shows the significance of the corrected comparison values explained just as in Probability plot, but the graphical representation makes the localized defects, like Typical Nerve Fiber bundle defect more visible.

Part 9 - VISUAL FIELD INDICES

They were first introduced in the world in OCTOPUS in 1985.

The global & most important characteristics of a visual field can be expressed by a few Indices, which are the average of all local defects, or the local variability of defects.

Visual Field Indices are more precise because the results are averaged over the test locations.

a) Mean Sensitivity (MS)

Like the local normal values ,the normal MS depends on the patient's age & hence, a unique normal range of MS doesn't exist.

b) Mean Defect (MD)

This is independent of age & includes all local defects-also the smaller ones hidden behind the "+" symbol.. About 90% of the normal fields have an MD in the range -2 to +2. MD is the most important index related to global damage. A trend in visual field change can be analyzed best by following MD changes.

c) Loss Variance (LV)

LV, in numerical terms, is nothing but variance(square value of the SD) of the local defects. For followup fields, plotting MD & LV is a powerful combination for the detection of visual field changes.

d) Short Term Fluctuation (SF)

Useful for accurate diagnosis in borderline cases. SF varies from 1.5dB for normal to 2.5dB & higher for disturbed visual fields.

e) Corrected Loss Variance (CLV)

This index corrects for the variance by subtracting the square of SF from LV. This

is even more sensitive value than LV to detect early local defects. For 90% of normal population, CLV is below 2.5dB.

f) Reliability Factor (RF)

Indicates patient's co-operation. It is calculated from the positive & negative catch trials, false positive & negative answers. RF should normally be <15%.A grade of "0" is excellent.

To The TOP (Tendency Oriented Perimetry)

TOP presents the maximum in fast threshold testing by reducing the examination time by nearly 80% to just over 2 minutes.

The TOP algorithm is a systematic method which takes into account that the threshold values of neighbouring locations are correlated.The anatomical & topographical interdependence of visual field defects establishes a "tendency" between the threshold of neighbouring zones.It takes advantage of this tendency by "Vertical Bracketing" & by interpolation.It can be used in conjunction with Flicker or Blue-on-yellow perimetry.

A multicentric study carried out in six leading institutions in USA & Asia showed an excellent correlation between the visual field indices obtained with TOP & the normal strategy.With TOP,there is a tendency to obtain shallower scotomas.But,the time saved & the reliability because of patient compliance far outweighs this. •

Optical Coherence Tomography

Dr Pavan Shorey
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Q: What is Optical Coherence Tomography (OCT)?

A: Optical Coherence Tomography is a diagnostic tool that can perform tomography (Cross sectional imaging of biological tissues) within 10 microns axial resolution using light waves.

Q: How is OCT suited to retinal diagnosis?

A: As retina is easily accessible to external light, it provides information of retinal tomography (Cross sectional imaging of retinal tissues) and is like taking histopathological sections in Vivo.

Q: Is OCT a substitute for Fluorescein Angiography?

A: It is not a substitute for Fluorescein Angiography which yields information about retinal circulation, its topography and abnormalities of retinal vasculature. OCT predominantly gives information about the macula which complements the information we get from FFA.

Q: What is the principle of OCT?

A: OCT is based on the principle of low coherence interferometry wherein an infrared (830mm) beam is projected onto the patient's retina in a scanning fashion. A second beam (Internal reference beam) is projected internal to the unit at a known reference distance. When the two light beams (internal reference beam and back scattered reflected light from retina) attempt to recombine, the reference beam must be altered in order to recombine with the diagnostic beam. This alteration results in a signal generation. The magnitude of back scattered and reflected light from target tissue demonstrates a false colour image in two dimensions.

Q: What are the two types of OCT machines available?

A: The two types of OCT machines available are Time Domain and Spectral OCT.

Q: What is Time Domain OCT?

A: The infrared light beam projected on the retina gets reflected back from the microstructures and gets scattered differently from tissues with different optical properties. Time domain OCT compares the time delay of light reflecting from various layers of the retina with time delay of light reflected from a reference mirror at a known distance. The signal acquisition time is prolonged because this technology relies on mechanical movements of internal components for thickness measurements thus limiting the speed of acquisition.

Q: What is Spectral/Fourier Domain OCT?

A: Here the reference arm is stationary. Hence the elimination of mechanical movement of reference results in faster (70 times faster) acquisition of data. The scanning speed increases to 28,000 A scans per second. This scan speed results in generation of 3D views of retina.

Q: Compare Time Domain OCT and Spectral Domain OCT?

A: The light source is 820 mm in Time Domain OCT and 840 mm in Spectral Domain OCT. The Time Domain OCT has a single movable detector while Spectral Domain OCT has a spectrometer resulting in faster scan

acquisition. Maximum A scans per B scans is 512 in Time Domain OCT while it is 8,000 in Spectral Domain OCT. Scanning speed is 400 A scans per second in Time Domain OCT while it is 28,000 A scans per second in Spectral Domain OCT. 3D OCTs are possible only in Spectral Domain OCT.

Obtaining an OCT image

- Mydriasis is a must to obtain artifact free OCT image. A normal or miotic pupil does not prevent an OCT evaluation of macula but can produce artifacts.
- Patient is aligned properly and asked to look at the fixation target.
- Image acquisition is controlled by a joystick and button depression by an operator.
- Various image acquisition sequences are available which vary from manufacturer to manufacturer.

Specific scanning protocols

- Retinal scanning protocols: Line scan, raster lens, cross hair, radial lines, x line, circle.
- Macular scanning protocols: Macular thickness scan and fast macular thickness map are two commonly used protocols. These protocols consist of radial scans length of 6 mm at equally spaced angular orientation (30°).
- RNFL scanning protocols: OCT 3 offers a variety of RNFL thickness measurements and analysis protocols.
- ONH scanning protocols: Optic disc scan and fast optic disc scan.

OCT Image interpretation

The OCT image closely resembles the histopathological appearance of the macula and has often been called an in Vivo biopsy. The histopathological correlation with OCT image has been found to be accurate. In order to interpret a diseased macula, it is important to know the normal appearance of macula on OCT. (Fig 1)

Normal macula scan

On a 10 mm horizontal line scan passing thru the foveola, two landmarks can be clearly delineated: The optic disc and fovea (Fig 1). The optic disc is seen towards the right of the tomogram and is identifiable by its contour. The fovea is seen to the left and is easily identifiable by the dip and thinning of retinal layers. The vitreous anterior to the retina is seen as a dark space. Differences in signal intensity of the reflected beam are represented by false color coding system.

Reflective structures

RED: Highly reflective structures: Nerve fibre layer and retinal pigment epithelium, choriocapillaries

YELLOW or GREEN: Medium reflective structures like nuclear layers and plexiform layers.

BLACK: Represents the absence of signal and is seen in vitreous.

The top of the scan represents the vitreous which is optically silent (Black). If there is a posterior vitreous detachment, it will appear as a thin horizontal line above the retina or inserting into it.

The anterior surface of retina demonstrates high reflectivity (Red). This represents the internal limiting membrane and the nerve fibre layer.

The axially aligned cellular layers of retina (inner nuclear, outer nuclear and ganglion cell layers) manifest as relatively low tissue signals (Green, Yellow).

The retinal pigment epithelium (RPE), Bruch's membrane and choriocapillaries complex comprise the second highly reflective band. This appears at a red linear stripe in OCT image.

Retinal thickness assessment:

The OCT determines the anterior and posterior surface of retina in order to calculate retinal thickness. It is determined by 6 radial lines.

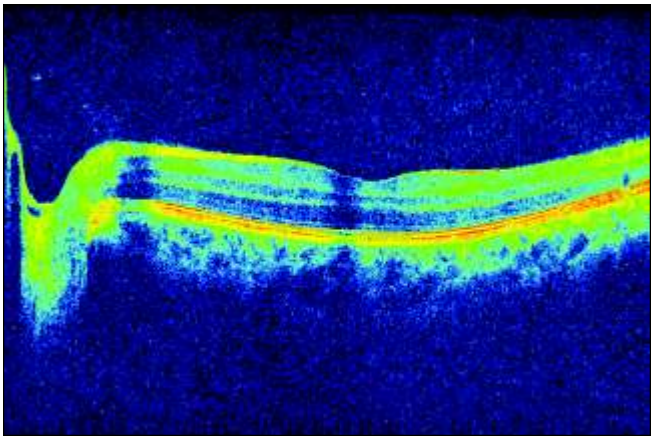


Fig. 1 : Normal Macular Scan

Averaging calculations results in topographical thickness map of macula. Colour coding indicates relative thickness.

RED: Thick, YELLOW/GREEN: Medium, BLUE/ BLACK: Thin

Actual values are given in microns. (Fig 2)

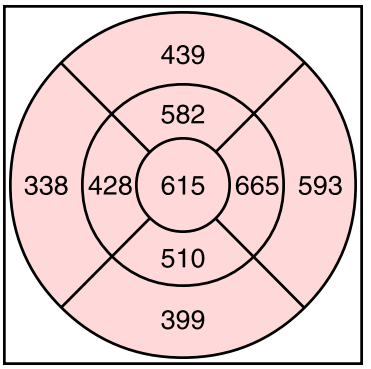


Fig. 2 : Macular Thickness Assessment

Patterns of abnormalities

1. Increased thickness: Due to retinal oedema seen in diabetic retinopathy, vein occlusions, CME etc.
2. Decreased thickness: Retinal atrophy secondary to laser, trauma, healed choroiditis
3. High Reflectivity
   - Superficial : Epiretinal membrane, subhyloid haemorrhage, cotton wool spots
   - Intraretinal : Hard exudates, dot & Blot intraretinal haemorrhage, fibrosis
   - Deep : Drusen, subretinal neovasecularization, neves, RPE hyperplasia
4. Low reflectivity
   - Serous fluid: Retinal oedema is the commonest cause of low reflectivity. The cystoid spaces are optically clear (Black), other causes: Retinal pigment epithelial detachment

OCT Scan Analysis

1. Qualitative aspects
   a. Morphological changes
   b. Reflectivity changes
2. Quantitative aspects
   - Thickness
   - Volume
   - Surface mapping
     a. Qualitative Morphological analysis: Changes in contour & location of changes (Preretinal, intraretinal, subretinal)
     b. Qualitative reflectivity analysis: Identifying increase or decreased reflectivity, shadowing and its location (Superficial, intraretinal or deep)

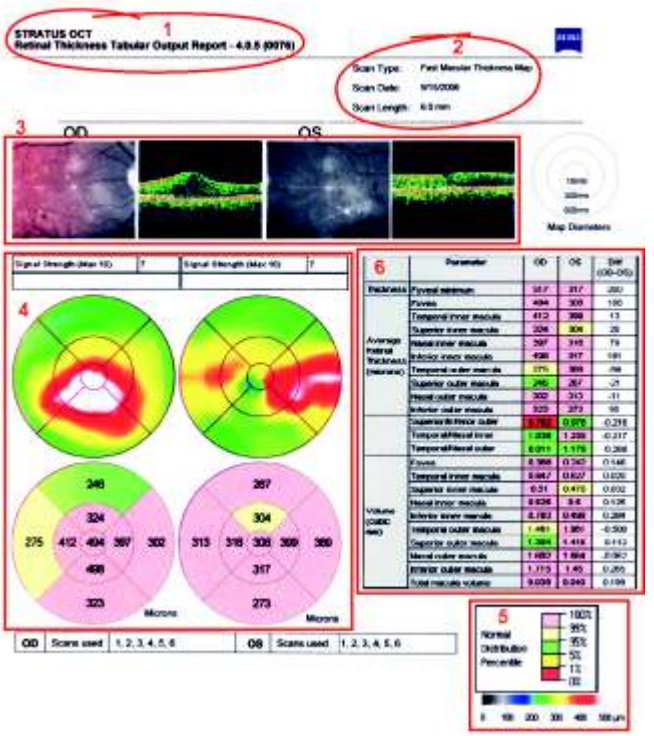
Quantitative analysis: Can be done for retinal thickness, volume and surface mapping.

The normal fovea thickness is 170-190 microns. The normal macular scan appears green while fovea appears blue

BLUE : 150-210µ, GREEN : 210-270µ, YELLOW : 270-320µ, RED : 350-470µ

How to read an OCT print out. (Fig 3)

1. See for the title of the report: Is it macular thickness map, fast macular thickness map, raster lines, radial lines etc. This report shows a retinal thickness tabular report.
2. Will show scan type, scan date & scan length (1, 3 or 6 mm) centered on the macula.



3. Fundus picture with corresponding OCT picture of the right and the left eye. The OD OCT picture show spongy oedema while the OS picture shows macular oedema.
4. This displays both thickness and volume for each eye. The upper maps show colour coded retinal thickness. The key to colour coded thickness is given in 5. The lower maps show average thickness in microns in various regions of macula.
5. Shows the normal distribution percentile of macular thickness as well as the key to colour coded thickness.
6. Retinal thickness volume tabular output: Gives the thickness of various regions of macula in microns as well as colour code. The two eyes are compared region for region and the difference in thickness is noted in the last column.

OCT in specific disease

1. Diabetic Macular Oedema:

Diabetic macular oedema is the most common cause of decreased vision in diabetic retinopathy. FA will help distinguish whether the macular oedema is focal or diffuse. But changes occurring within the layers of the macula are picked up by OCT. It can detect and quantify macular oedema, it can detect cystoid changes, hard exudates and serous detachment. OCT is able to diagnose macular traction, Taut posterior hyaloid membrane.

OCT shows 5 distinct patterns in diabetic macular oedema

1. Sponge-like retinal thickness (Fig 4)
2. Cystoid macular oedema (Fig 5)
3. Serous retinal detachment (Fig 6)
4. Foveal traction detachment
5. Taut posterior hyaloid membrane (Fig 7)

2. Vein Occlusions: OCT is useful in detecting macular oedema, quantifying it.

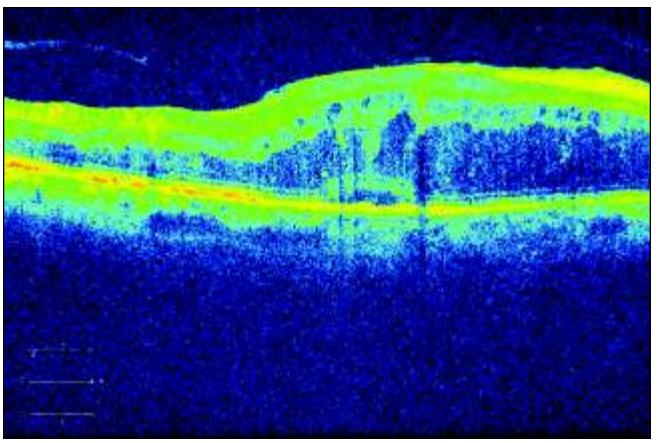


Fig. 4 : Spongy Diabetic Macular Oedema

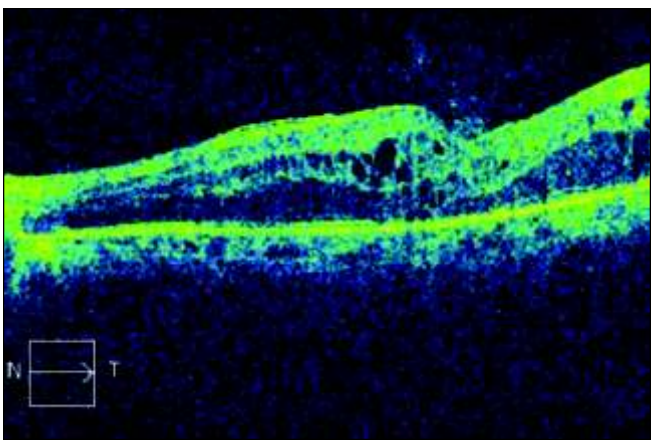


Fig. 5 : Diabetic Cystoid Macular Oedema

It is useful in follow up of these patients when intervention in form of intravitreal anti VEGF, intravitreal steroids is done. It is also useful for the follow up of such patients. (Fig 8)

3. Age related macular degeneration:

1. Drusen: Appear as hyper reflective protrusions within the retinal pigment epithelium. (Fig 9)
2. Subretinal neovascularization or choroidal neovascular membrane is imaged as a multi layered, highly reflective with loss of retinal contour in the overlying region. It may be located

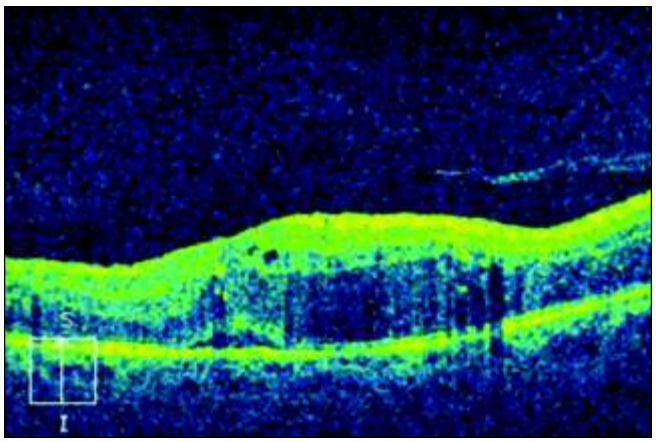


Fig. 6 : Serous Retinal Detachment

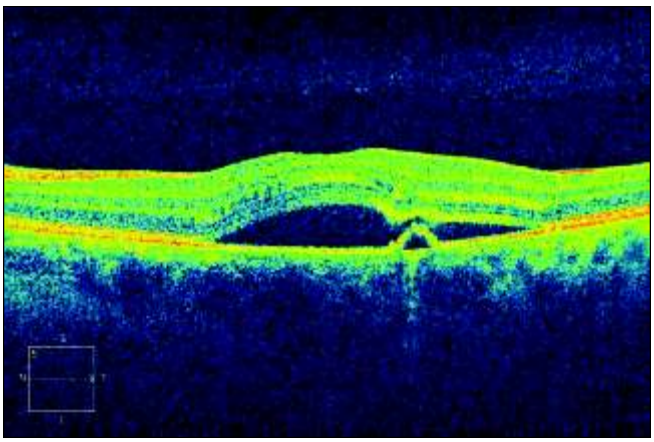


Fig. 9 : Drusen at Pigment Epithelium

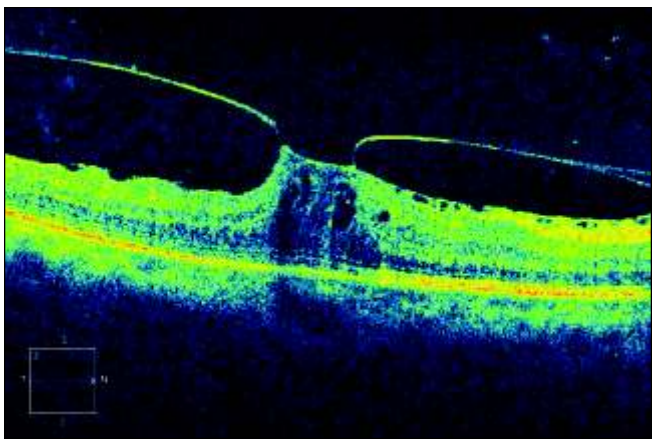


Fig. 7 : Taut Posterior Hyaloid Membrane

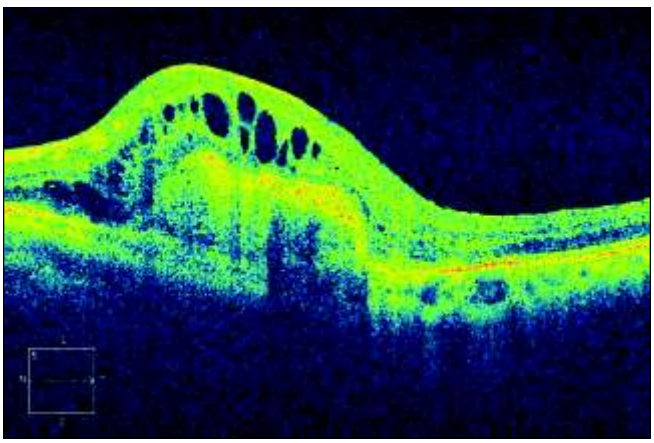


Fig. 10 : Subretinal Neovascularization

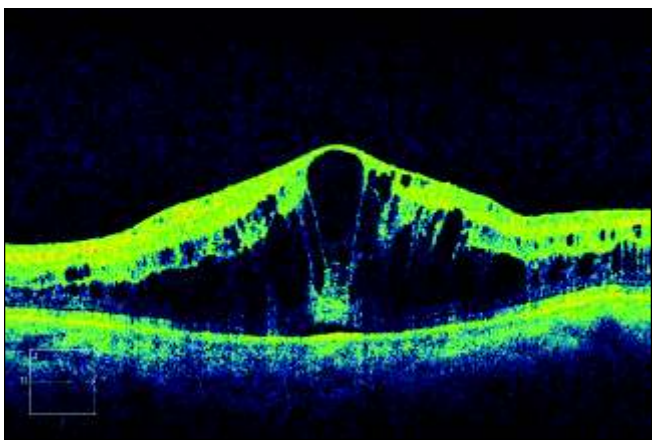


Fig. 8 : Macular Oedema in CRVA

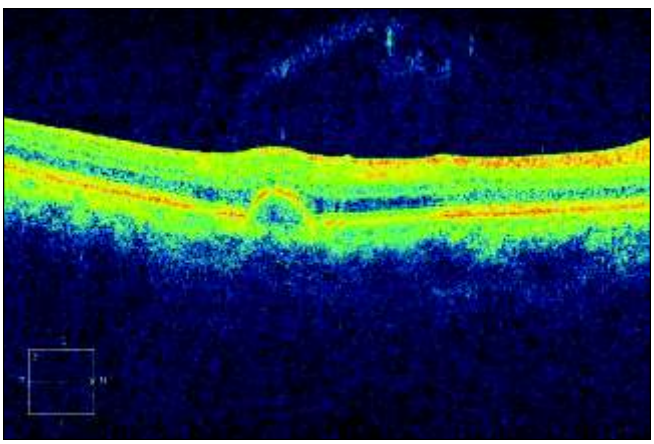


Fig. 11 : Pigment Epithelial Detachment

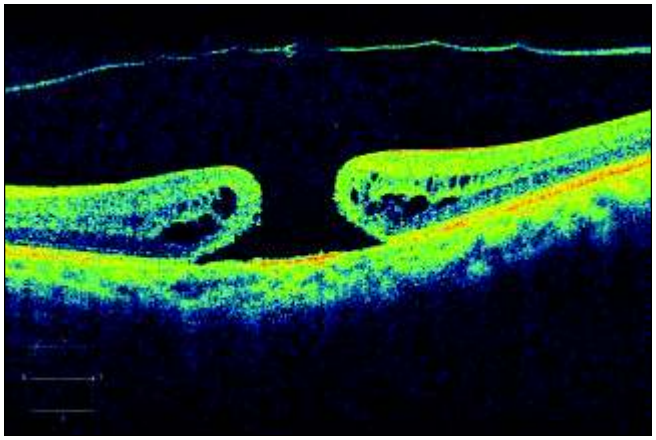


Fig. 12 : Macular Hole

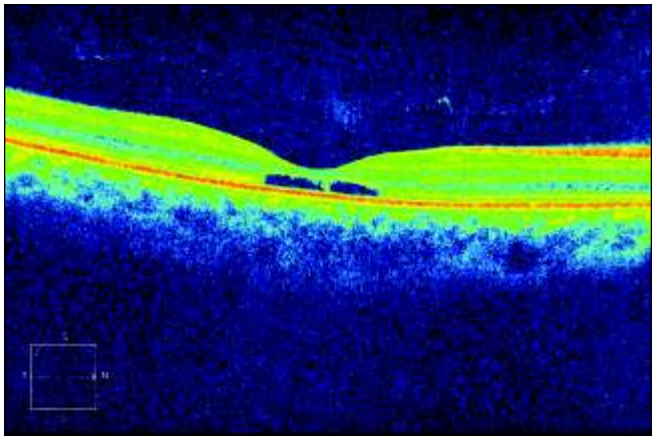


Fig. 13 : Lamellar hole

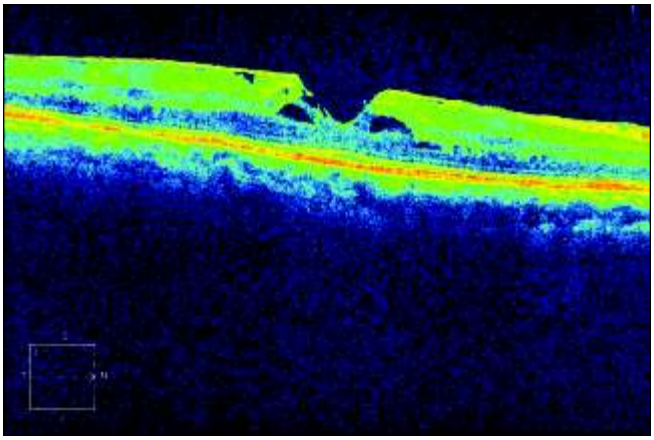


Fig. 14 : Epiretinal Membrane

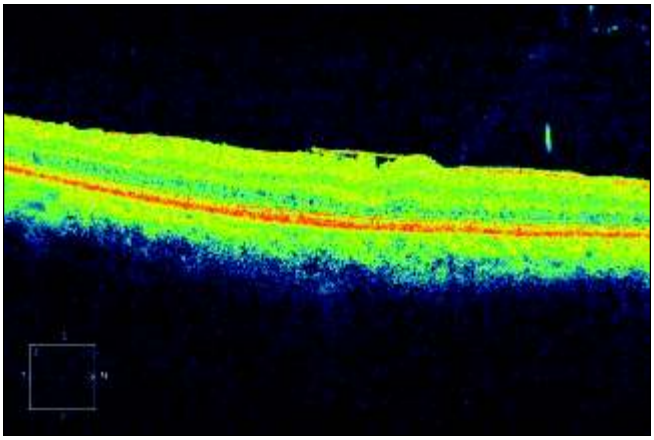


Fig. 15 : Adherent Epiretinal Membrane

in the prechoriocapillaries region or in front of RPE or both. (Fig 10)

3. Serous retinal detachment: Appears as hyporeflective separation of neuron sensory retina. (Fig 6)

4. Pigment epithelial detachments: Appear as dome shaped hyporeflective elevation on retinal pigment epithelium. (Fig11)

4. **Macular hole:** OCT is useful in detecting early stages of macular hole (Stage 1a, 1b), in diagnosing and staging macular hole 2, 3, 4, in detecting epiretinal membrane and the relationship of vitreous to the fovea (Fig 12, 13). It is also useful in post macular hole surgery.

5. **Epiretinal membrane:** Are thin translucent membranes on the inner retinal surface in the macular area. Over a period of time, they contract and may produce oedema, degeneration or cystoid spaces and decreased vision.

OCT helps in assessing the adhesiveness of the ERMS to the retinal surface and changes in the underlying retina. The ERMS may be:

1. Clearly separable by surgery wherein clear spaces are seen between the ERM and the nerve fibre layer (Fig 14)

2. Globally adherent ERMS where no clear area of separation is seen between ERM and inner retinal surface (Fig 15)

OCT demonstrates the extent of the membrane, changes occurring in the vitreoretinal interface, changes like cystoid macular oedema, viteroretinal traction and macular hole. •