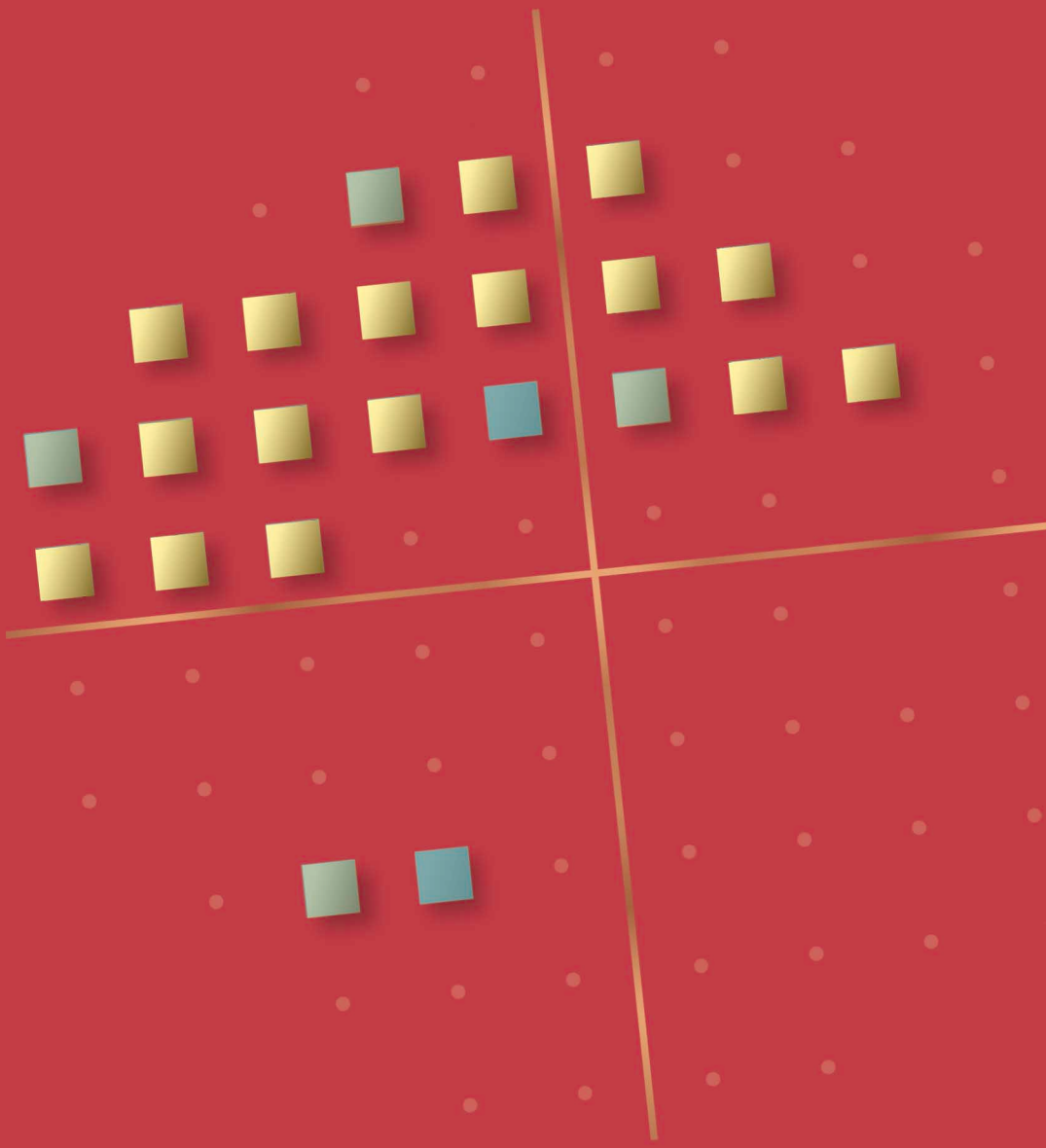
THE FIELD ANALYZER PRIMER

Essential Perimetry

THIRD EDITION

Anders Heijl
Vincent Michael Patella



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Contents

Foreword

HAVING WITNESSED the development of perimetry from manual kinetic methods to the present state of highly sophisticated automated perimetry, I found it a particular pleasure to read this excellent textbook. Visual acuity and visual field share the prize for the most important visual functions. Because it measures visual function outside the fovea, perimetry is essential for diagnosing and treating glaucoma — as the authors point out — and it is often useful for retinal and neurological disease. As with every diagnostic technique, understanding the background, possibilities, and limitations of perimetry is vital. This book offers an excellent overview of these aspects of the technique.

Although both the examination and the evaluation of perimetric test results have been computerized, the investigator still needs to interpret the results. It is as an aid to such interpretation that the authors have written this book with special emphasis on the Humphrey Field Analyzer. After describing the essentials and basic principles of perimetry, the authors discuss the most important

recent changes: faster examination techniques and better interpretation. These improved techniques have made automated perimetry into a highly efficient procedure that can be easily repeated. Because of the inherent variation of this and every other method, repetition is vital. Baseline field condition should be based upon a number of repeated examinations and, similarly, establishing progression requires a series of examinations. The fast examination technique makes all this possible and practical, as well as improving reliability.

All this is explained eloquently and clearly by the authors, who are among the world's top experts in the field. The text is lavishly illustrated, an invaluable feature in a book on perimetry. The three major subdivisions, glaucoma, neurological and retinal disease, are well treated with, of course, special emphasis on glaucoma — the one disease where we could not do without perimetry. In any technique artifacts may appear. It is important to be aware of the artifactual possibilities of perimetry and to differentiate them from true defects. The consequences of this differentiation are highly important, and the authors explain them clearly.

This textbook illustrates both the ripeness of the technique and the capabilities of the authors to explain it in clear language. Perimetry will continue to be one of the two essential visual function tests. Nowadays it has been developed to a stage where it can be used routinely and repeatedly by every professional and for almost every patient. *Essential Perimetry* by Anders Heijl and Vincent Michael Patella is highly recommended and with great delight.

—Professor Erik L. Greve
Graveland, The Netherlands

Preface

AUTOMATED PERIMETRY was just gaining acceptance sixteen years ago when the first edition of this primer was published. That text emphasized technical and psychophysical topics and contemplated a wide spectrum of possible testing options. Today, automated perimetry has become more standardized, and *Essential Perimetry* reflects the consensus that has developed by concentrating on the specific procedures that, over the years, have been incorporated into the standard of care.

In order to keep the book short and easily approached, we have of necessity condensed complex ideas in ways that we hope will be useful to practicing doctors and technicians. Condensation and summarization require that judgments be made based upon our own opinions and clinical experience. For this reason we have also cited the primary references whenever possible, so that the interested reader may review the original reports and form his or her own conclusions.

On a more personal note, this third edition celebrates twenty years of close collaboration between the authors in

the development of automated perimetry. We wish to thank our editor, Mary Jean Haley, without whose guidance this text would not exist. And we would like to recognize the long-term members of the Swedish perimetry development team: Boel Bengtsson, Peter Åsman, Jonny Olsson, and Buck Cunningham. Thanks also go to Melissa Allison, who supported the project through all its ups and downs, and to Mandy Ambrecht and Cindy Metrose.

—Anders Heijl, MD, PhD

—Vincent Michael Patella, OD

Introduction

How to Use This Primer

THIS BOOK IS MEANT as an introduction to and primer on clinical perimetry, particularly computerized perimetry using the Humphrey® Field Analyzer. It is not meant to replace classical textbooks on the subject, but rather is intended as a brief overview for the ophthalmic resident and as a reference on current Humphrey perimetry for the busy ophthalmic practitioner.

Because of its purpose, this primer does not follow the outline of most textbooks. For example, the bare essentials of present-day practical perimetry are covered in a very condensed form in just a few pages in Chapter 1.

The doctor who only has time for absolutely basic information may choose just to read Chapter 1 and to refer to the other chapters only on subjects of special interest. A more interested reader, or a resident or new practitioner, may choose to begin with Chapter 1 and then read the rest of the book in order to understand not only how to use perimetry but also why.

1

The Essentials of Perimetry

THIS CHAPTER PROVIDES a quick outline of essential perimetric facts. The topics presented here are treated more fully in later chapters.

What is Automated Static Perimetry?

Automated static perimetry is the most important clinical tool for measuring visual function outside the fovea. Threshold testing involves precise quantification of visual sensitivity, while suprathreshold testing is used mainly to establish whether visual function is within the normal range.

When is Perimetry Called For?

Perimetry is essential in glaucoma management. It is frequently useful in diagnosing and managing neurological diseases, and it has a role in the diagnosis and treatment of many retinal diseases. Perimetry is also used to certify visual function in patients with vision disabilities.

GLAUCOMA

Perimetry is fundamental in diagnosing and managing glaucoma. Test results that reproducibly demonstrate field loss are the most conclusive and concrete means of establishing a diagnosis of chronic open-angle glaucoma. The best currently available method of following the progression of the disease is repeated visual field testing. Imaging the optic disk or retinal nerve fiber layer is also important, but it cannot replace perimetry in evaluating glaucoma patients.

NEUROLOGICAL DISEASE

Quantitative visual field testing is of great value in diagnosing and managing neurological disease, but methods other than quantitative perimetry, such as confrontation tests, are also sometimes used. When it comes to managing neurological disease, field testing is not as crucial a technique as it is in glaucoma management; neuroimaging can often replace perimetry.

RETINAL DISEASE

Visual field testing has a role in diagnosing and treating many retinal diseases, but direct observation of the fundus through ophthalmoscopy is usually of greater value in retinal diagnosis. Perimetry then becomes one of many ancillary tests. In the work-up of retinal diseases, testing in the area outside the central 30 degrees plays a somewhat larger role than it does in diagnosing or following glaucoma or neurological disease.

Visual field testing does provide a means for following the functional influence of many retinal diseases. Here the role may sometimes resemble that of field testing in low vision management and visual rehabilitation.

GLAUCOMATOUS VISUAL FIELD LOSS

Glaucomatous visual field loss usually occurs first in the so-called Bjerrum areas of the upper and lower hemifields. These two areas curve around the macula, extending upward and downward from the blind spot toward the nasal field in two arcs. Early glaucomatous field defects most often take the form of relative scotomas, or small regions of decreased sensitivity. Defects in the nasal field are particularly common, and sensitivity differences across the horizontal meridian are often used diagnostically, particularly in the nasal hemifield *(see figures 5-7, 5-8, and 5-9 in Chapter 5)*. Perimetric testing of glaucoma patients is seldom done outside the central 30 degree field because only a small percentage of glaucomatous defects occurs in the peripheral field alone.

Considerable test-retest variability is a hallmark of glaucomatous visual field loss; variable reduction of sensitivity occurring in the same area, but not at exactly the same test point locations, commonly precedes definite glaucomatous field defects. Although an overall reduction in sensitivity is frequently seen in combination with localized loss, homogeneous reduction of sensitivity alone is almost never seen in glaucoma. It occurs regularly in eyes with media opacities or miosis.

NEUROLOGICAL VISUAL FIELD LOSS

Most neurological field defects are hemianopic, that is, part of the defect respects the vertical meridian through the point of fixation. As with glaucoma, the great majority of defects start in the central 30 degrees of the visual field *(see figures in Chapter 6)*.

RETINAL VISUAL FIELD LOSS

Perimetry is used to test for a large variety of field defects caused by retinal disease. Such defects are often deep,

have steep borders, and frequently are highly reproducible *(figures 7-1 and 7-3)*.

Selecting a Test

It is important for the clinician to choose one standard test and use it for most field testing.

Static computerized perimetric tests are defined in terms of the locations tested and the algorithm used to measure the sensitivity at each test point. It is important for the clinician to choose one standard test and use it for most field testing. This facilitates developing an in-depth understanding of the test results and ensures test-to-test comparability of results, both for a given patient and among patients.

Standard automated perimetry is usually performed with one of four similar threshold measuring tests: 30-2 or 24-2 SITA Standard™, or 30-2 or 24-2 SITA Fast™. We recommend that the clinician select one of these tests to use as the default test in almost every case. All are high-efficiency threshold tests that concentrate on the central field where evidence of most diseases is to be found. They differ in their test point patterns and in the test algorithms used to perform the threshold measurements.

The 30-2 pattern comprises 76 test point locations covering the central 30 degree field with a grid of points 6 degrees apart. The 24-2 test point pattern includes 54 test points covering the central field out to 24 degrees, except nasally where it extends to 30 degrees. It is identical to the 30-2 pattern except that most of the outermost ring of stimuli has been removed *(fig. 3-1)*.

SITA Standard is a testing algorithm that offers very high accuracy and a relatively short test time (four to eight minutes per eye, depending on the test point pattern used and the status of the patient's eye). SITA Fast is a very fast threshold test (two to six minutes per eye) with a diagnostic sensitivity similar to that of the Full Threshold test.

Threshold testing is always a good choice, and in ophthalmic clinical settings it is almost always to be preferred to suprathreshold screening tests. Threshold

testing can detect the earliest visual field changes and is the standard of care for following patients who have established field loss.

PERIMETRIC FOLLOW-UP

It is usually most suitable to follow a patient over time using the same SITA test that was used for diagnosis. The same test strategy, that is SITA Standard or SITA Fast, should be used every time. One very important reason for this is that perimetric test results are affected by visual fatigue and, as a result, tests of different durations have different normal threshold values. It is more informative to compare a series of fields obtained from the same eye in clinical follow-up if the same algorithm has been used for all tests.

PERIPHERAL FIELD TESTING

Computerized testing of the area outside the central thirty degrees is rarely performed for diagnostic purposes. The Humphrey perimeter does have, however, complete facilities for both suprathreshold and threshold testing in the peripheral field. Because variability is much larger in the peripheral than in the central visual field, suprathreshold perimetry may be considerably more helpful there than it is in the central 30 degree field.

Peripheral suprathreshold testing is frequently used to certify visual function in drivers and to establish the level of visual disability for insurance purposes. Note that the goal in such certification testing is quite distinct from medical diagnosis, in that the former is done with very bright stimuli in order to rule out blindness, while the latter uses more refined methods with the goal of detecting subtle changes.

Several models of the Humphrey perimeter can also perform kinetic testing. This feature is more valuable in the peripheral than in the central field, and its use is largely confined to tests for disability or driving.

OTHER TESTS

Although the clinician can choose to use a single default test for over 95% of all field testing in most clinical settings, other tests are sometimes called for. Short wavelength automated perimetry (SWAP), also known as blue-yellow perimetry, can detect glaucomatous visual field loss at earlier stages than standard white-on-white perimetry (Johnson et al. 1993b; Sample et al. 1993; Polo et al. 2000). When the macula area is the only area of interest, the SITA Standard or SITA Fast 10-2 tests are to be preferred *(fig. 3-4)*. In eyes seriously damaged by advanced glaucoma, it may be necessary to concentrate all testing in a remaining central island of the field by shifting to the 10-2 pattern, or to change to a larger stimulus *(see Chapter 3)*.

The Humphrey perimeter offers a selection of specific, non-standard functional tests that are sometimes needed for legal purposes. These tests and their uses may differ from country to country.

Interpreting the Results

STATPAC™ analysis is automatically applied to the results of standard Humphrey threshold tests, either to identify visual fields that fall outside the normal range, or to identify patients whose vision continues to deteriorate. The description below identifies important features of the Humphrey Field Analyzer test result printouts *(fig. 1-1)*. A detailed guide to interpreting these results is presented in Chapter 4.

DEMOGRAPHICS AND TESTING CONDITIONS

The patient's name, identification number, and date of birth are presented at the top of the printout, along with the date and time of testing, visual acuity, pupil size, and eye tested. On some models, the pupil size is measured and recorded automatically. The printout also shows the test pattern and test strategy used, the test duration, stimulus size, and the background brightness.

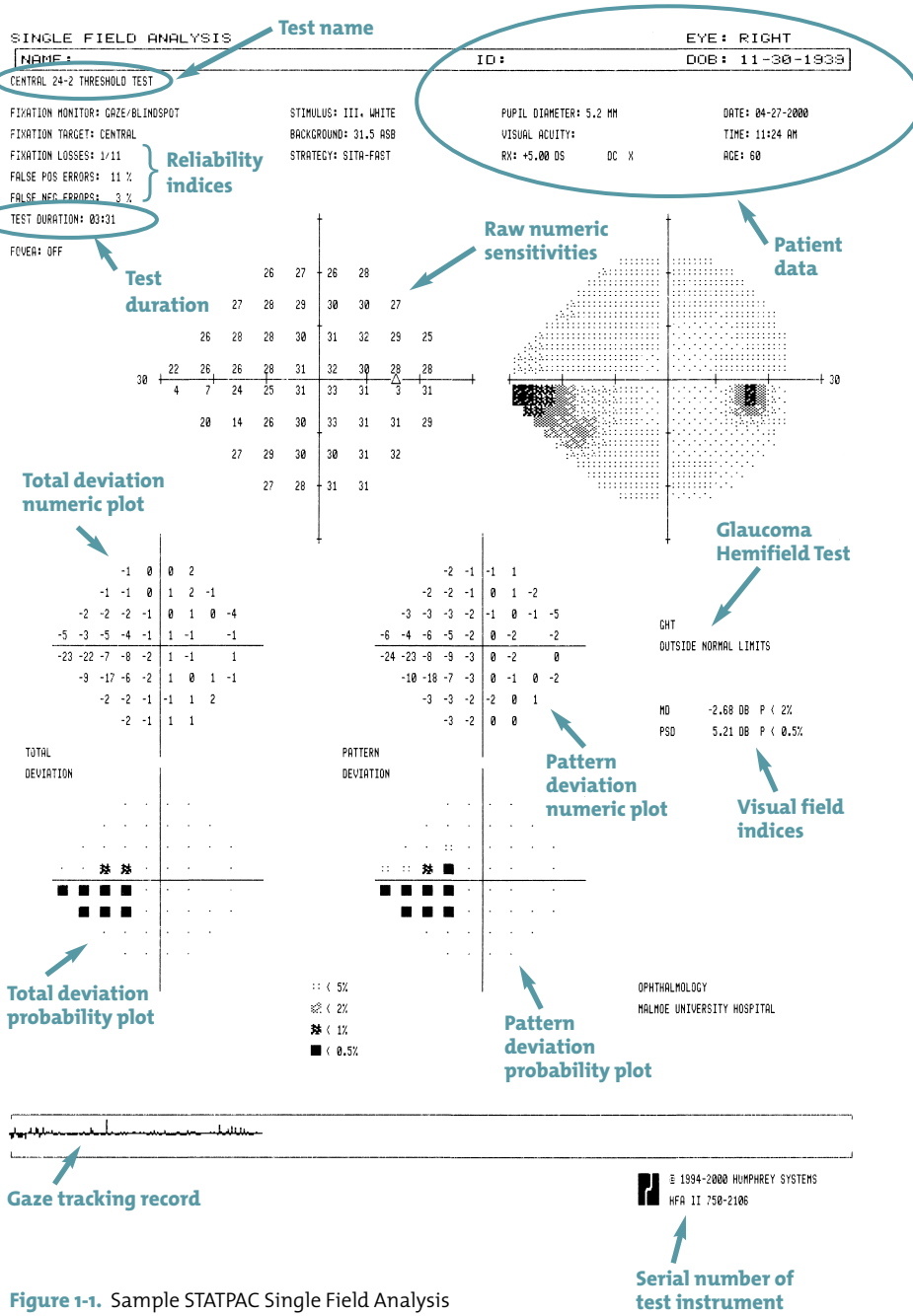

Figure 1-1. Sample STATPAC Single Field Analysis

An explanation of the reliability indices and other information shown at the top of the printout is found in Chapter 4.

DIAGNOSING FIELD LOSS

Total Deviation Probability Plots: The total deviation plots are helpful as diagnostic tools because they highlight areas of the visual field that fall outside the normal range, after correcting for the patient's age. Measured visual field defects are expressed in terms of the percentage of normal subjects that could be expected to have such a sensitivity. A p< 2% probability symbol, for instance, indicates that fewer than 2% of normal subjects would be expected to have such a low sensitivity.

Pattern Deviation Probability Plots: The pattern deviation plots may be thought of as highlighting the localized loss typical in glaucoma or other diseases while filtering out generalized loss. They flag areas that deviate significantly from normal, after first correcting for any overall change in the height of the hill of vision, which is usually the result of cataract or a small pupil.

Numerical Printouts: Although the numerical printouts cannot be rapidly and intuitively interpreted, it can sometimes be rewarding to study them because they show the actual measured threshold values upon which all the other analyses and printouts are based. Decibel values correlating to the total and pattern deviation probability plots are shown on the Single Field Analysis printout described in Chapter 4. While most users find the probability plots much more informative, these decibel defect values can sometimes provide further useful detail.

Grayscale Printouts: These old favorites seem to give an immediate and easily comprehensible picture of measured visual field sensitivity, at least in moderate to severe visual field loss. Significant but shallow field loss may be

unrecognizable in grayscale printouts, however, while common and non-significant midperipheral reductions of sensitivity may be overemphasized. For this reason, one should focus on the probability plots rather than on the grayscale printouts. The grayscale printout is useful in highlighting common artifactual field loss such as that caused by trial lens defects and false positive responses.

Glaucoma Hemifield Test (GHT): The GHT is an expert system that analyzes test results by comparing local defects in zones of the upper field with those found in mirror image zones in the lower hemifield. The GHT detects glaucomatous visual field loss with both high sensitivity and high specificity and expresses its analysis in plain language.

Visual Field Indices: Mean deviation (MD) and pattern standard deviation (PSD) are not intended for diagnosis, but they can be helpful in follow-up and also in scientific studies for dividing groups of eyes into stages of a disease. Levels of significance are shown next to MD and PSD values that fall outside the normal range.

FOLLOW-UP

Perimetric results in abnormal fields may show considerable test-retest variability. When following chronic disease, a series of fields is usually required in order to be sure that true visual field changes have occurred. Determining the stability of abnormal visual fields over time is clinically important. Identifying progressive loss as early as possible may be challenging and require some experience.

The glaucoma change probability plots discussed in Chapter 4 differentiate between random test-retest fluctuations and significant changes in glaucomatous fields. Alternatively, a series of fields may be qualitatively analyzed for change using an Overview printout or using regression analysis of MD.

COMMON INTERPRETATION PITFALLS

Several common, typical patterns of artifactual test results are worth recognizing. These include fields from eyes with partial ptosis or prominent eyebrows, fields with correction lens or lens holder artifacts, fields from patients with large numbers of false positive errors ("trigger-happy" fields), and so-called cloverleaf fields. Patients without previous experience of automated perimetry sometimes produce seemingly abnormal results characterized by concentric contraction or mid-peripheral reduction of sensitivity. These and other features of the test results are discussed more fully in Chapter 8.

GENERAL GUIDELINES TO INTERPRETING HUMPHREY VISUAL FIELD TEST RESULTS

In order to interpret visual field test results the user must master and understand many of the topics summarized in this chapter and covered in more detail in the balance of this book. The following steps are offered as a rough outline of how to proceed in general when trying to judge whether or not a visual field test result is normal. Judging whether or not a series of tests represents medical stability is a more complex matter.

1. Are the results within the normal range?

If the disease under consideration is glaucoma, is the GHT normal or outside normal limits?

Are there patterns of loss on the probability plots, especially the pattern deviation probability plot, that are clearly outside normal limits?

2. If the results are not within the normal range, are they definitive?

Patterns of loss that are clearly consistent with other findings have increased credibility. These include the following:

- Clear nasal step or arcuate scotoma correlating well with optic nerve head observations
- Clear hemianopia
- Loss clearly correlating with ophthalmoscopic findings
- Loss clearly correlating with the clinical history

Patterns of loss that are not well defined, or that are not supported by other observations, may require retesting or further evaluation

3. Are there any red flags that suggest the test results should be reconsidered?

- Signs of excessive false positive responses, trial lens defects, or other artifact, as outlined in Chapter 8
- False positive rate of 15% or higher
- Fixation losses exceeding 20%

2

Basic Principles of Perimetry

COMPUTERIZED PERIMETRY is most effective when the user is familiar with the basic principles underlying its operation and use.

Normal and Abnormal Visual Fields

The normal field of vision extends more than 90 degrees temporally, 60 degrees nasally and superiorly, and about 70 degrees inferiorly, but most diagnostic visual field testing concentrates on the area within 30 degrees of fixation. Visual sensitivity is greatest at the very center of the field and decreases toward the periphery. The visual field is commonly represented as a hill, or island of vision *(fig. 2-1)*. The height of the normal hill of vision varies with age, the general level of ambient light, stimulus size, and stimulus duration.

Field defects characteristic of certain diseases will be discussed later. For the moment it should simply be said that a field defect is any statistically and clinically significant departure from the normal hill of vision. Field

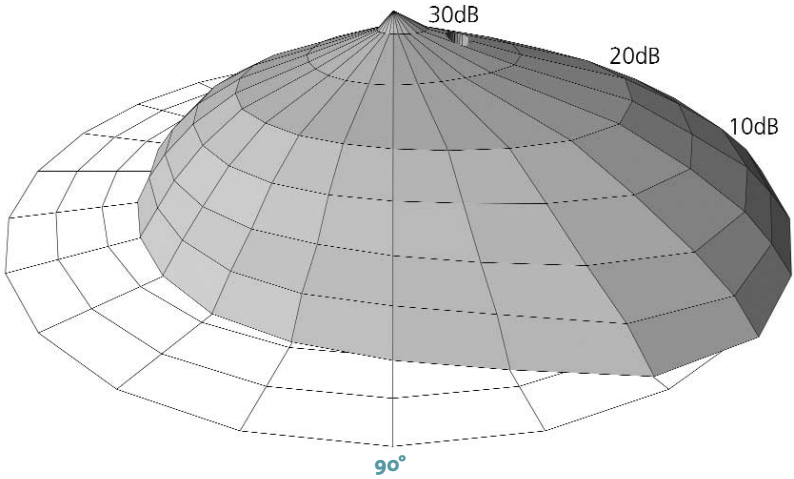

Figure 2-1. This is a graphic representation of the normal hill of vision for the right eye of a 51-year-old person tested with a size III white stimulus. Vision extends more than 90 degrees temporally and less in other directions. The height of the hill represents sensitivity, which is highest at the point of fixation and gradually decreases in the periphery. Most testing for the purpose of medical diagnosis is done within the central 30 degrees.

defects may be localized and may also be combined with general depression of the whole field. Localized field defects can be described in terms of both size and depth, and accurate measurements of such defects are helpful in making many diagnoses. An area of the visual field where the patient can perceive some stimulus but where sensitivity is less than normal is called a relative defect, while an area where the maximum available stimulus is not seen is termed an absolute defect.

A generally depressed field without localized loss is a non-specific finding and is most commonly caused by media opacities, miosis, or lack of proper refractive correction during the test. Field defects that are quite evident on perimetric test results may, of course, not be causing the patient any obvious visual problems; in fact, patients are very often totally unaware of medically significant defects.

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Applications of Perimetric Findings

This book primarily addresses the application of perimetry to diagnostic decision making. The goal of perimetry in such cases is to obtain information important to the decision at hand, and perimetric testing is directed toward those portions of the visual field that are most likely to be informative about the presence or stability of a particular disease. Such examinations generally involve careful measurement of threshold sensitivity at various locations in the field in order to identify subtle changes.

Perimetry may also be used to determine the extent of remaining visual function for insurance purposes or in order for the patient to qualify for a driver's license. In such instances, subtle defects are often ignored, as they are unlikely to affect visual performance. Most commonly, these examinations are performed by presenting a very bright stimulus throughout the tested area—a stimulus that would not be missed unless there is rather profound loss of vision.

Computerized Static Perimetry

Computerized static perimetry has been the clinical standard of care for at least fifteen years. Before that, kinetic perimetry was usually performed using the Goldmann manual perimeter. Over the years a number of researchers have reported computerized static perimetry to be superior to various methods of expertly performed kinetic perimetry (Lynn 1969; Heijl 1976; Katz et al. 1995).

Computerized threshold static perimetry involves determining the dimmest stimulus that can be seen at a number of pre-determined test point locations. Static perimetry was performed manually long before computers were widely available, but because of the complexity of the technique and the difficulty of keeping track of

multiple patient responses, the method was used mainly in research settings. Computerization made it possible to automate complex thresholding algorithms and to keep track of patient responses at all of the points under examination. Improvements in computer processor speed later facilitated the automation of increasingly complex—and increasingly efficient—methods of data acquisition, such as SITA, and data analysis that previously had been impractical in clinical care.

Another important benefit of computerization is that it allowed testing to be standardized, which has greatly improved test comparability between clinics and around the world. Indeed, standardization in perimetry now is so highly valued that most clinics and hospitals have standardized on Humphrey perimetry and on a narrow range of tests—usually 30-2 or 24-2 SITA threshold tests.

Issues in Instrument Design

A basic perimeter might be characterized as an instrument that can present a stimulus of known size and brightness against a known background for a known amount of time in a known location in the visual field. Efficient visual field testing can be achieved only if each of these factors and others are carefully chosen.

STIMULUS SIZE AND INTENSITY

The Humphrey perimeter uses projected stimuli. The standard white stimuli can be varied in intensity over a range of 5.1 log units (51 decibels) between 0.08 and 10,000 apostilbs (asb). The decibel (dB) value refers to retinal sensitivity, rather than to stimulus intensity, with 0 dB corresponding to the maximum brightness that the perimeter can produce (10,000 asb) and 51 dB to 0.08 asb *(fig. 2-2)*. In standardized testing with a size III white stimulus, the dimmest stimulus that can be seen foveally by a young, well-trained observer is at most

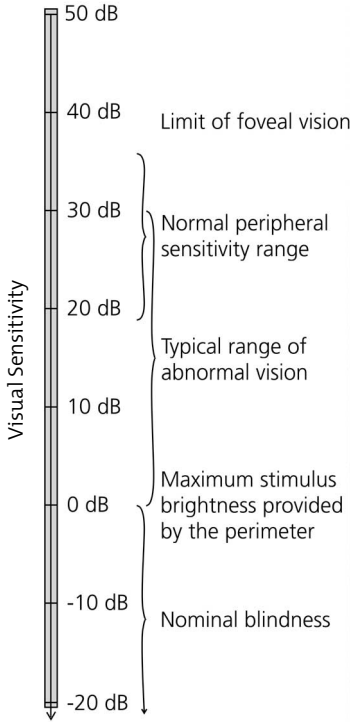


Figure 2-2. Visual field sensitivity is measured and expressed in decibels. Under standard testing conditions, the maximum sensitivity found in healthy young normal subjects is a little under 40 decibels, and normal sensitivity in the central 30 degree field ranges between this value and approximately 20 decibels. Sensitivity can be much reduced in visual field defects. Areas of the field that are blind even to the instrument's maximum stimulus are called absolute defects.

about 38 to 40 dB. Thus, the upper (and dimmest) 10 decibels of stimulus range—from 41 to 51 dB—really fall outside the range of human vision.

Threshold sensitivity is determined in computerized static perimetry by varying only the stimulus brightness, not stimulus size. The Humphrey perimeter is capable of testing with the five Goldmann stimulus sizes *(fig. 2-3)*, but the 0.43-degree Goldmann size III stimulus is used most of the time. In practice, size V, which is occasionally employed in advanced field loss, is the only other commonly used stimulus size. Size V is also the standard stimulus size in blue-yellow perimetry (SWAP).

BACKGROUND ILLUMINATION

Standard Humphrey perimetry projects stimuli against a background with a brightness of 31.5 apostilbs. This background illumination was originally used by the Goldmann perimeter and has been adopted as a standard by the International Perimetric Society (International Council of Ophthalmology 1979). This adaptation level was chosen because it approximates the minimum brightness for photopic, or daylight, vision—vision that depends upon

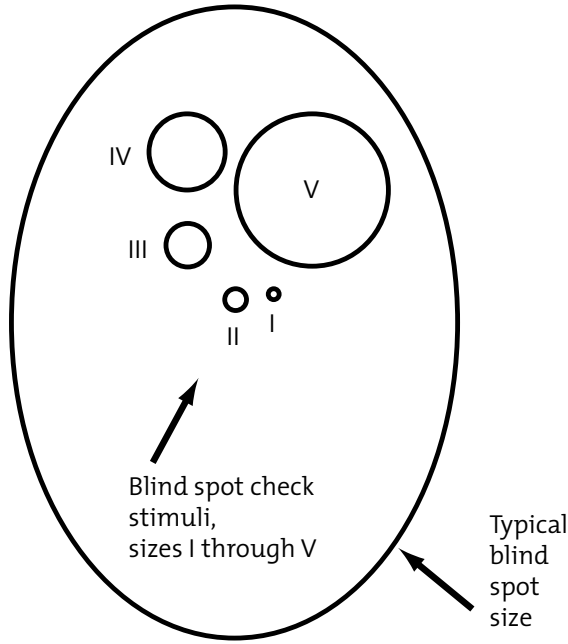


Figure 2-3. Goldmann test spot sizes, I through V. All Goldmann standard test targets are much smaller than the physiological blind spot. The typical blind spot is roughly 5 by 7 degrees. About two hundred size III stimuli or 12 size V stimuli fit inside the area of a typical blind spot.

retinal cone function rather than on rods. The advantage of testing the photopic visual system is that visibility depends more on object contrast than on absolute brightness as it does in rod vision. Small changes in pupil size or clarity of media have little effect on test results, and small irregularities in background brightness can be remedied by commensurate adjustments in stimulus brightness to keep stimulus contrast at the desired level.

STIMULUS DURATION

Stimulus duration significantly affects the visibility of stimuli when they last only a very short time. Thus, a stimulus lasting 0.002 seconds is roughly twice as visible as one lasting only 0.001 second. On the other hand, it is just as easy to see a spot that is shown for one second as it is to see one that is shown for three seconds. The principle of temporal summation holds that for very short durations, the visibility of a stimulus increases with duration; when

a stimulus lasts more than about 0.5 seconds, on the other hand, its visibility is basically independent of duration (Lynn 1969; Aulhorn and Harms 1972).

The Humphrey perimeter uses a stimulus duration of 200 milliseconds (ms), which is long enough for visibility to be little affected by small variations in duration, but still shorter than the latency for voluntary eye movements (about 250 ms). As a result, the patient does not have time to see a stimulus in the peripheral visual field and look toward it (International Council of Ophthalmology 1979).

STIMULUS LOCATION AND FIXATION MONITORING

In order to map visual field sensitivity accurately it is necessary to know where on the retina each stimulus is presented. It is not difficult to calibrate where the instrument itself shows the stimulus, but knowing where the patient is looking at the moment of stimulus presentation can be complex. Fortunately, most patients fixate with rather high precision, and the problem of proper stimulus location has primarily become one of identifying those few patients whose gaze is so unsteady that they should be reinstructed on proper fixation technique.

In order to map visual field sensitivity accurately it is necessary to know where on the retina each stimulus is presented.

The original Humphrey perimeter and one of the current models rely upon the Heijl-Krakau blind spot monitoring technique rather than a gaze tracker. This method provides an index of the quality of patient fixation during an examination by periodically presenting stimuli in the blind spot. Positive responses indicate poor fixation. Because the normal blind spot is about six degrees in diameter, fixation shifts of half of that amount—about three to four degrees—can be detected. One disadvantage of this method is that fixation checks add to the test time and therefore can be made only occasionally during the test.

The gaze tracker on recent models of the Humphrey perimeter measures gaze direction with a precision of

about one degree and records a measurement each time a stimulus is presented. The gaze tracking results are shown on the video screen during testing and are printed at the bottom of the test results printout. On the gaze printout, lines extending upward indicate the amount of gaze error at each stimulus presentation, with full scale indicating gaze errors of 10 degrees or more. Lines extending downward indicate that the instrument was unsuccessful in measuring gaze direction during that particular stimulus presentation. *(See Chapter 4 for further discussion.)*

Threshold Testing Strategies

The objective of static threshold perimetry is to determine the minimum stimulus that can be seen at each tested location. Such findings are always subject to some variability because patients make mistakes and because the visual system itself is subject to certain variabilities. Successful strategies balance time efficiency with provisions to counteract such errors.

All Humphrey strategies start testing at a single location in each quadrant of the visual field. If a stimulus is seen, subsequent stimuli at that location are dimmed one step at a time—usually by 3 or 4 decibels—until they are no longer seen. Conversely, if the initial stimulus is not seen, then subsequent presentations are made brighter in steps until the patient presses the response button. Some strategies repeat this process for confirmation of the finding, either using the same step size, or perhaps a smaller step, such as 2 dB. Testing is then expanded to other test point locations, until threshold sensitivities have been determined throughout the tested area.

In the early days of automated perimetry, threshold testing frequently took twenty minutes or more per eye because the test strategies were not very efficient. Efficiency was soon improved by using test results at a measured point to determine the initial stimulus brightness at

adjacent points, and by measuring patient reaction times in order to make small adjustments to the pace of the test. Even with these improvements, testing times averaged 15 minutes and were sometimes as long as 20 minutes.

The more recent SITA methods take advantage of new mathematical techniques to achieve dramatic reductions in testing time without sacrificing accuracy. First, the patented SITA strategies are based on a complex model of the visual field that allows for more accurate choices of the initial stimulus brightness and more complete use of all available information when calculating threshold sensitivity. New mathematical modeling also allows SITA to make much more complete use of response time information, resulting in a test pace that is almost completely determined by the patient instead of the machine. Patients with slow reactions get slowly paced tests, but more often, a SITA test ends up running at a fairly rapid and interesting pace because most patients are quite capable of moving more quickly than the older strategies allowed.

SITA Standard can complete a 30-2 test in about half the time of the Humphrey Full Threshold strategy with no loss of reproducibility or sensitivity to glaucomatous loss.

SITA strategies gain further efficiency by ceasing to present stimuli at a given location when predetermined levels of testing certainty are reached, based upon the statistical consistency of patient responses. This consistency calculation shortens test time when reliably consistent responses are given, and extends it when there still is uncertainty (Bengtsson et al. 1997). The primary difference between the SITA Standard and SITA Fast strategies is the amount of certainty required before testing can be stopped (Bengtsson and Heijl 1998). Finally, SITA increases efficiency by keeping a complete record of the location, brightness, and timing of every stimulus presented—a complete test timeline. This timeline is analyzed automatically to reconsider the complete pattern of patient responses to correct for patient errors and to come to a more precise determination of threshold sensitivities. The overall effect of these efficiency improvements is that SITA Standard and SITA Fast reduce testing

time by 50% relative to the strategies they replace, without loss of diagnostic information *(refer ahead to figures 3-3a, 3-3b, and 3-3c)*.

The Perimetrist and the Patient

Manual perimetry required great skill because the perimetrist had to understand and perform all testing strategies with no assistance from the instrument itself. Even though the Humphrey Field Analyzer is programmed with highly refined testing and analysis methods, the technician continues to play a central role. Without proper patient management and instruction, the results of perimetric examinations are often of poor quality.

It is particularly important to tell the patient what to expect during the test. Perimetrists who have undergone visual field testing themselves will be better prepared to brief patients. The perimetrist should explain the patient's task, show him or her what the stimulus will look like, where it might appear, how long the test will last, when blinks are allowed, how to sit, how to pause the test, and so on. The patient should understand that more than half of the stimuli shown in a threshold test will be too dim to be seen, and that the stimuli that are seen are likely to be barely visible. Further, the perimetrist must be available at least periodically during the test to reassure the patient and to see that he or she is still in proper position.

Patients who understand this and who are tested by staff members with a positive attitude toward visual field testing will have few problems with modern, time-efficient threshold perimetry. It is easy to help patients recognize the value of perimetry in determining their level of treatment, and they will be happy to do visual field testing once or twice a year in order to see that effective treatment is instituted and to assure that unnecessary treatments are avoided.

Without proper patient management and instruction, the results of perimetric examinations are often of poor quality.

In addition to making sure the patient understands the test, successful perimetry requires good physical conditions for the test. Refractive blur reduces visual sensitivity to perimetric stimuli, and it is standard practice to provide trial lens correction when testing the central visual field. One diopter of refractive blur in an undilated patient will produce a little more than one decibel of depression of the hill of vision when testing with a Goldmann size III stimulus (Weinreb and Perlman 1986; Heuer et al. 1987; Herse 1992).

The nominal testing distance of the Humphrey HFA II perimeter is 30 cm, and fully presbyopic patients are therefore provided with +3.25 diopter near additions relative to their distance refraction. Patients who are less than fully presbyopic are given smaller additions, either according to standard age-based correction tables programmed into the perimeter or based upon clinical judgment. Usually, all refractive correction is accomplished using standard 37 mm trial lenses held in place by a trial lens holder attached to the perimeter, but correction may be done with the patient's own spectacles, as long as they are single vision lenses or contact lenses. Testing outside of the central visual field is done without trial lens correction because the trial lenses and their holder would restrict the peripheral vision and produce artifactual visual field loss.

One eye is tested at a time, and the eye that is not being tested is covered with a patch. The patient is seated in front of the instrument, and chair height and instrument height should be adjusted for patient comfort. Proper comfort is more important in perimetry than, for instance, in slit lamp biomicroscopy because the examination takes longer and because the patient may be supervised only occasionally during the test.

3

Ordering a Test

WHEN A PERIMETRIC TEST is needed, a 30-2 or 24-2 SITA Standard threshold test using a size III white stimulus is the best choice in most cases. This chapter explains why this is so, and then discusses the exceptions to this rule.

Choosing a Test Pattern

The Humphrey Field Analyzer 30-2 test pattern measures visual sensitivity at 76 locations within 30 degrees of fixation—the area commonly referred to as the central visual field. The 24-2 test pattern consists of the 54 most central test locations of the 30-2 pattern *(fig. 3-1)*. At one time many doctors, and many university centers, made the 24-2 pattern their standard test because there was evidence that little diagnostic information was lost and considerable testing time was saved by testing only 54 points rather than 76 (Alexander et al. 1995). New testing algorithms, especially SITA, have now reduced test times so much that there is much less incentive to test fewer points, and the 30-2 pattern gives more test locations from which disease progression may be judged. It may also be more useful in following established field loss.

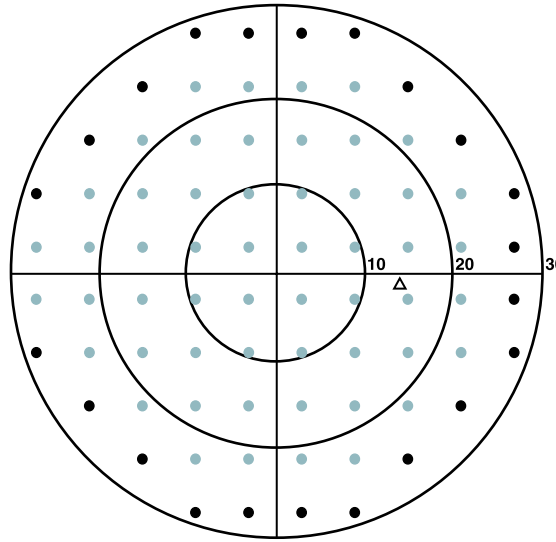


Figure 3.1. The Humphrey perimeter 30-2 and 24-2 test patterns. Distance between test points is 6 degrees. Points included in the 24-2 pattern are shown in blue.

CENTRAL VS. PERIPHERAL TESTING

Most visual field tests are ordered in connection with the diagnosis or management of glaucoma, and the standard of care in glaucoma management concentrates almost exclusively on testing the central field. A few early glaucoma patients will first present with field loss outside the central 30 degrees (Caprioli and Spaeth 1985; Stewart and Shields 1991), but this occurs infrequently, and responses in the peripheral field are associated with high variability.

The standard of care in glaucoma management concentrates almost exclusively on testing the central field.

Even in neurological disease, most of the diagnostic information is usually in the central field (Hard-Boberg and Wirtschafter 1985; Keltner, Johnson et al. 1999). Thus, the standard 30-2 or 24-2 test point patterns are the preferred standard for neurological visual field testing. There are only few exceptions to this. One such exception could be when a small central scotoma is suspected in a patient who has normal or near-normal visual acuity but a history that suggests acute optic neuritis. In such a case, a 10-2 test with the foveal threshold turned on will provide a denser grid with a higher number of test points in the very central visual field.

Occasionally, peripheral testing is done to rule out retinal detachments, or to differentiate between detachment and retinoschisis in eyes that cannot be well visualized ophthalmoscopically, but this is the exception rather than the rule *(see Chapter 7)*.

Choosing a Stimulus Size

Computerized static perimetry has established the Goldmann size III, white stimulus as the standard. It is small enough at 0.43 degrees in diameter to be used even in fairly detailed examinations, and large enough to be visible when the patient's refractive correction is not quite perfect. Normative data and statistical analysis packages for standard perimetry using white stimuli are based upon the Goldmann size III stimulus.

In cases of advanced glaucoma, many or most points may show absolute defects with size III stimuli, jeopardizing perimetric follow-up with a central 24-2 or 30-2 test. One can then switch to the size V stimulus, which is four times the diameter of size III. Testing with size V stimuli will result in sensitivity levels that are 5 to 10 decibels higher than those found using size III, often extending the available sensitivity range and making it possible to follow such patients *(figures 3-2a, 3-2b)*. It should be noted that if the size V stimulus is used, one no longer has access to several of the analytical follow-up tools available for the standard size III tests.

Choosing a Test Strategy

THRESHOLD TESTING

In general, threshold testing provides more diagnostic information than suprathreshold testing. The aim of a threshold test is to quantify the patient's visual sensitivity at each test point. The result is a set of sensitivity values representing the minimum brightness the patient can see at each tested point.

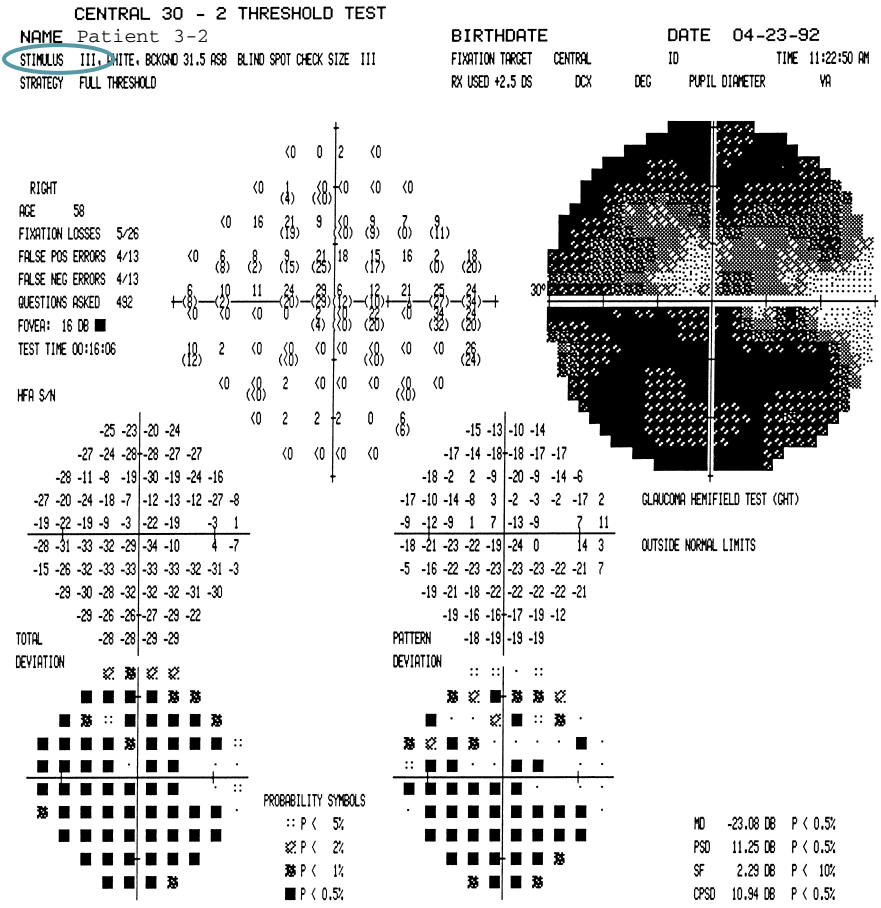


Figure 3-2a. The initial 30-2 test using a size III stimulus does not contain enough data for good follow-up.

Figure 3-2. Following end stage glaucoma with a larger stimulus

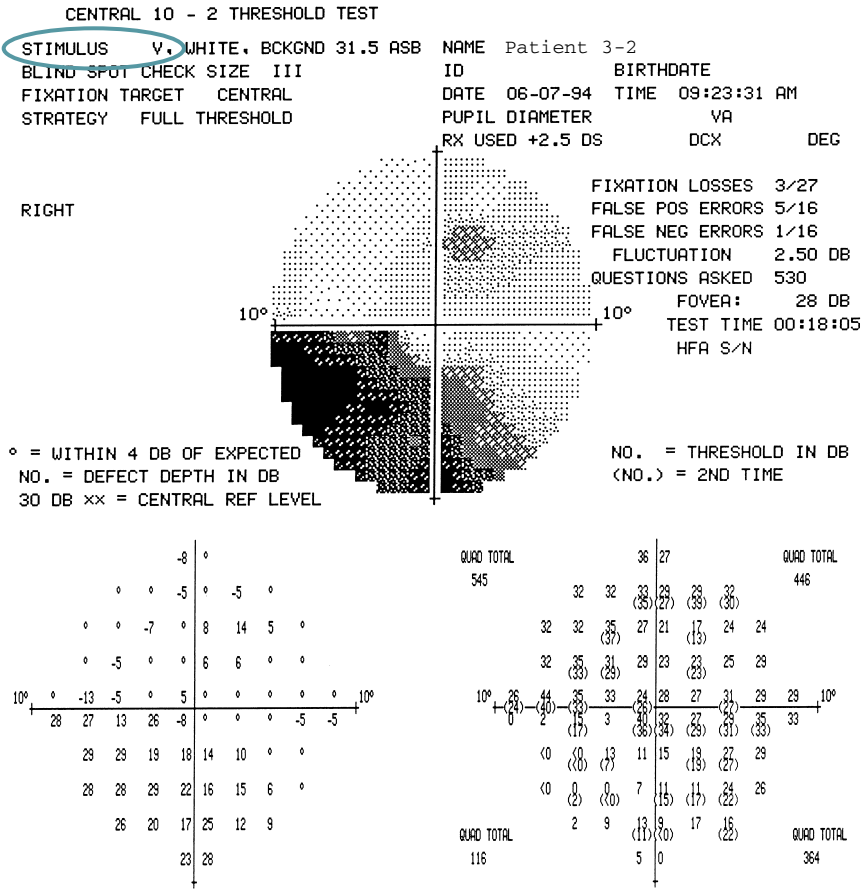


Figure 3-2b. The same patient was tested with a size V stimulus. Switching both to a larger stimulus and to the 10-2 pattern resulted in enough data for meaningful long-term follow-up. Note that the patient produced a few impossibly high sensitivity measurements on the size V 10-2 test—39 to 44 decibels at three test points—and 5 out of 16 errors on false positive catch trials, all indicating a mild to moderate pattern of trigger-happy responses. The patient was re-instructed in proper testing technique, and follow-up testing showed improved test reliability. The central reference level on this printout indicates the height of the center of the hill of vision inferred from surrounding test point sensitivities. The XX printed next to the calcuated central reference level means that it falls below the normal range.

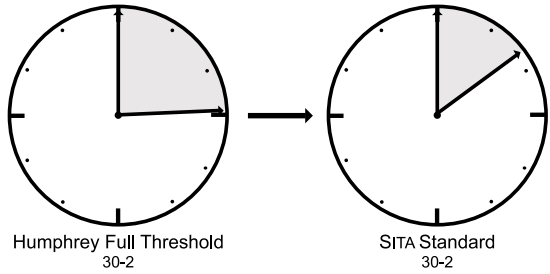
SITA Fast takes about half the time of FastPac and provides the same performance.

The patented SITA thresholding strategies available on recent Humphrey Field Analyzer models are much faster than the older strategies they replace. SITA Standard can complete a 30-2 test in about half the time of the Humphrey Full Threshold strategy with no loss of reproducibility or sensitivity to glaucomatous loss (Inazumi et al. 1998; Bengtsson and Heijl 1999a; Wild, Pacey, Hancock, Cunliffe 1999; Wild, Pacey, O'Neill, Cunliffe 1999; Remky and Arend 2000; Sharma et al. 2000). SITA Standard has also been found to shorten testing time without jeopardizing the clarity of results in children (Donahue and Porter 2001). SITA Fast takes about half the time of FastPac and provides the same performance (Bengtsson and Heijl 1998; Wild, Pacey, Hancock, Cunliffe 1999; Wild, Pacey, O'Neill, Cunliffe 1999). The SITA strategies have clear advantages over the older strategies and should be used whenever available. SITA Standard is more precise and more able to correct for patient errors, but it is not quite as quick as SITA Fast *(figures 3-3a, 3-3b, 3-3c)*. SITA Fast may best be used with younger patients or with those who have experience with threshold perimetry.

SUPRATHRESHOLD TESTING

Suprathreshold testing and threshold testing have different goals. Suprathreshold testing, also referred to as screening, is intended to establish whether or not sensitivity is abnormally low at any location in the visual field. Because a suprathreshold test presents the patient with fairly bright stimuli that should be seen if vision is normal, it is easy to use with patients who have never been tested before. Before the advent of the current, efficient threshold testing methods, suprathreshold tests took considerably less time than threshold tests. Suprathreshold tests, however, do not provide quantitative data, and they are not as sensitive to early glaucomatous field loss as threshold tests (Mills et al. 1994). As a result, suprathreshold testing is used less often in glaucoma diagnosis now that highly efficient threshold tests can be done

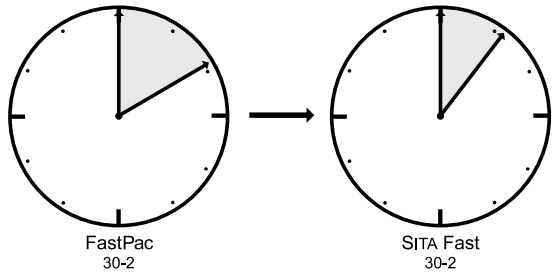
Figure 3-3a.
Switching from the older Full Threshold strategy to SITA Standard cuts test time almost in half for glaucoma patients.



14 minutes per eye

8 minutes per eye

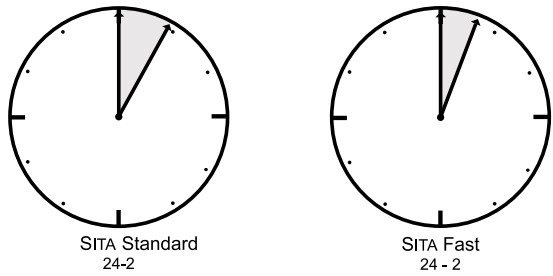
Figure 3-3b.
Switching from FastPac to SITA Fast cuts test time almost in half for glaucoma patients.



9 minutes per eye

5.5 minutes per eye

Figure 3-3c.
Modern threshold perimetry can be very time efficient. Normal subjects can be tested in about 4 minutes; glaucoma patients will take somewhat longer.



4 minutes to test a normal visual field

3 minutes to test a normal field

Figure 3-3. SITA thresholding strategies are much faster than the older strategies they replace.

in almost the same time. If suprathreshold screening for glaucomatous field loss is conducted, the 64-point central test pattern using the age-related or threshold-related strategies is a good choice.

Suprathreshold testing can be sensitive to neurologically based field loss (Siatkowsky et al. 1996), and the 76-point age-related screening test pattern provides a useful alternative to the 24-2 or 30-2 threshold tests.

Following Glaucomatous Field Loss

THE STANDARD TEST

The practitioner may choose any of the SITA Standard or SITA Fast 30-2 or 24-2 programs for both glaucoma detection and follow-up.

EXCEPTIONS

Patients with central vision loss caused by conditions such as macular degeneration may not be able to see the standard fixation target. The Field Analyzer offers an alternative target that calls for such patients to fixate in the center of a large diamond pattern.

In the very late stages of glaucoma when mainly central islands of vision remain, one can switch to a SITA Standard or SITA Fast 10-2 test, which covers only the central 10 degrees of the visual field *(figures 3-4 and 3-5)*. Another possibility is to use the larger stimulus, size V, with a 30-2, 24-2, or 10-2 pattern *(refer back to figures 3-2a, 3-2b)*. This stimulus size cannot be used with the SITA algorithm, however, so one would have to use the Full Threshold or FastPac algorithms instead. Extended testing of large portions of the field already known to be blind is not only a waste of time, it can be upsetting to the patient, and thus may reduce patient compliance.

Changing test programs in follow-up also makes comparisons with earlier tests more difficult and less

Changing test programs in follow-up always makes comparisons with earlier tests more difficult and considerably less exact.

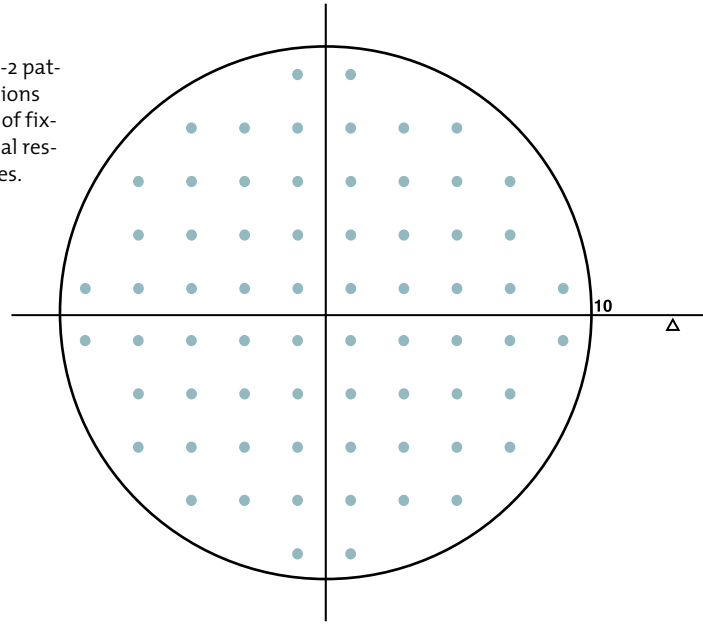


Figure 3-4. The 10-2 pattern tests 68 locations within 10 degrees of fixation, with a spatial resolution of 2 degrees.

exact. When switching from the earlier standard Humphrey threshold tests, Full Threshold or FastPac, to the corresponding newer, faster SITA Standard or SITA Fast, the most relevant comparisons can be made by focussing on probability plots *(see Comparing SITA Results with Older Strategies in Chapter 4)*.

SWAP

Short wavelength automated perimetry (SWAP), also known as blue-yellow perimetry, is a specialized technique in which blue, Goldmann size V stimuli are presented on a bright (100 Cd/m^2) yellow background (Wild 2001; Johnson 2002; Solimen et al. 2002) *(fig. 3-6)*. The yellow background serves to reduce the responsiveness of the red and green cone systems so that the blue stimuli are seen primarily by the blue cone system.

Three prospective clinical trials have found that SWAP detects glaucomatous visual field loss at an earlier stage than conventional methods (Johnson et al. 1993a; Sample et al. 1993; Polo et al. 2002). Similarly, three prospective studies have found that SWAP detects progression of field loss in glaucoma patients earlier than

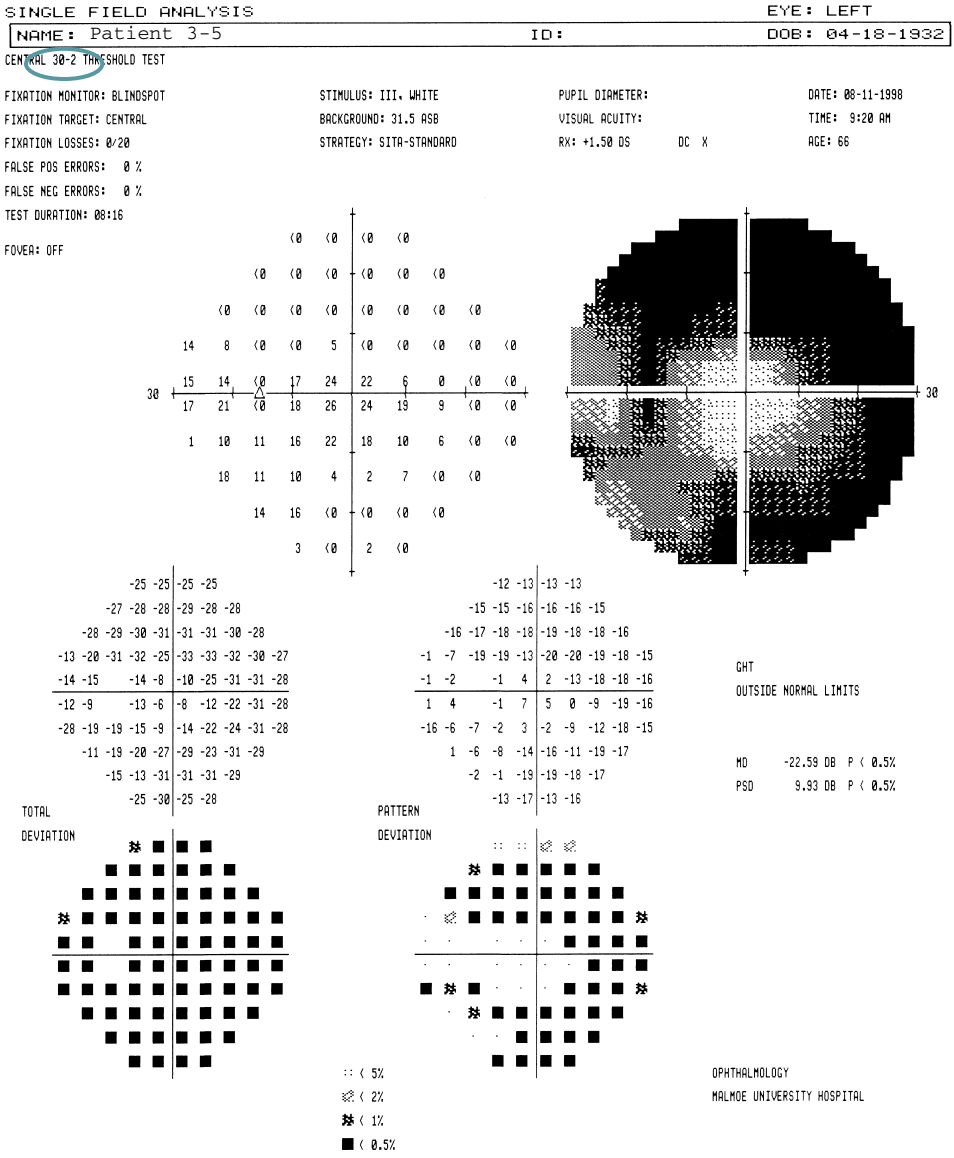


Figure 3-5a. When glaucoma is so advanced that much of the central field is blind, as shown here, the 30-2 pattern may not offer enough detail for follow-up.

Figure 3-5. Following end stage glaucoma by switching to the 10-2 pattern.

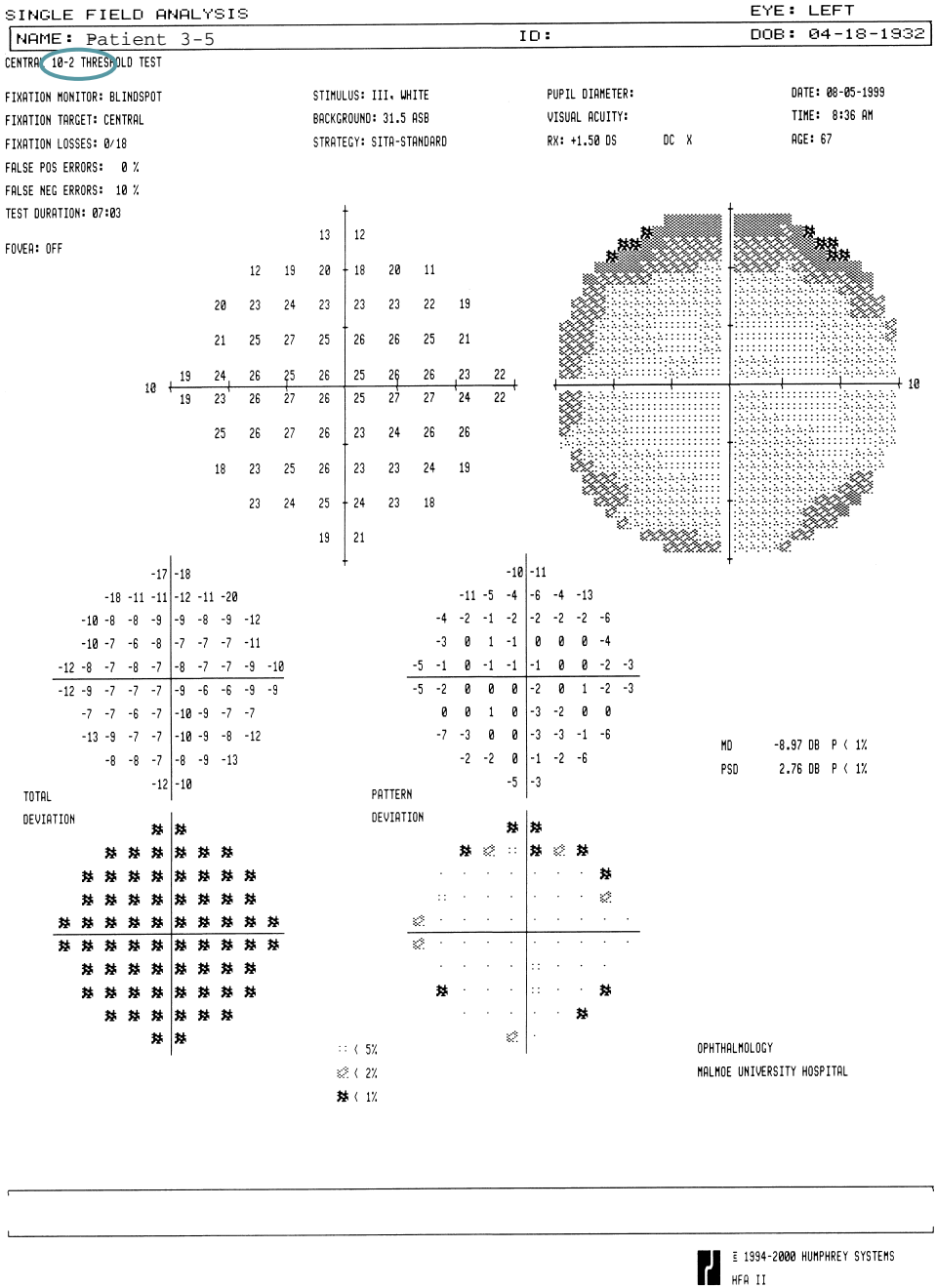


Figure 3-5b. One may concentrate testing on the remaining field by switching to the 10-2 pattern as shown here.

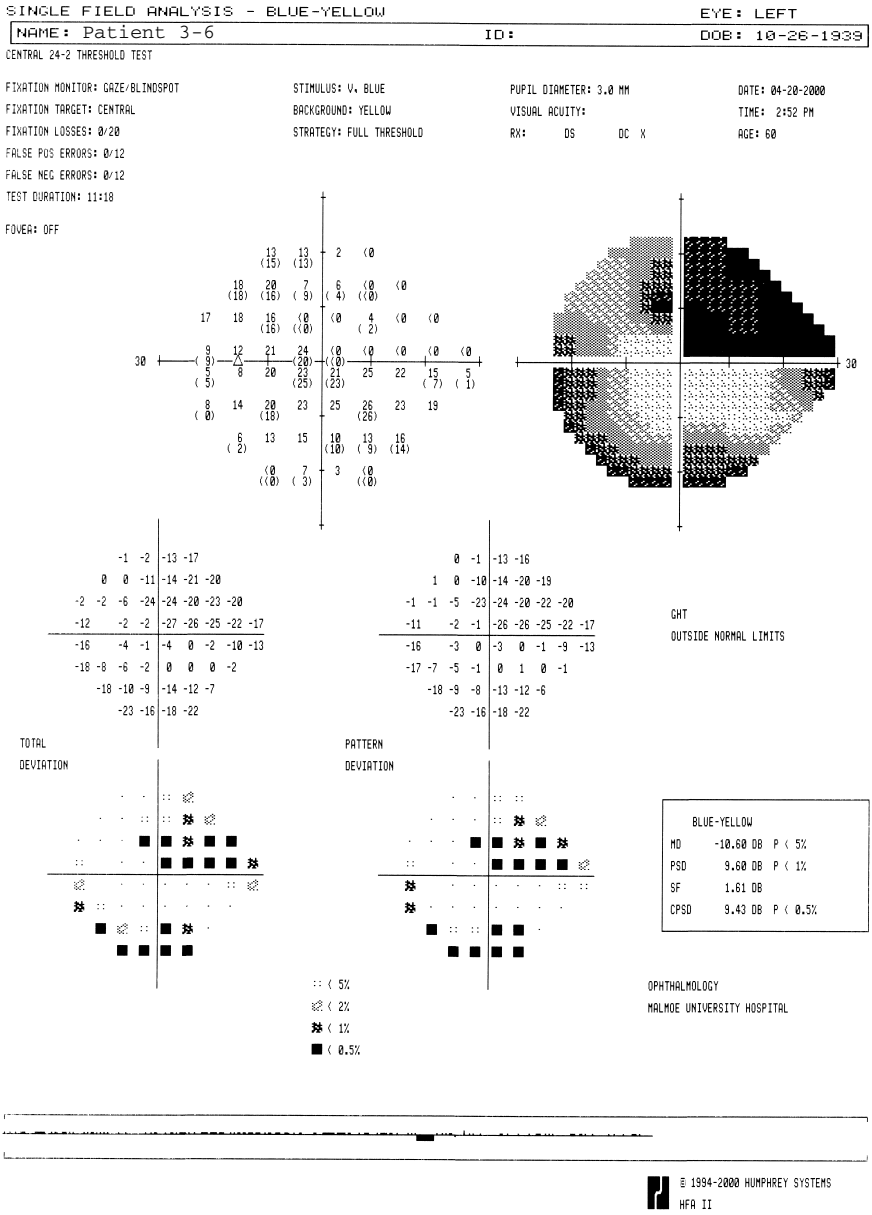


Figure 3-6. Central 24-2 SWAP test showing glaucomatous defects in the left visual field of a 60-year-old man.

standard perimetry (Sample and Weinreb 1992; Johnson et al. 1993b; Bayer and Erb 2002). SWAP has also been found to be more sensitive than standard perimetry in detecting neuro-ophthalmic disease (Keltner and Johnson 1995), age-related macular degeneration (Remky et al. 2001), migraine (McKendrick, Cioffi, and Johnson 2002), and diabetic macular edema (Hudson et al. 1998a) *(fig. 3-7, and refer ahead to figure 7-5b)*.

One possible explanation for SWAP's strong performance might lie in the fact that human vision has extensive redundancy and that SWAP testing isolates and tests primarily the blue-cone system, with very little response contributed by the other systems. In comparison, a standard white light stimulus will be detected by all three cone systems and perhaps by the rod system as well. The ability of SWAP testing to minimize the effect of the visual system's redundancy may be the factor that allows it to detect defects at an earlier stage *(refer ahead to figures 4-9a, 4-9b)*.

SWAP testing is available on the Humphrey perimeter, and STATPAC analysis capabilities are provided for the 30-2 and 24-2 test patterns. A SITA strategy for SWAP was under development when this book went to press *(figures 3-8a, 3-8b)*.

Testing for Disability, Drivers' Licenses, Blepharoplasty, Chloroquine

Perimetric testing for disability, fitness to drive, and blepharoplasty all require a different approach from that used in standard diagnostic perimetry. The goal in the latter is to detect changes that indicate early or progressive

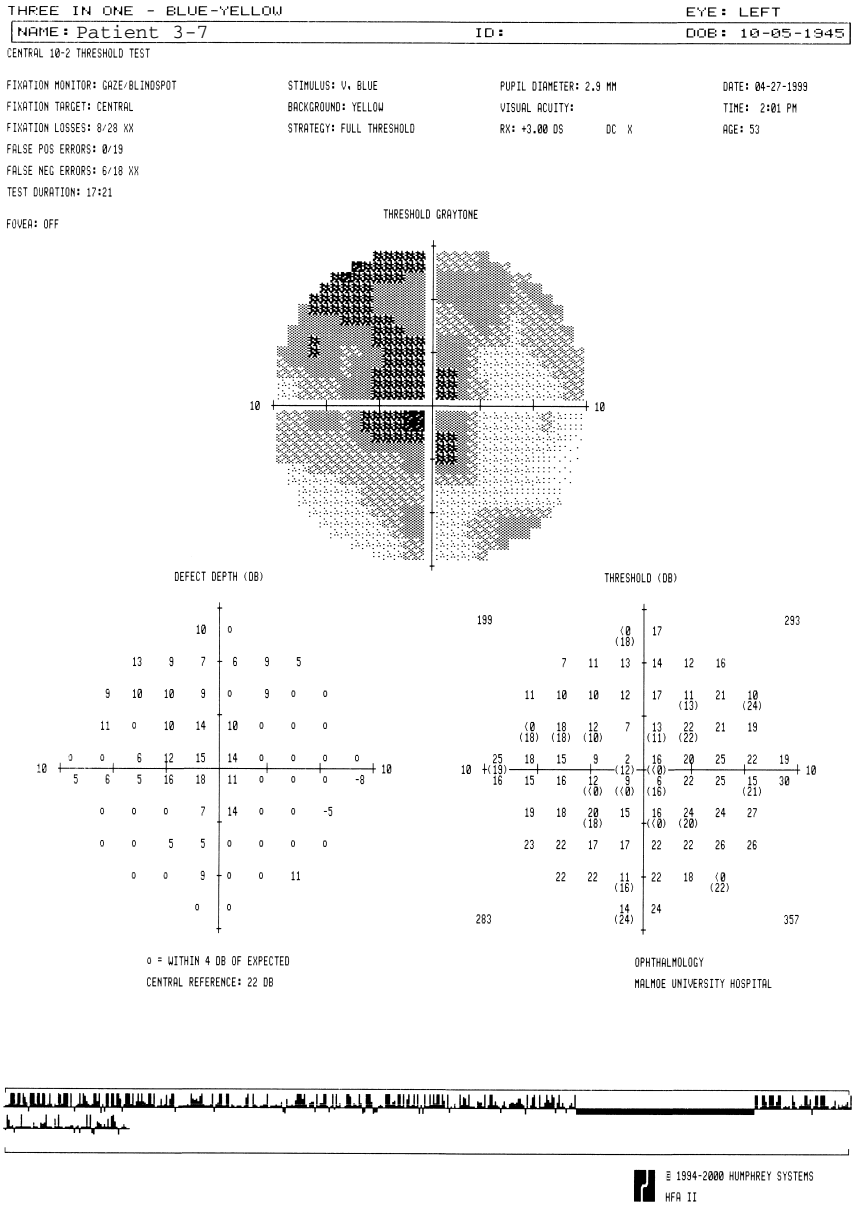


Figure 3-7. Central 10-2 SWAP field for the left eye of a 53-year-old patient with diabetic macular edema. Hudson and co-workers (1998a) have suggested that SWAP offers improved sensitivity for detection of clinically significant diabetic macular edema in comparison to standard white-on-white testing.

disease. Such changes are usually much too subtle to be noticed by the patient in everyday visual tasks. In the former, the goal is to rule out profound visual dysfunction; thus tests for dysfunction are best performed using strong stimuli that will be missed only if there is clear, well-defined damage. The stimulus most commonly used for such tests is the Goldmann III 4e stimulus, which in Humphrey terms is a 10 dB white, size III stimulus. Such a stimulus should be used in a single-level, suprathreshold testing mode, since threshold testing takes longer and adds no significant information in these applications.

DISABILITY

Standards for perimetric assessment of visual disability vary from country to country and, in some countries, from one government agency to the next. The standards most commonly used in the US are printed in the *Physicians' Desk Reference for Ophthalmology* and are based upon information published by the American Medical Association in its *Guide to Evaluation of Permanent Impairment.* The Esterman test is one of the methods so specified, and binocular and monocular versions of this test are offered as standard testing options on current Humphrey perimeters. The Esterman test is performed using the patient's customary distance spectacle prescription, without making any correction for testing distance in the perimeter; the goal is to take into account whatever visual field limitations might be imposed by the spectacles, and the assumption is that the stimuli used are strong enough not to be much affected by any refractive blur caused by the near testing distance *(fig. 3-9)*.

DRIVING

Automobile drivers' licensing is sometimes based partially upon visual field assessment. In most jurisdictions such assessment is the exception rather than the rule, and there are currently no internationally accepted standards. Some authors have suggested that the overall

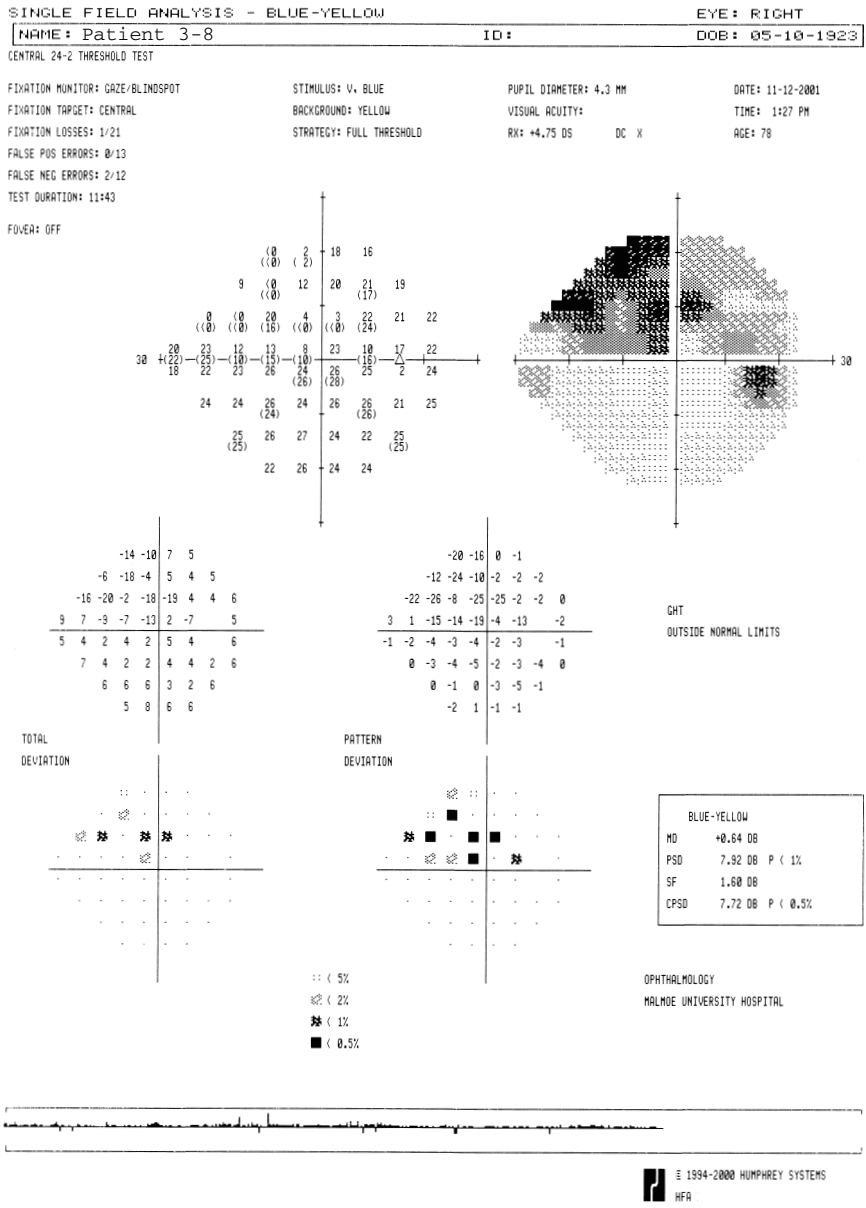


Figure 3-8a. SWAP Full Threshold testing of a 78-year-old glaucoma patient took 11 minutes and 43 seconds.

Figure 3-8. Comparison of test times using two different SWAP strategies

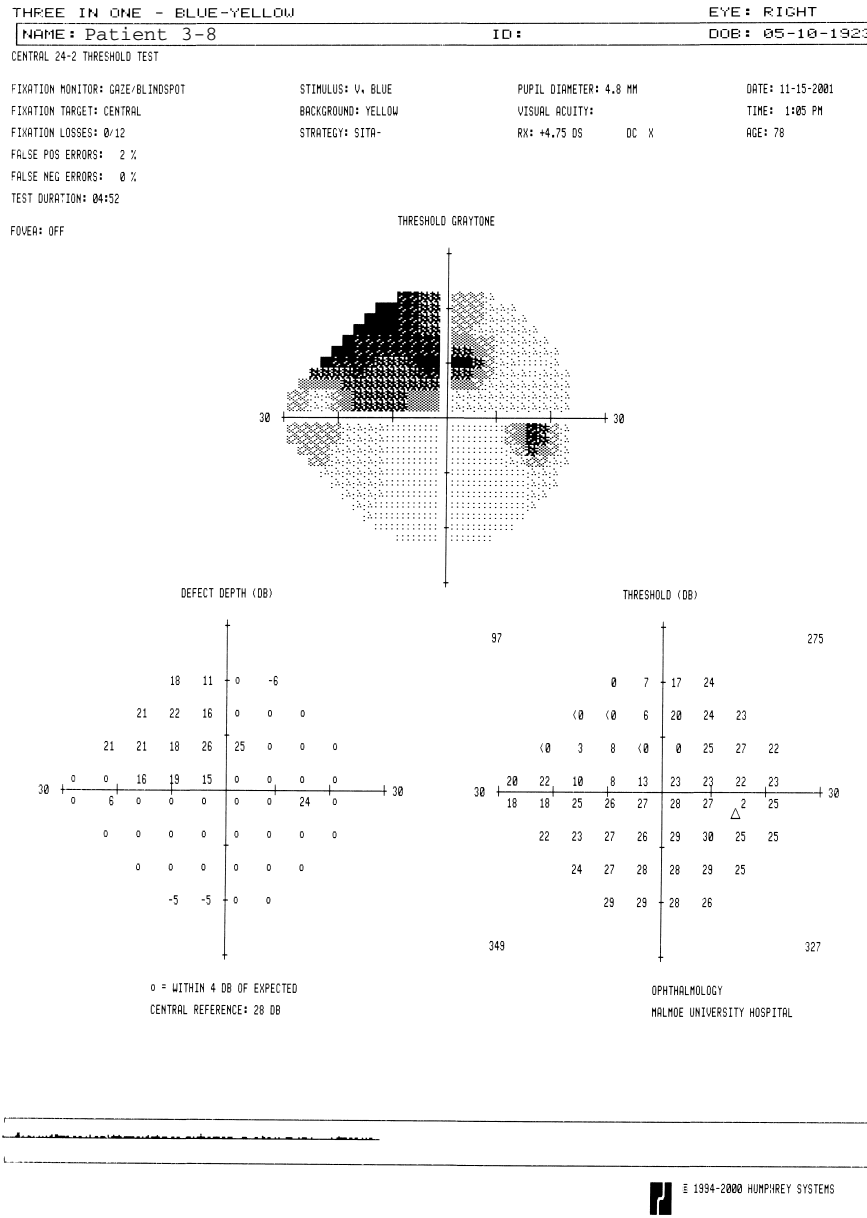


Figure 3-8b. SITA SWAP testing took 4 minutes and 52 seconds. No probability plot is shown for this field because STATPAC for SITA SWAP was in development when this book went to press.

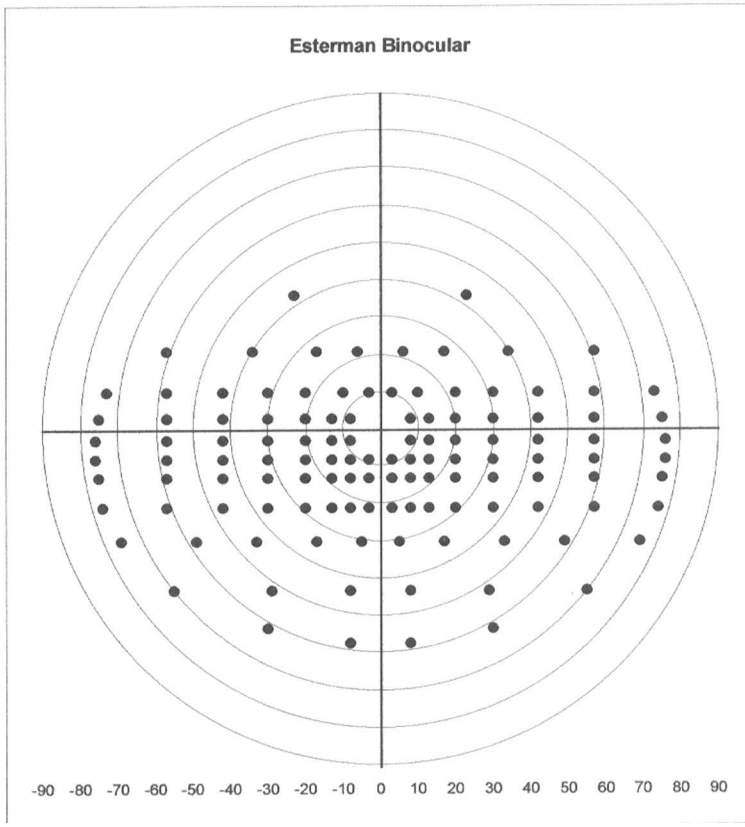


Figure 3-9. Binocular Esterman test. The Esterman test for functional scoring of peripheral vision divides the visual field into areas on the basis of functional importance. More points are tested in the central field than peripherally, and more in the inferior field than superiorly. Test results are scored on the basis of the percentage of points seen.

binocular visual field is most important in driving and that losses in one eye may well be compensated for if the other eye's overlapping field is still functional (Johnson and Keltner 1983; McKnight et al. 1991; Wood and Troutbeck 1994).

One text has suggested that, in the absence of more conservative guidelines from local authorities, drivers should have binocular visual fields extending at least 50 degrees both to the right and to the left of fixation (Anderson and Patella 1999). These authors do not provide any suggestions regarding the superior and inferior

fields except to note that overhead objects such as traffic signals usually do not require an extensive superior visual field, at least when viewed from a distance.

BLEPHAROPTOSIS

Perimetry is frequently used to document visual impairment secondary to blepharoptosis, although non-perimetric methods also may be used (Cahill et al.1987; Hacker and Hollsten 1992). Such testing is best done using single-level suprathreshold testing and a bright stimulus. It is also important to remember that it is quite normal, especially in elderly patients, to find asymptomatic restrictions of the upper portion of the central 30 degree visual field caused by the eyelid. Thus, it may be best to concentrate on testing the central field using, for instance, the 76-point screening pattern with a 10 dB single-level suprathreshold stimulus.

TESTING FOR DRUG-INDUCED MACULOPATHIES

Patients undergoing long-term treatment with chloroquine or hydroxychloroquine are frequently sent for ophthalmic consultation in order to monitor for drug-associated maculopathy. With the increasing use of hydroxychloroquine, some have suggested that monitoring with automated perimetry is no longer necessary, as long as suggested dosing guidelines are followed and as long as the patient receives routine visual acuity, color vision, and Amsler grid testing, along with corneal examination (Easterbrook 1999). Nevertheless, automated perimetric examination is still part of the standard of care in many communities and, when requested, probably is best performed using a standard size III white stimulus, the 10-2 test pattern, and SITA Standard or SITA Fast. Use of red stimuli has been advocated by some, but no clear advantages have been established relative to standard white stimulus testing (Easterbrook and Trope 1988).

4

STATPAC

STATPAC IS A COMPUTERIZED analysis package that is included in the operating system of all Humphrey perimeters. STATPAC greatly simplifies visual field interpretation by differentiating between normal and abnormal visual fields, and by identifying significant change in a series of visual fields.

STATPAC determines if a patient's visual field results fall within the range normal for his or her age. A STATPAC analysis may also involve comparing test results with the patient's own baseline from earlier tests in order to determine if the observed change is larger than that typically seen when stable patients return for follow-up testing.

Sensitivity ranges vary with testing conditions, the length of the test, and the testing strategy; databases have been constructed for many combinations of instrument, strategy, and test pattern. The normal database for SITA, for instance, was based upon normal subjects enrolled at fifteen participating university centers.

Standard threshold test results may be printed out in any of four formats: Single Field Analysis, Overview, Glaucoma Change Probability, and Change Analysis.

SWAP test results may be printed out using the first two of these. The Single Field Analysis is devoted to the analysis of a single test, while the purpose of the other printouts is to look for trends in a series of tests. This chapter describes these basic STATPAC analyses.

The Single Field Analysis

The STATPAC Single Field Analysis (SFA) of threshold test results is perhaps the most useful and important printout provided by the Humphrey perimeter *(fig. 4-1)*. The analysis compares the results of a single threshold test with age-corrected normative data and highlights any sensitivity values or patterns that deviate significantly from normal. The Single Field Analysis also presents patient demographic data, indices of test reliability, and raw test results.

DEVIATION PLOTS

Total Deviation Probability Plots: Total deviation probability plots indicate all test locations that are outside normal limits, whether because of a general depression of the whole visual field, or because of localized loss. Threshold sensitivity is compared with the age-corrected normal values at each test point to produce the total deviation (TD) decibel plot. Negative values indicate sensitivities that are below the median age-corrected sensitivity, and positive values indicate higher than normal sensitivities. The normal range of sensitivity is larger in the periphery than in the center of the field, and also larger superiorly than inferiorly. Thus, a depression of 5 decibels from age normal may be quite significant at the center of the field, but totally within the normal range of variability in the periphery of the test area.

A deviation of 5 decibels may be quite significant at the center of the field, but totally within the normal range of variability in the periphery of the test area.

The significance of these deviations from normal are indicated in the associated total deviation probability plot, in which sensitivities that are worse than those found in 5%, 2%, 1%, and 0.5% of normal subjects of the

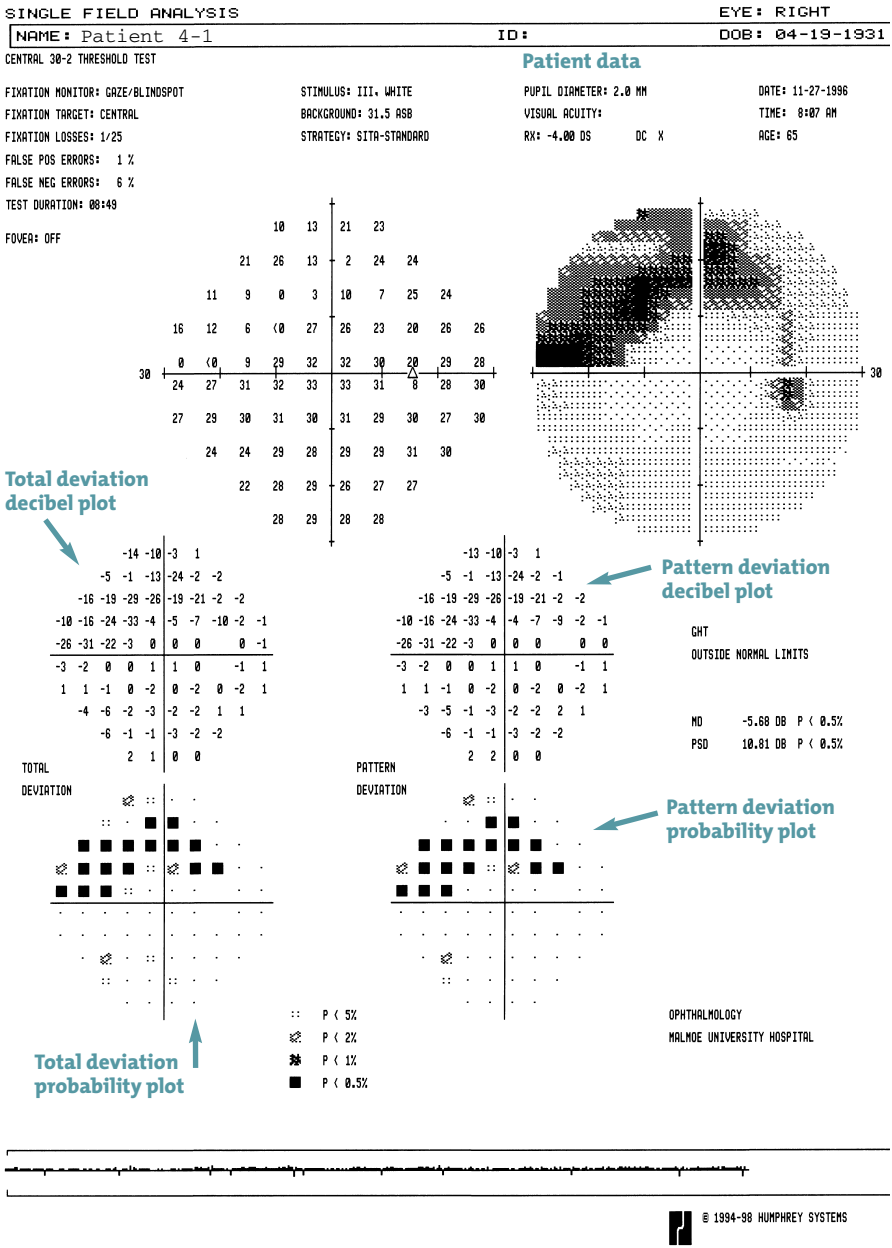


Figure 4-1. STATPAC Single Field Analysis

same age as the patient are highlighted with appropriate symbols. A 2% symbol, for instance, indicates that fewer than 2% of normal subjects have a sensitivity that low or lower. A key showing the meaning of the symbols is given near the bottom of the printout.

The range of normal threshold values changes from test point to test point, and does not follow theoretical Gaussian distributions (Heijl, Lindgren, and Olsson 1987). As a result, attempts to construct probability plots based upon idealized theoretical models provided poor diagnostic performance as shown by Heijl and Åsman (1989). For these reasons, Humphrey's probability plots are based on empirically determined normal ranges found in large groups of subjects, some representing a random sample of the normal population tested in multi-center clinical trials.

The single most useful analysis on an SFA printout is the Pattern Deviation (PD) probability plot.

Pattern Deviation Probability Plots: The single most useful analysis on an SFA printout is the pattern deviation (PD) probability plot. The pattern deviation analysis shows sensitivity losses after an adjustment has been made to remove any generalized depression and uses the same symbols as the total deviation plots to show which points are significantly worse than normal. Thus, the pattern deviation decibel and probability plots primarily highlight only significant localized visual field loss.

The great strength of the probability plots is that they ignore variations that are within the normal range and highlight subtle, but significant, variations that might otherwise escape notice *(figures 4-2a, 4-2b)*. Beginning field defects regularly show up earlier in the probability map than in grayscale printouts. Furthermore, STATPAC's probability plots help de-emphasize common artifactual patterns, such as eyelid-induced depressions of sensitivity in the superior part of the field, that are often overemphasized on the grayscale. Note that the correction for homogenous depression used in the PD plot is based upon the sensitivities at the best points in the TD

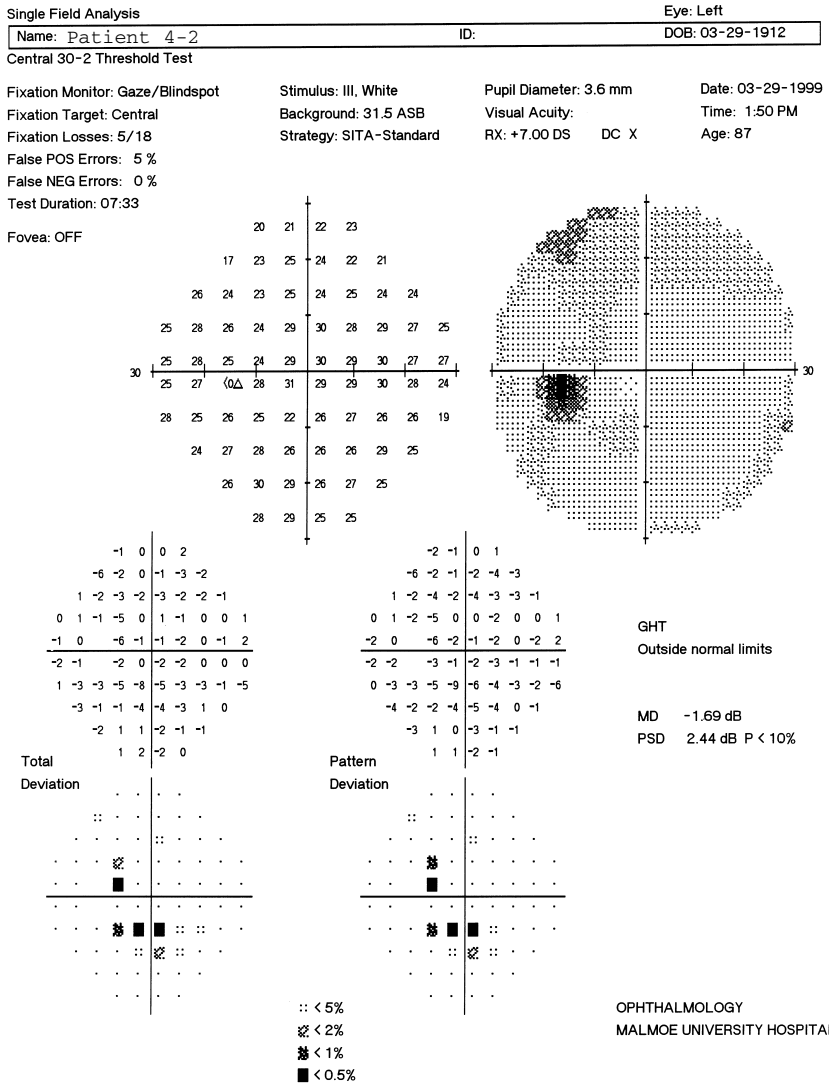


Figure 4-2a. Early glaucomatous field loss is clearly indicated on the probability plots and on the GHT, but not on the grayscale. PSD is significant only at the <10% level, even though the defects are quite marked on the probability plots.

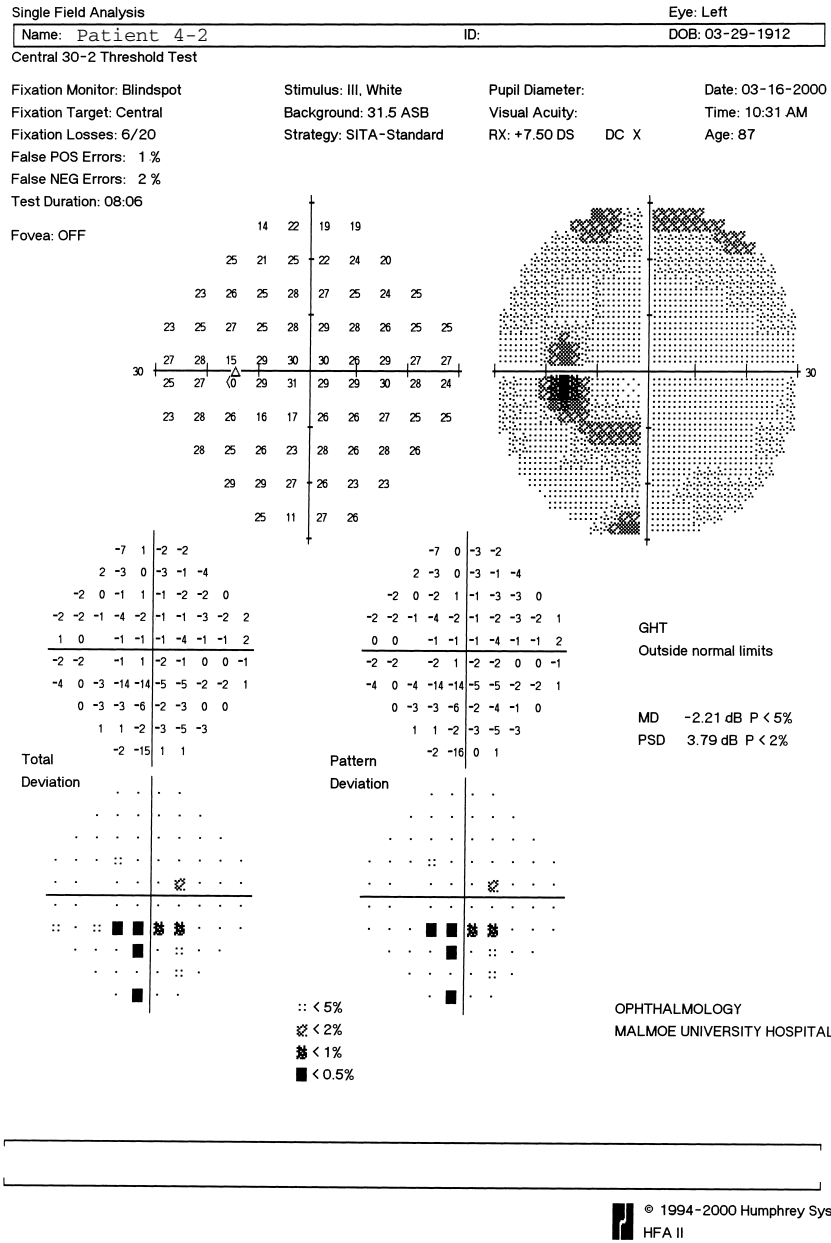


Figure 4-2b. When the same patient was tested one year later, the field loss was clearly visible on the grayscale as well.

plot; thus, if visual field loss is so far advanced that even the best points are almost blind, then the PD plot will be unable to highlight localized loss. Such situations are obvious even when looking at the grayscale, however, and should not lead to missed diagnoses.

Comparing Total And Pattern Deviation: It is useful to compare the total deviation and pattern deviation plots. If the plots look more or less the same, then there is little or no generalized loss. A uniformly depressed total deviation plot combined with a normal-looking pattern deviation plot probably indicates a cataract *(figures 4-3a, 4-3b, 4-3c)*. The opposite pattern—a normal total deviation plot and an abnormal-looking pattern deviation plot—often is associated with a trigger-happy patient who has repeatedly pressed the response button when no stimulus was seen *(see Chapter 8)*.

GLAUCOMA HEMIFIELD TEST

The Glaucoma Hemifield Test (GHT) is a plain-language classification of threshold test results in the following categories (Åsman and Heijl 1992a; 1992b).

- The "Outside Normal Limits" message is displayed whenever sensitivities in one or more of the five zones in the upper half of the field are significantly different ($p<0.01$) from the sensitivities measured in the corresponding zones in the lower half of the field *(fig. 4-4)*.
- Fields are labeled as "Borderline" whenever zone pairs differ by an amount greater than is seen in most normal subjects ($p<0.03$), but the difference does not reach the level required for the "Outside Normal Limits" message.
- The GHT will give a "General Depression of Sensitivity" or "Abnormally High Sensitivity" message whenever even the best test point locations are either so low or so high as to be at levels seen in only 0.5%

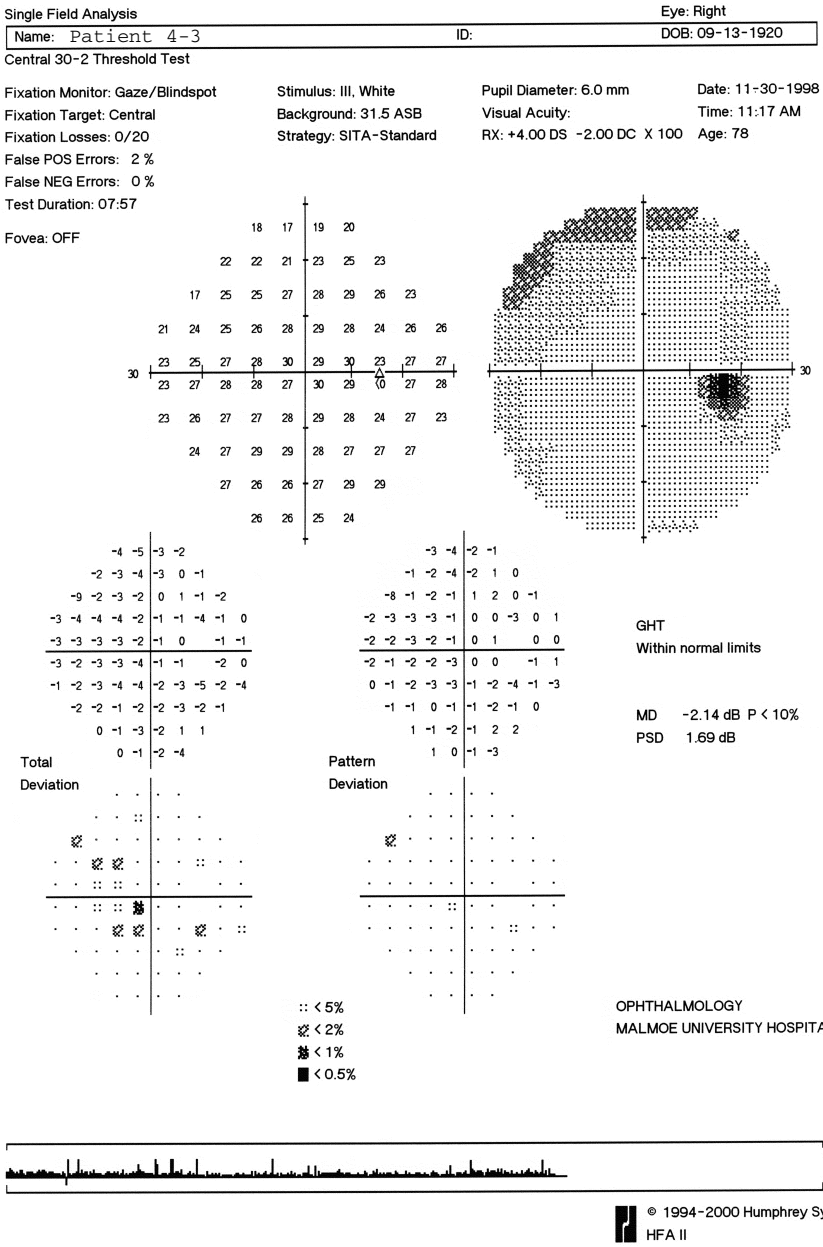


Figure 4-3a. First of three fields in a patient who is developing a cataract

Figure 4-3. Comparing total and pattern deviation plots. Three consecutive visual fields were taken over two years in an eye with progressive cataract. While the total deviation plots indicate significant field loss, the pattern deviation plots filter away the generalized depression resulting from the cataract and show that there is no localized field loss.

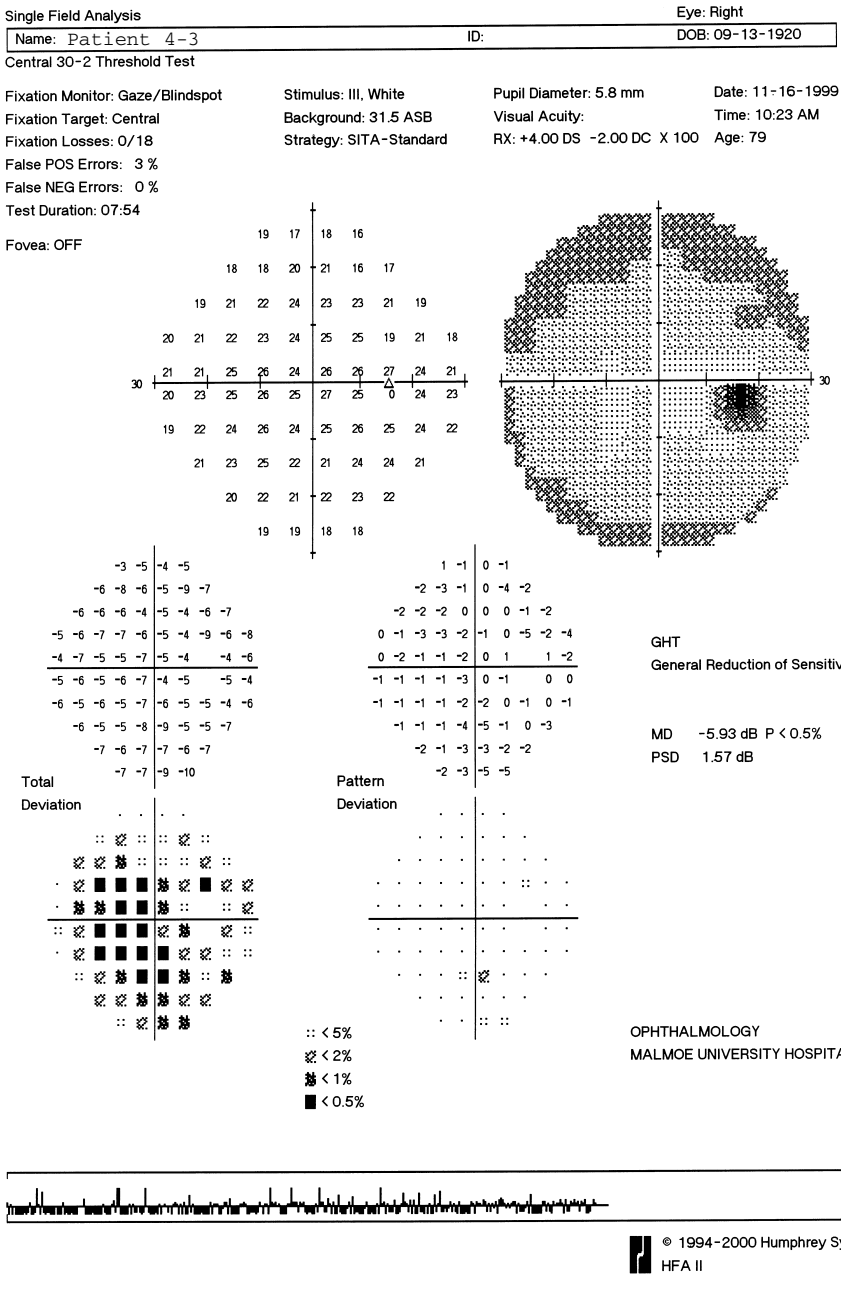


Figure 4-3b. Second of three consecutive fields in a patient developing a cataract

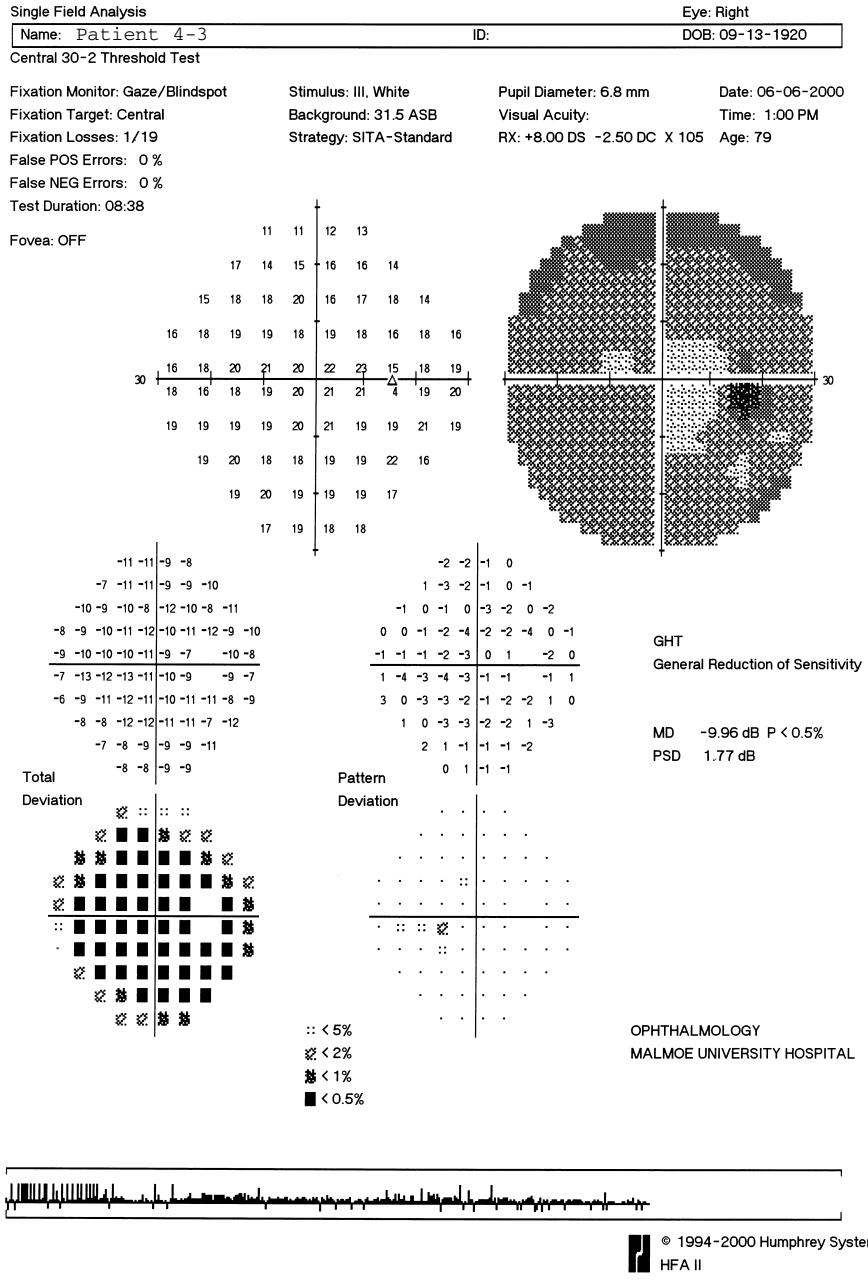


Figure 4-3c. Third of three consecutive fields in a patient developing a cataract. As the gaze tracker record shows, the patient's fixation was highly variable at the beginning of the test. After that, fixation quality improved considerably, and measured gaze was usually accurate to within a few degrees.

of normal subjects. "General Depression of Sensitivity" will not be displayed, however, when sensitivity differences between the superior and inferior hemifields are large enough to result in an "Outside Normal Limits" message.

- The "Within Normal Limits" message is presented whenever none of the above significance limits are reached.

Sensitivity differences between the upper and lower hemifields are a hallmark of glaucomatous field loss. The GHT analyzes these differences in terms of deviations from the age-corrected normal reference field and then translates them into the probability domain, first in individual test point locations, and then for the whole central field. The result is a very powerful interpretation tool. The GHT has also been reported to be the single most effective method of visual field analysis and, after over ten years of use, enjoys wide acceptance worldwide (Katz et al. 1991).

5

Glaucomatous Visual Field Loss

COMMON PATTERNS of glaucomatous field loss correspond directly to the patterns of optic nerve damage typical of the disease. Glaucomatous fields show more variability than normal fields, and variable reductions in sensitivity frequently precede definite loss. Complete and quantitative understanding of the amount of variability typically found in glaucomatous fields greatly aids in determining whether a patient's follow-up test results indicate true disease progression.

Anatomy and Glaucomatous Visual Field Defects

Glaucomatous field loss is the result of axonal damage at the level of the optic disc, and is therefore the functional correlate of neural loss or reduced neural function.

■ RETINAL NERVE FIBER LAYER AND OPTIC DISC ANATOMY

Retinal ganglion cell axons follow an arcuate path to the optic nerve *(fig. 5-1)*. Axons extending from the optic disc toward the temporal retina curve around the macular area. Neurons from the temporal superior and inferior

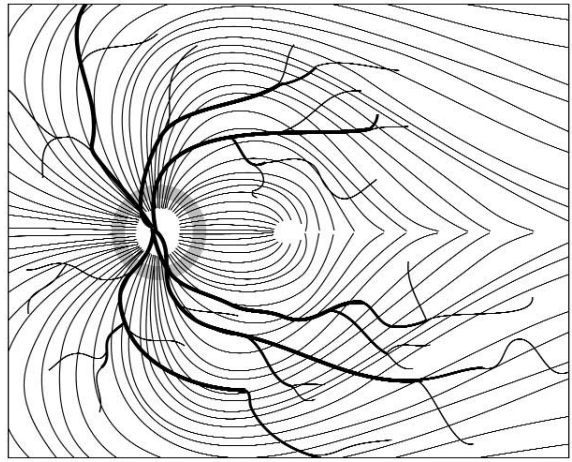


Figure 5-1. Retinal nerve fiber pattern of the central retina

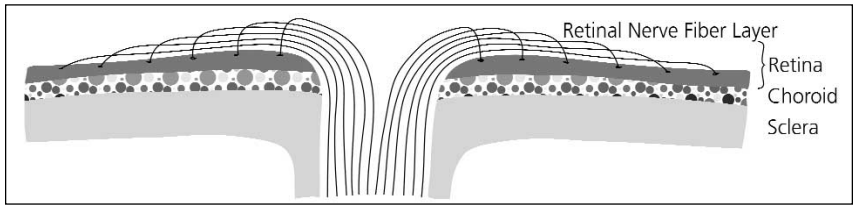


Figure 5-2. All axons of the optic nerve converge on and exit the eye through the optic disk. Axons are systematically layered so that longer ones originating far from the disk are situated deeper in the retina and more peripherally in the optic disk.

retinal areas do not mix, but respect the horizontal temporal raphe. Axons maintain a retinotopic organization in the optic disc in the sense that longer axons are situated in the optic disc periphery close to the scleral canal, while shorter axons from ganglion cells nearer to the optic disc follow a more central course through the optic disc *(fig. 5-2)*.

■ COMMON GLAUCOMATOUS FIELD DEFECTS AND THEIR ANATOMICAL CORRELATES

Glaucomatous visual field defects commonly take the form of paracentral scotomas, arcuate scotomas, nasal steps, and contractions of the nasal field. Several different types of defects often occur concurrently in the same field.

Arcuate Defect—the Bjerrum Scotoma: A focal notch at the optic disc that reaches the edge of the disc will lead to the loss of all retinal nerve fibers in the area corresponding to the notch and, therefore, to a deep arcuate

Several different types of defects often occur concurrently in the same field.

field defect connected to the blind spot *(fig.5-3)*. It usually extends around the point of fixation and ends abruptly at the nasal horizontal meridian corresponding to the temporal raphe to produce what is known as a Bjerrum defect. Focal notches at both poles of the optic nerve can result in a double arcuate defect *(fig. 5-4)*.

Paracentral Scotomas: If the notch is partial, that is, if it involves only a portion of the axons in the affected area of the optic disc, it is likely that the involved fibers are of approximately the same length and originate from only a part of the arcuate segment. The resulting visual field defect is a paracentral scotoma. Paracentral scotomas can occur anywhere in the central field *(fig. 5-5)*, but they are particularly common nasally *(figures 5-6a, 5-6b)*.

Nasal Steps: A more widespread involvement of fibers in the optic disc will seldom be entirely symmetrical, but usually will involve a larger percentage of lost fibers in either the inferior or superior half of the optic disc. As a result, differential light sensitivity in the opposite visual field halves will not be the same. This is likely to manifest itself as an abrupt difference of sensitivity across the nasal horizontal meridian in the visual field—a nasal step *(figures 5-7 and 5-8)*. Nasal step damage in one hemifield can be combined with loss in the other hemifield *(fig. 5-9)*.

Characteristics of Glaucomatous Field Loss

LOCALIZED AND GENERALIZED VISUAL FIELD LOSS

Paracentral and arcuate scotomas as well as nasal defects are examples of localized field loss, that is, defects that have shape. Generalized, homogenous visual field loss, in contrast, is a uniform loss of sensitivity across the whole visual field, resulting in a depression of the hill of vision without any significant change of its shape *(figures 5-10a, 5-10b)*. Isolated, homogenous visual field loss is exceedingly rare in glaucoma, and therefore not seen frequently

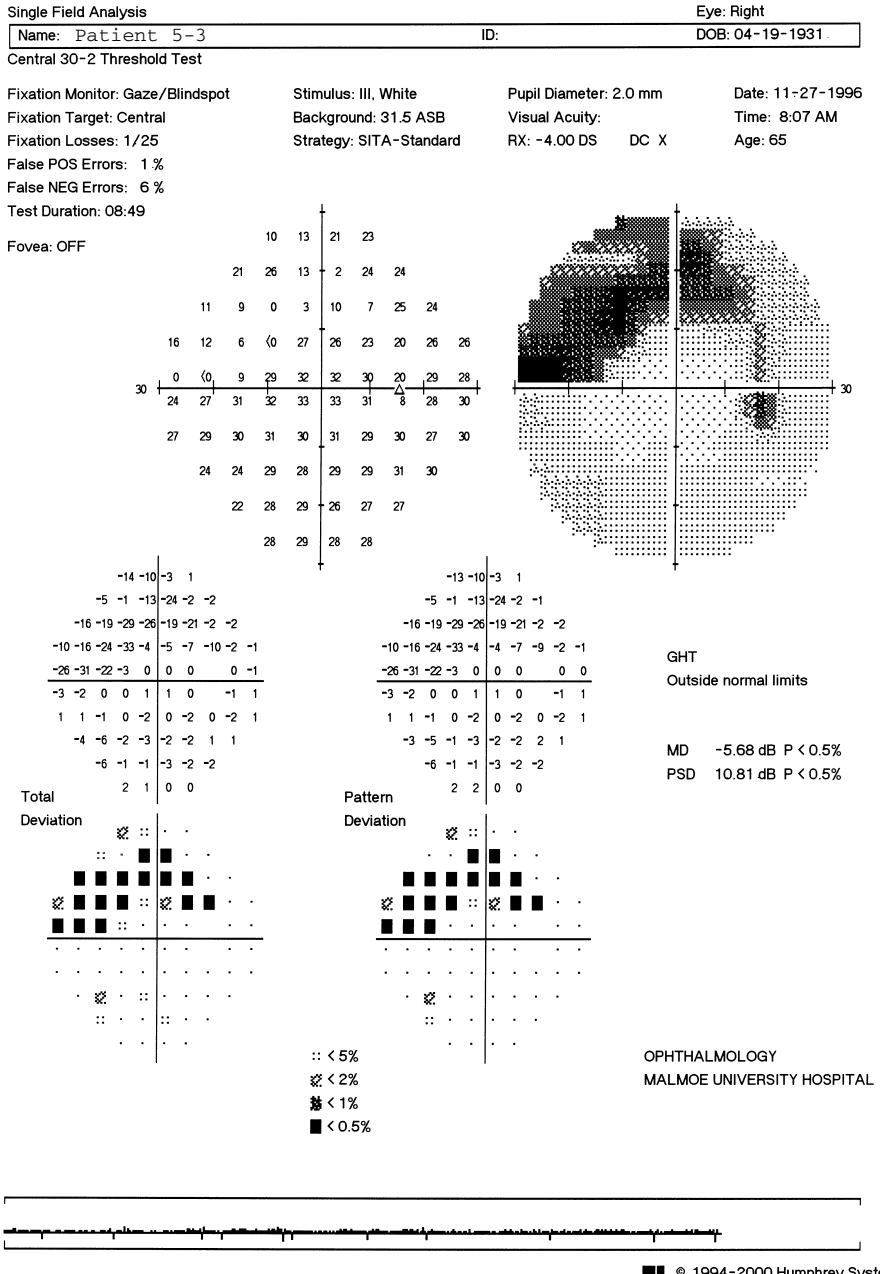


Figure 5-3. Superior arcuate scotoma

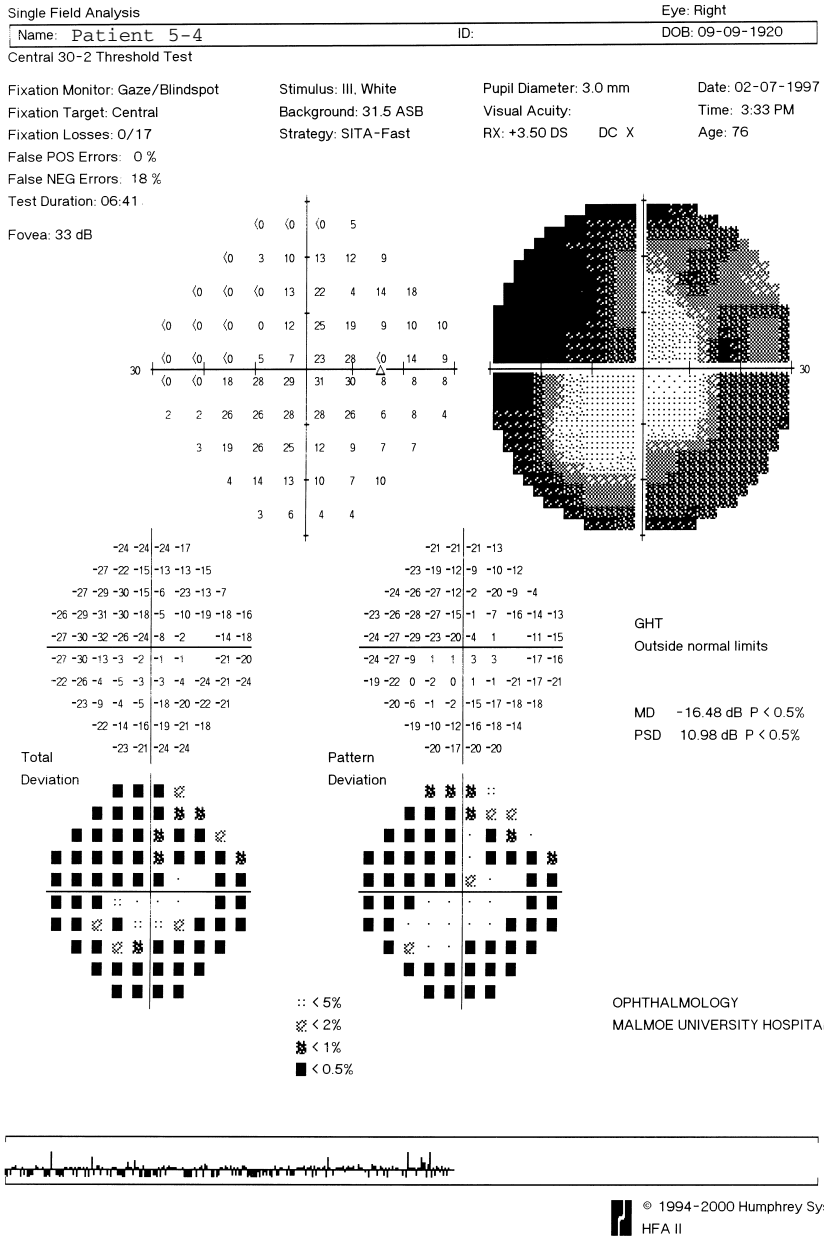


Figure 5-4. Advanced double arcuate defect with loss extending near fixation supero-nasally

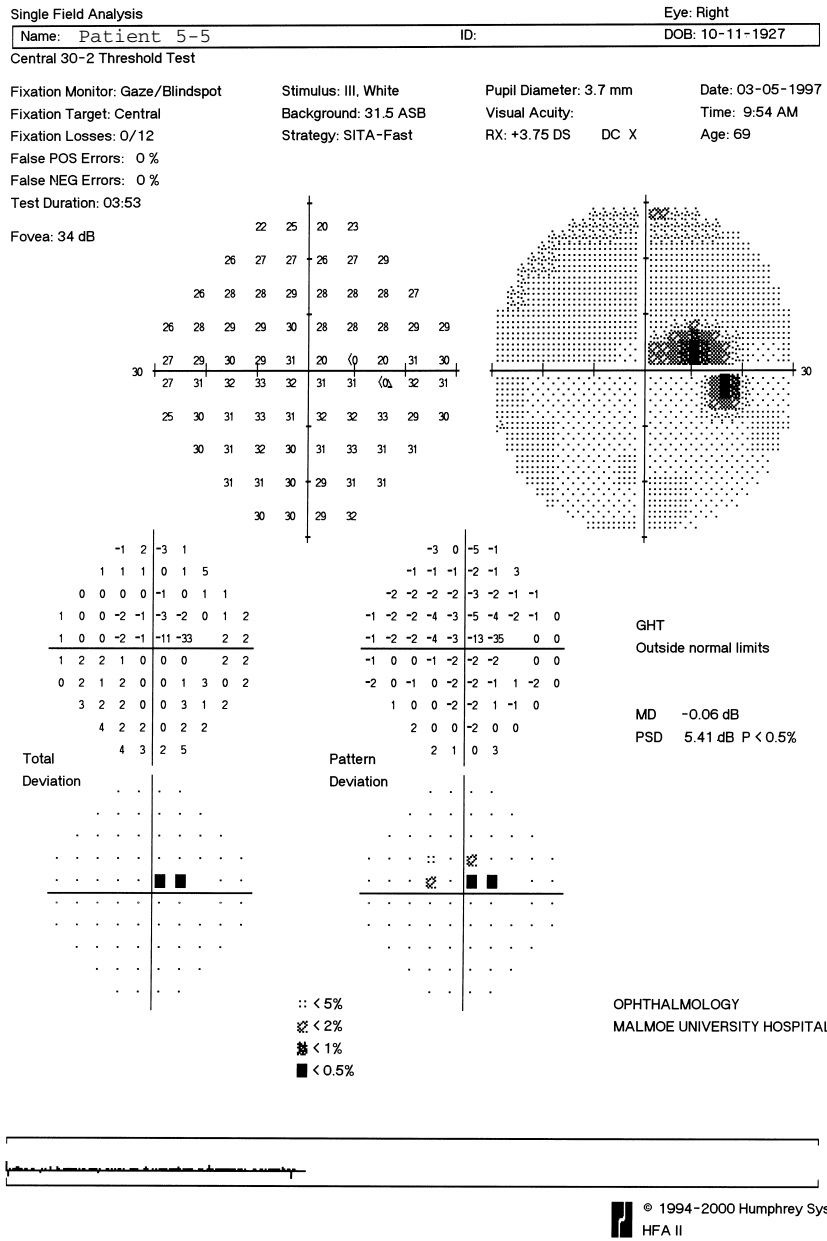


Figure 5-5. Early central glaucomatous defect

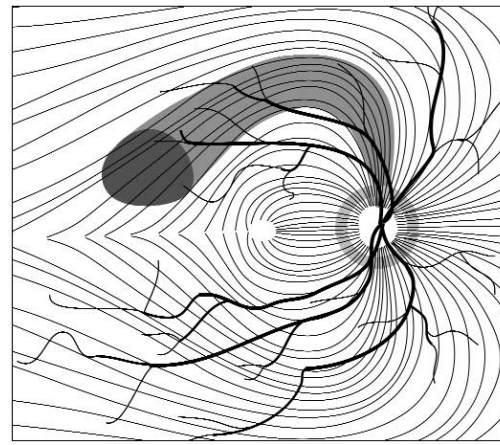


Figure 5-6a. This is how the retinal nerve fiber layer appears in the case of focal optic disk damage. The damaged fibers project in an arcuate pattern and are of approximately the same length. The corresponding ganglion cells are located in the dark oval area above the temporal raphe. This illustration is intended to approximate the pattern of nerve fiber loss that would be expected to be associated with figure 5-6b.

enough to be useful as a diagnostic sign (Heijl 1989; Langerhorst, van den Berg, and Greve 1989). In any case, it is not specific to glaucoma and is more frequently caused by increasing media opacities and miosis *(figures 5-11a, 5-11b)*.

When visual field loss is encountered in test results, separating localized from generalized loss and concentrating on the former will facilitate detection of specific, localized glaucomatous field damage. The pattern deviation plots available on the Humphrey STATPAC printouts are designed to do just that *(see Chapter 4)*.

EARLY GLAUCOMATOUS FIELD LOSS

Early glaucomatous field loss may develop very gradually over a period of several years (Werner and Drance 1977; Heijl and Bengtsson 1996a). Local depressions of sensitivity frequently come and go for quite some time before finally resolving into stable and repeatable defects *(fig. 5-12)*. The narrower normal limits of SITA mean that statistically and clinically significant defects can be identified in probability plots even before they are clearly visible in grayscale representations *(fig. 5-13)*. This happens regularly in patients who are developing early glaucomatous visual field loss, and it is therefore important to focus on probability plots rather than grayscale representations.

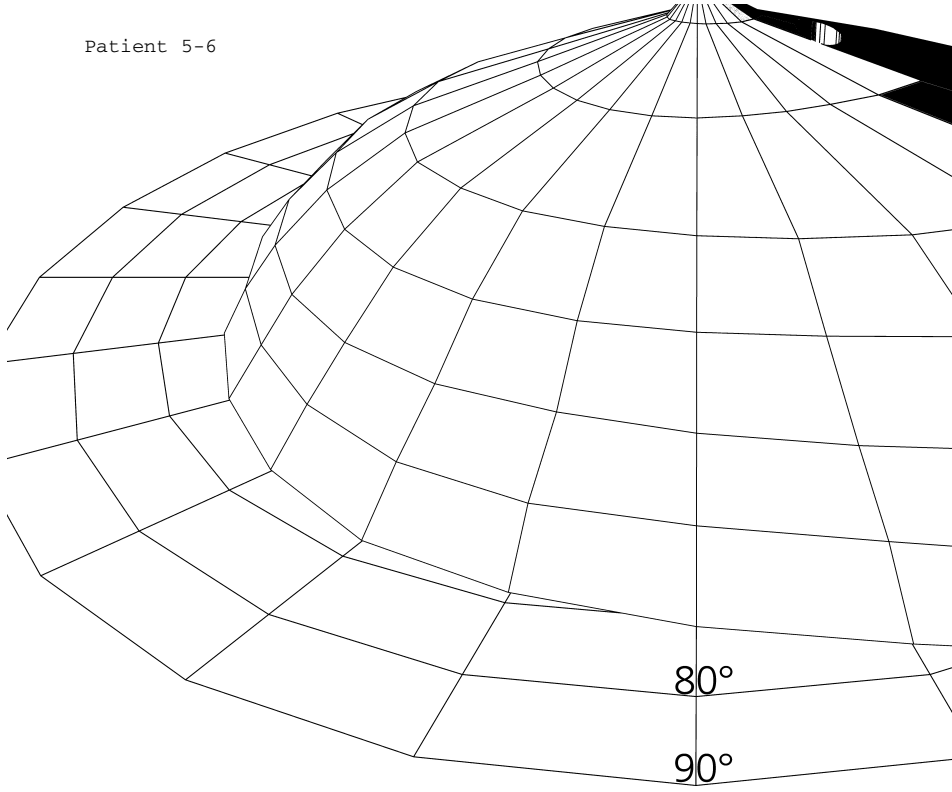


Figure 5-6b. Large paracentral glaucomatous field defect. The expected corresponding nerve fiber layer damage is illustrated in figure 5-6a.

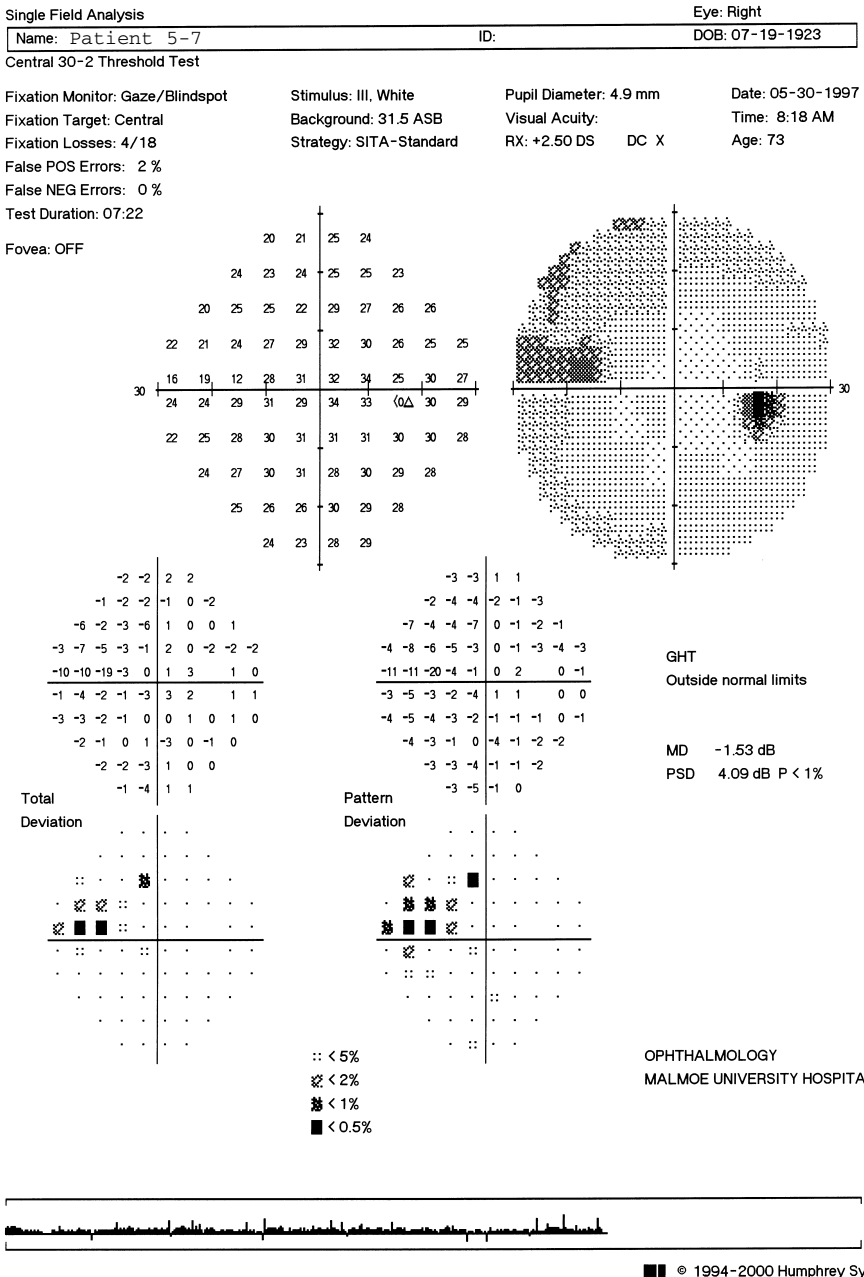


Figure 5-7. Superior nasal step. Sensitivity values along the horizontal meridian in the nasal field are lower superiorly than inferiorly. The GHT indicates that the finding is outside normal limits.

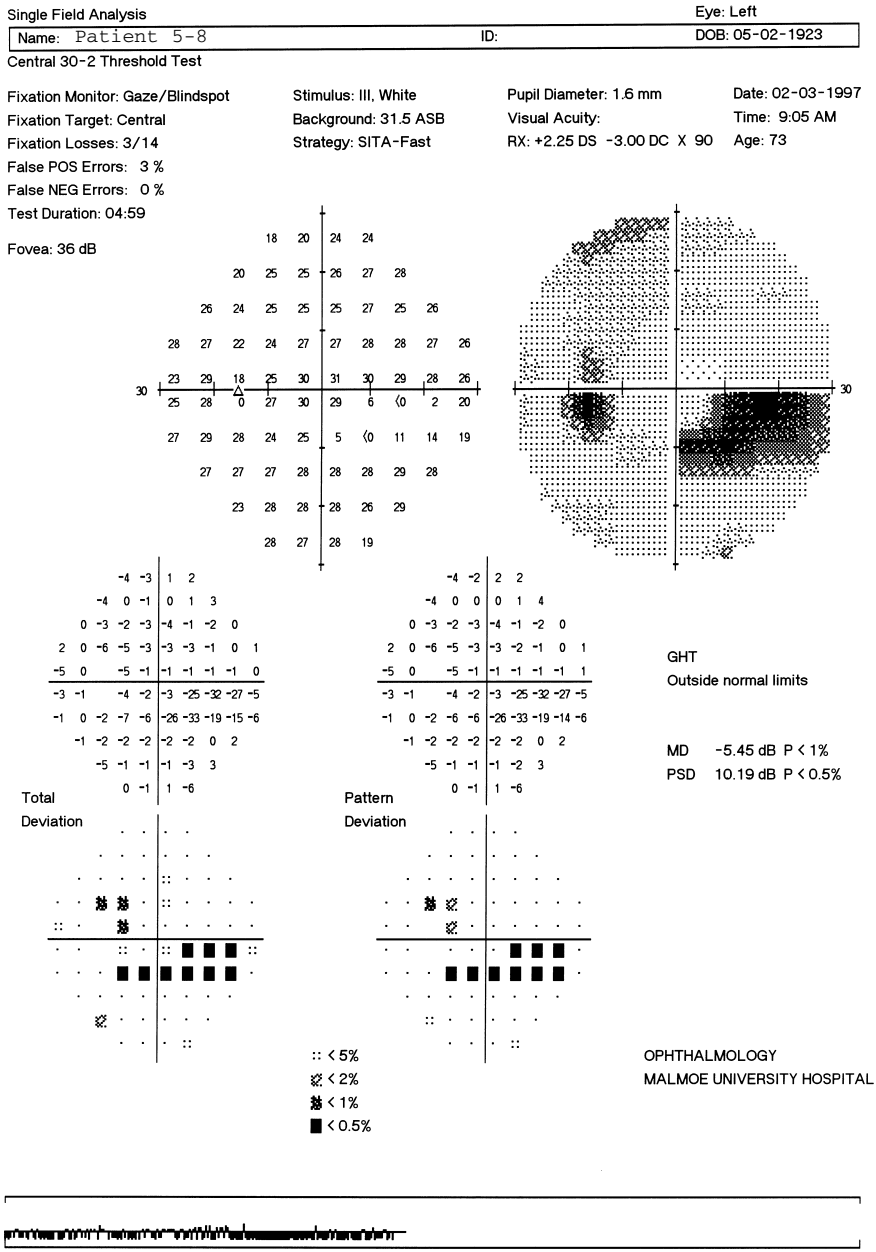


Figure 5-8. Inferior nasal step extending back to blind spot

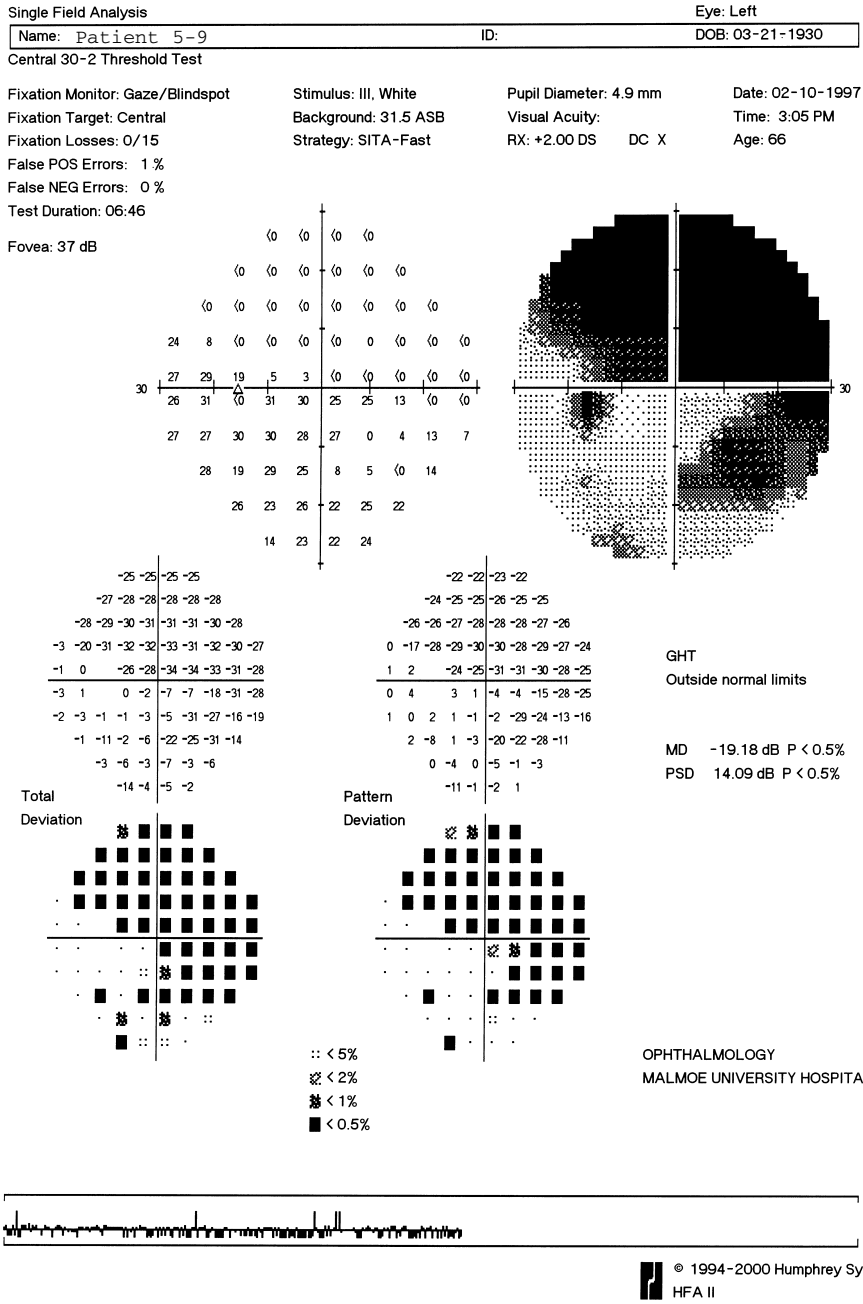


Figure 5-9. Superior altitudinal defect combined with inferior nasal step

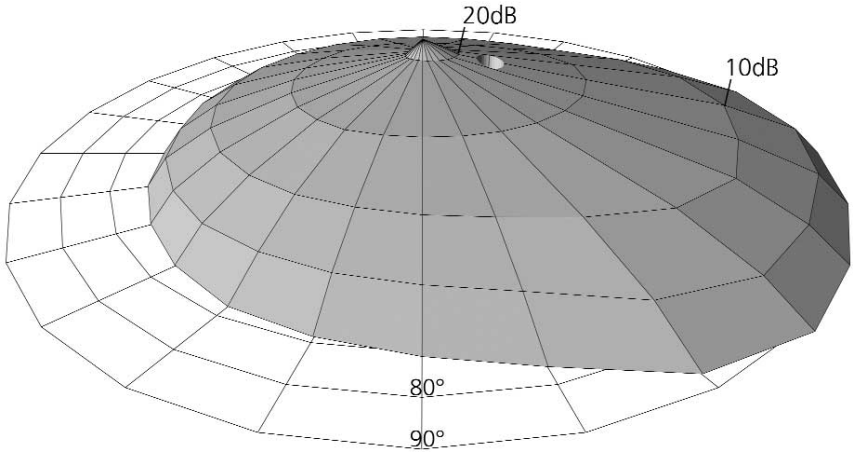


Figure 5-10a.

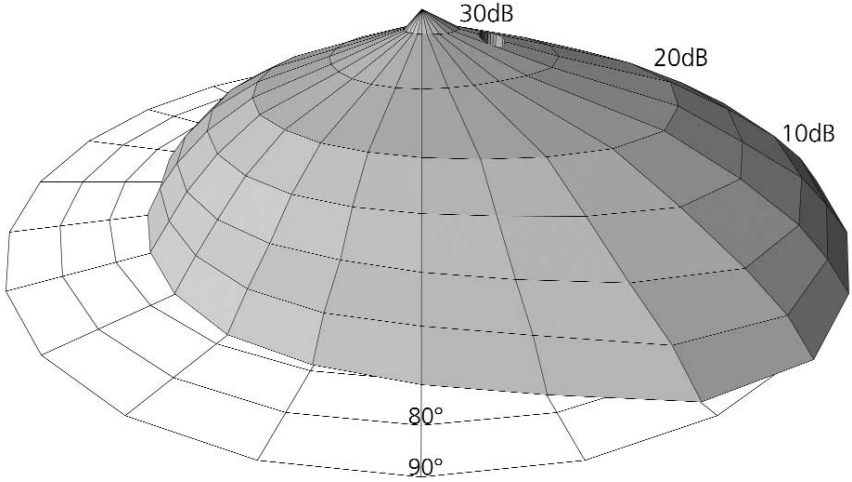


Figure 5-10b.

Figure 5-10. Generalized depression of the hill of vision, 5-10a, compared to normal hill of vision, 5-10b

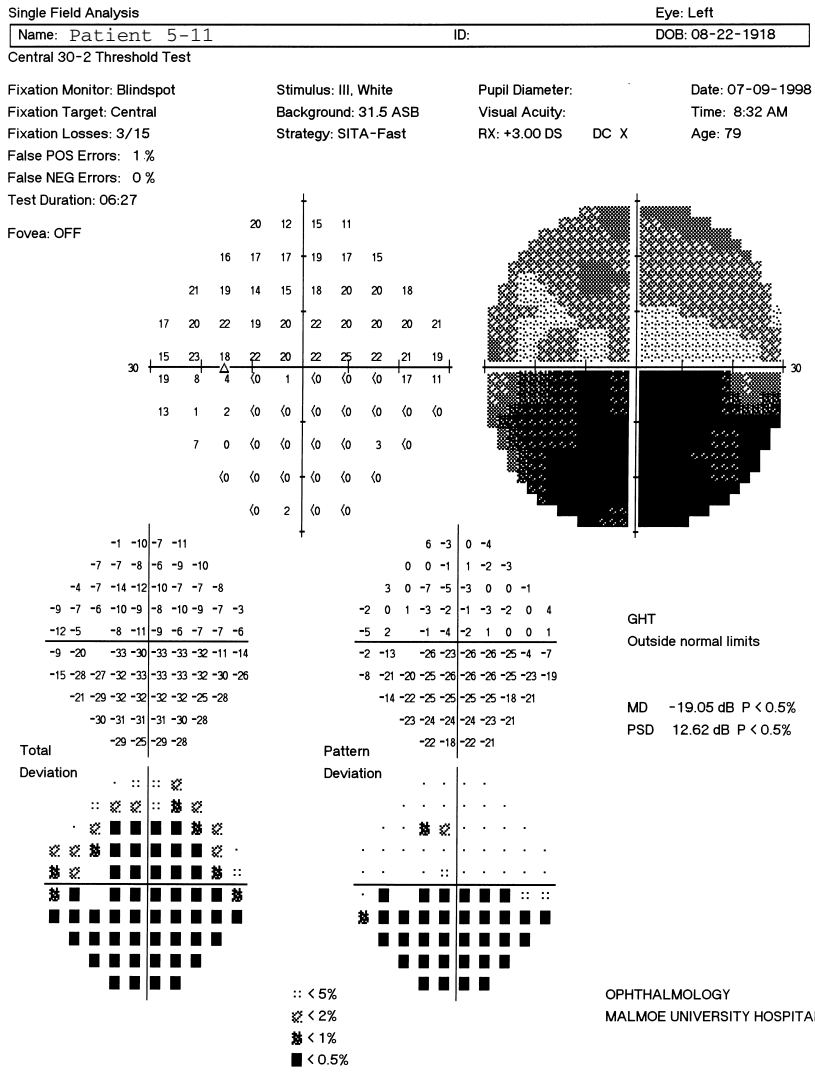
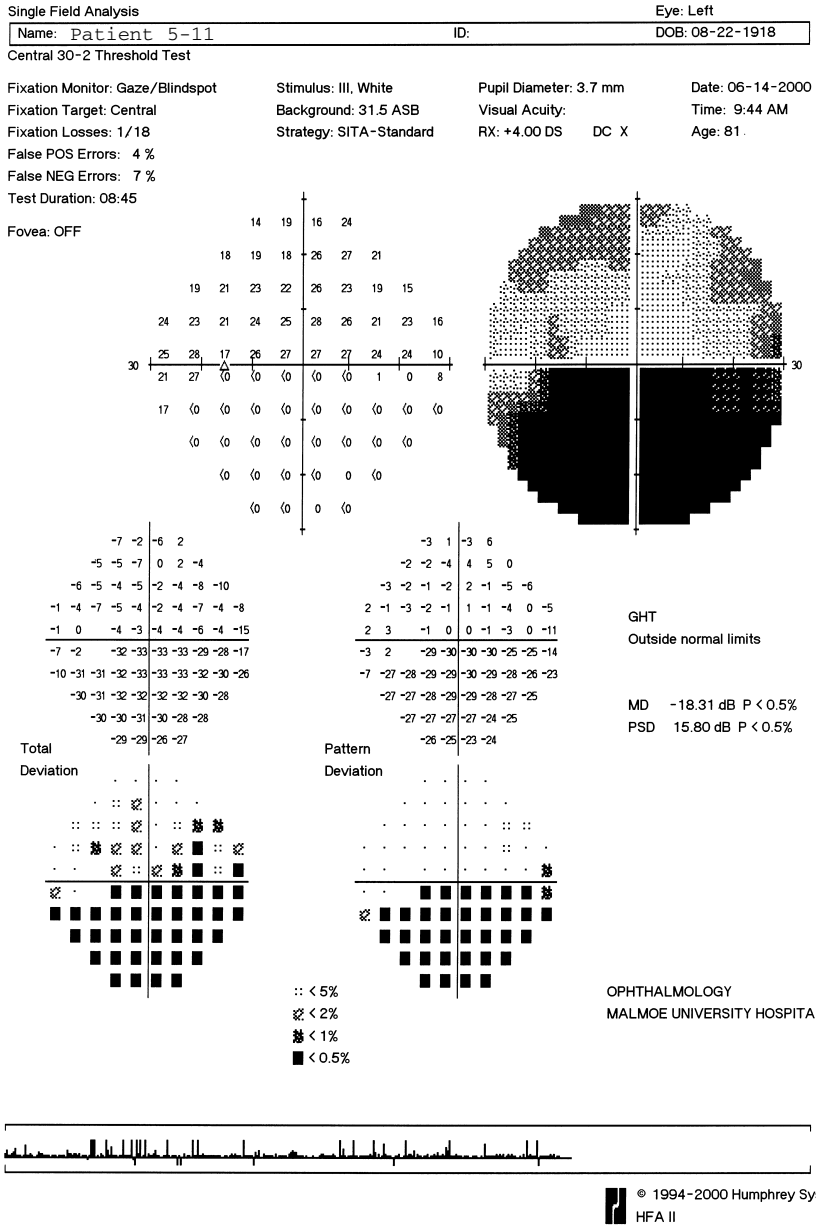


Figure 5-11a. Before cataract surgery this patient's field showed a combination of cataract and glaucomatous altitudinal field loss.

Figure 5-11. Differentiating between generalized and localized field loss in a patient with cataract and glaucoma



5-11b. After the cataract was removed, the pattern deviation probability map remained largely unchanged. The total deviation map improved in the superior field to more closely resemble the pattern deviation map, in accordance with the expected improvement in media clarity. Note that the first test was performed using SITA Fast, and the second using SITA Standard. While cross-strategy comparisons of raw thresholds often are misleading, the probability plots of such fields may be usefully compared.

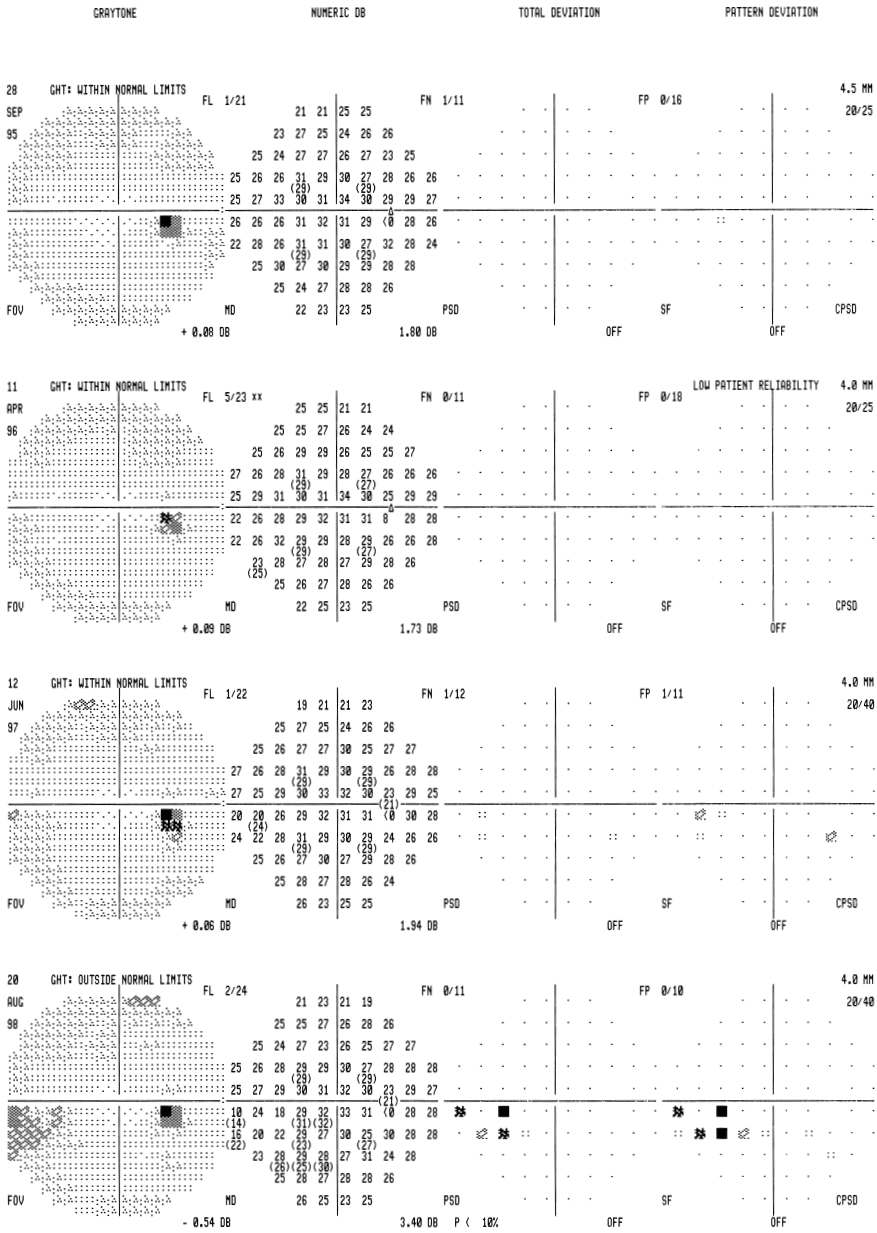


Figure 5-12. The six fields shown on these two pages show a typical gradual transition over a four-year period from a normal visual field to early but well-established glaucomatous field loss. Test-retest variability is increased in the area that finally becomes definitely abnormal.

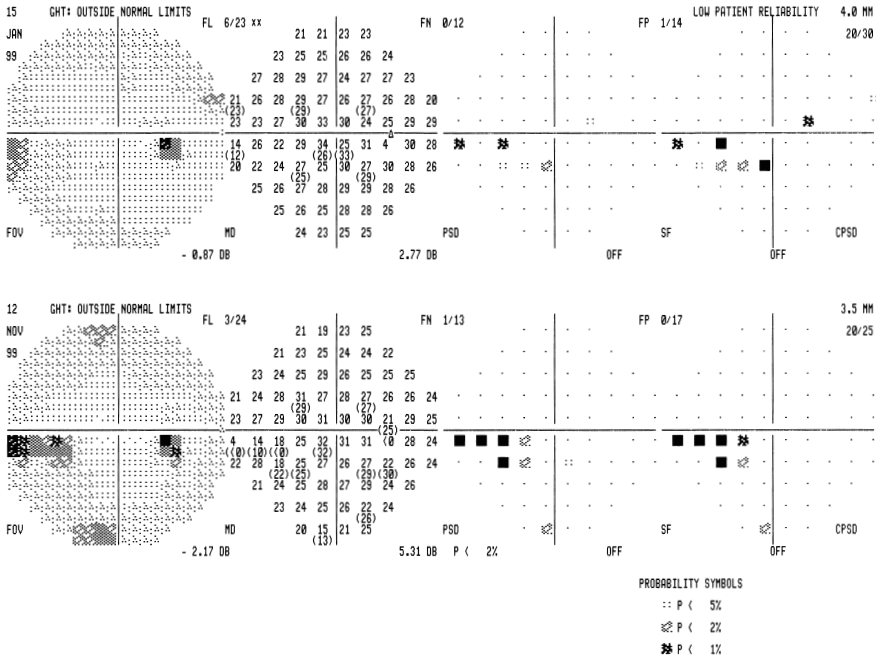


Figure 5-12. (continued)

Considerable test-retest variability is common in glaucomatous field loss.

GLAUCOMATOUS VISUAL FIELD VARIABILITY

Visual field variability can be considerable in glaucomatous eyes. Threshold values at individual test point locations frequently vary from test to test of the same eye, even if the tests are administered within a short time period. Such increased local fluctuations also typically precede definite glaucomatous field defects.

The random test-retest variability of glaucomatous fields is bound by certain laws, however, and depends on test point defect depth, test point location, and overall visual field status. Most of the variability occurs in pathological points rather than in normal ones, and variability tends to be higher farther away from fixation than more centrally, just as in normal fields (Heijl, Lindgren and

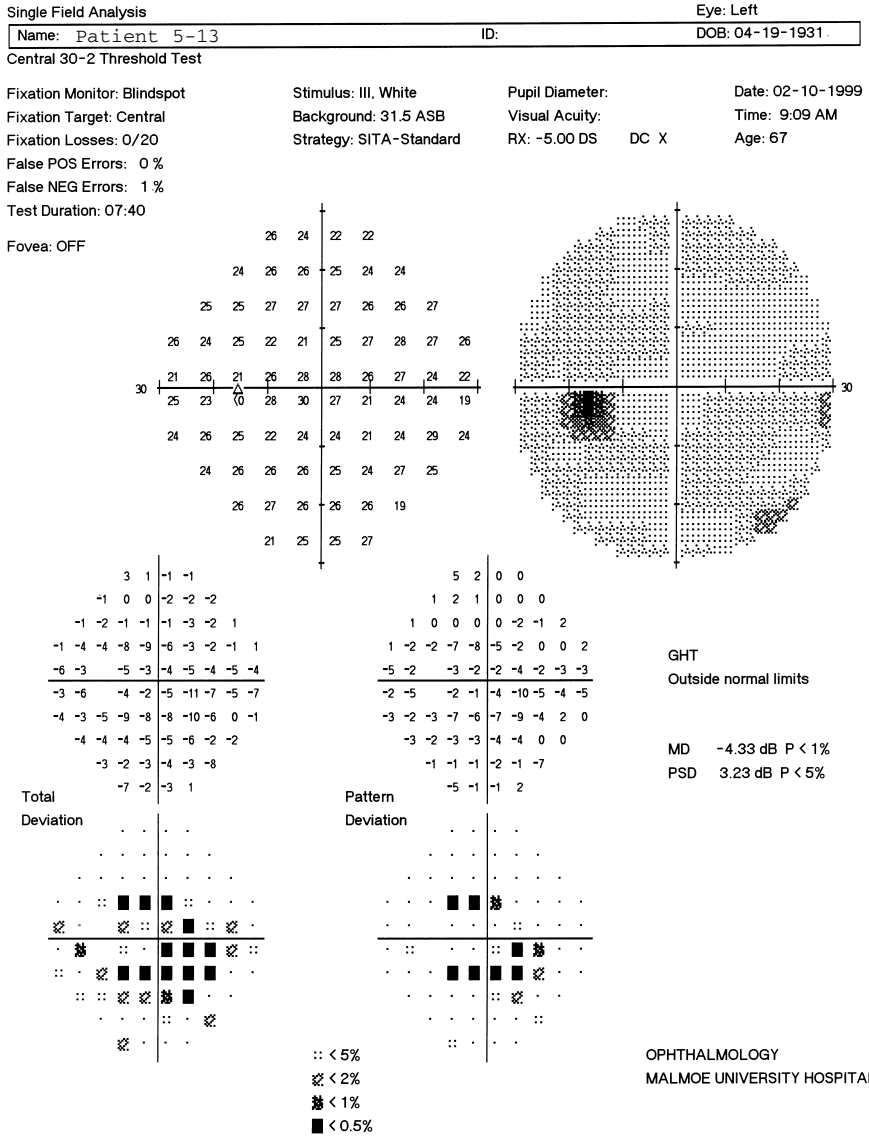


Figure 5-13. Double arcuate scotoma shown by a SITA Standard threshold test. Probability plots often reveal field loss that is not evident in traditional grayscale analyses.

Lindgren 1989; Heijl et al. 1991). Overall field status is also of importance; fields with widespread areas of damage show higher variability than fields with smaller defects. Knowledge of the nature of this variability helps interpretation of test results in glaucoma follow-up and is incorporated in STATPAC's glaucoma change probability plots.

Judging whether or not a glaucomatous visual field is progressing usually requires a series of at least three or four fields. Basing judgements about disease progression on only one progressed field is very risky unless the changes encountered are very large and/or are confirmed by other clinical findings, such as changes in optic disc configuration. Fortunately, glaucomatous field progression is usually slow enough that there is time for the patient to take a confirmatory field test when change is suspected.

PITFALLS IN PERIMETRIC GLAUCOMA FOLLOW-UP

A large percentage of glaucoma patients have coexisting media opacities, complicating follow-up analysis of their visual fields. As mentioned previously, these problems can be largely avoided by using analyses based on pattern deviation.

Medically induced miosis also results in general reduction of sensitivity, particularly in eyes that have some cataract. For this reason it is difficult to compare consecutive fields when the patient has been treated with miotics at some, but not all, visits *(figures 5-14 a, 5-14b)*. Again, a comparison will be facilitated by concentrating on the pattern deviation plots, which will eliminate most of the effects of the miotics.

Large, sudden visual field changes are not typical in glaucoma.

Large, sudden visual field changes are not typical in glaucoma. Such changes often occur for reasons other than progression of the glaucomatous disease process, e.g., arterial or venous occlusions in the retina or neurological disease. If a large change is seen and part of the field loss seems hemianopic or occurs in the other eye as well, neurological causes are generally the rule *(see Chapter 6)*.

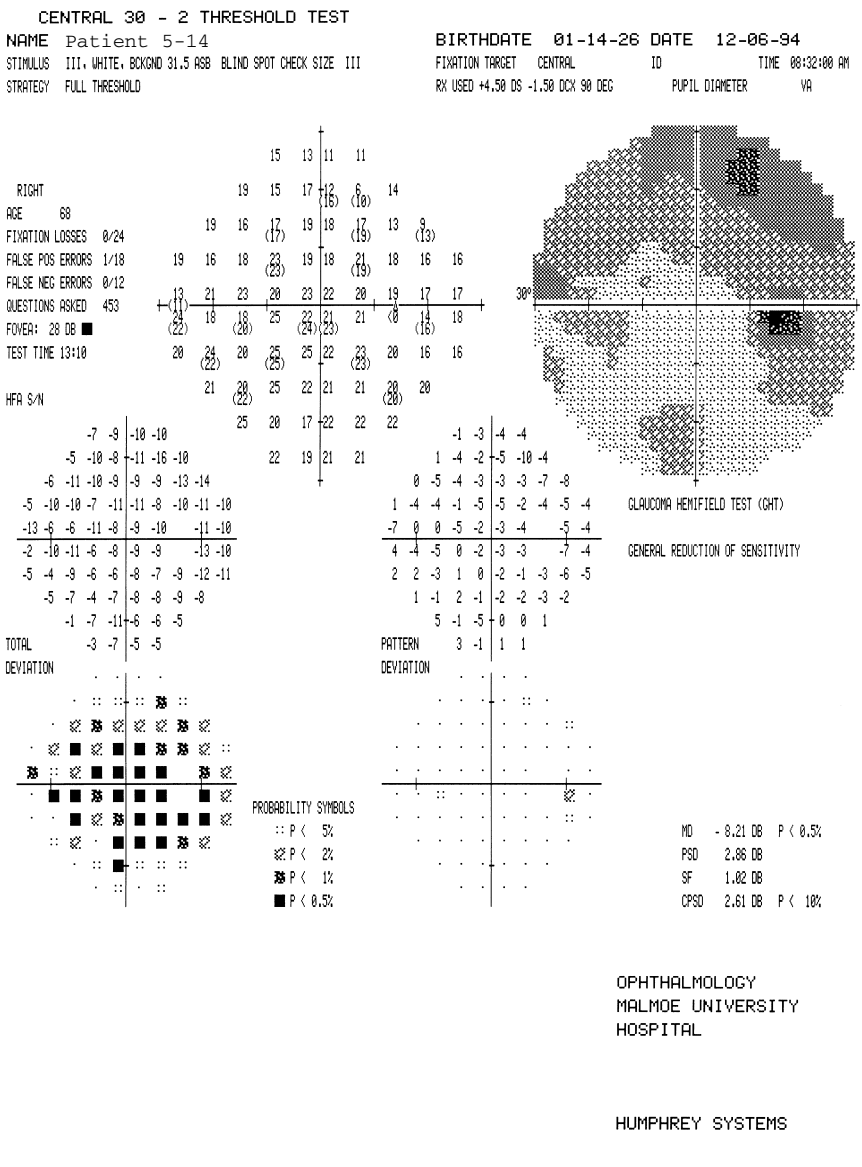


Figure 5-14a. This 68-year-old patient has ocular hypertension, mild cataract, and visual acuity of 20/25. In the first field (5-14a) the patient had been treated with a beta blocker plus 2% pilocarpine bid. When the second field (5-14b) was taken, pilocarpine had been discontinued. The first field shows a general reduction of sensitivity that is absent in the second field. Miotics can cause considerable generalized reduction of sensitivity.

Figure 5-14. Effect of miotics on visual field test results

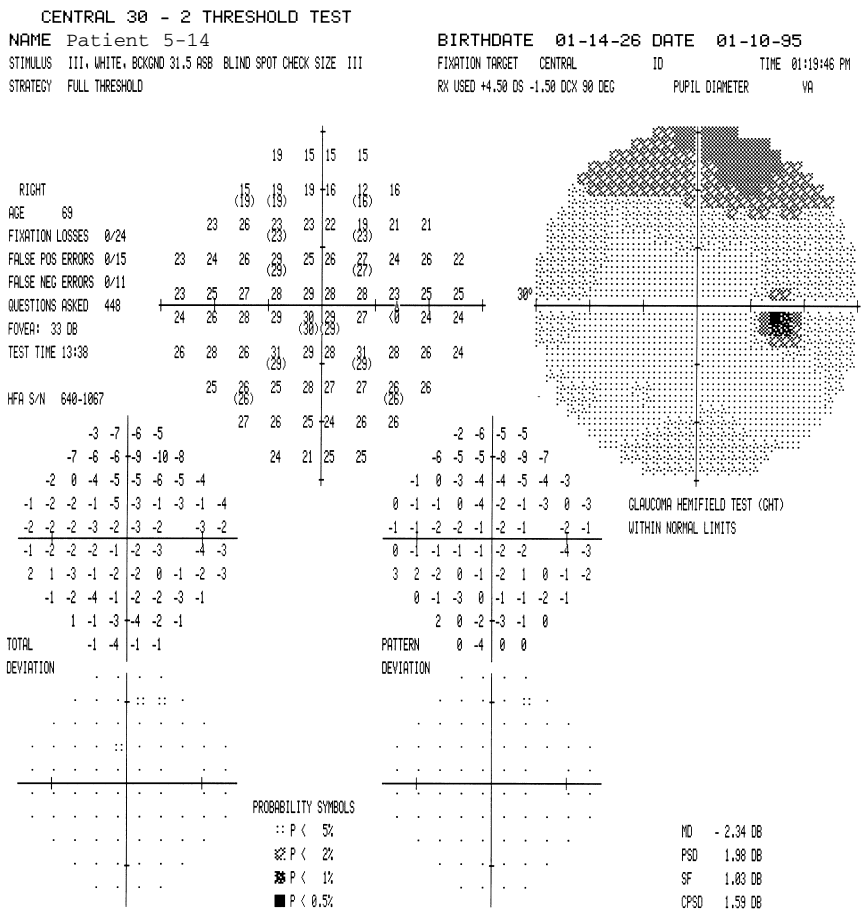

CENTRAL 30 - 2 THRESHOLD TEST
NAME Patient 5-14
BIRTHDATE 01-14-26 DATE 01-10-95
STIMULUS III, WHITE, BCKGND 31.5 ASB BLIND SPOT CHECK SIZE III
FIXATION TARGET CENTRAL ID TIME 01:19:46 PM
STRATEGY FULL THRESHOLD
RX USED +4.50 DS -1.50 DCX 90 DEG PUPIL DIAMETER VA
RIGHT
AGE 69
FIXATION LOSSES 0/24
FALSE POS ERRORS 0/15
FALSE NEG ERRORS 0/11
QUESTIONS ASKED 448
FOVEA: 33 DB
TEST TIME 13:38
HFA S/N 640-1067
30°
GLAUCOMA HEMIFIELD TEST (GHT)
WITHIN NORMAL LIMITS
TOTAL DEVIATION
PATTERN DEVIATION
PROBABILITY SYMBOLS
:: P < 5%
P < 2%
P < 1%
P < 0.5%
MD - 2.34 DB
PSD 1.98 DB
SF 1.03 DB
CPSD 1.59 DB
OPHTHALMOLOGY
MALMOE UNIVERSITY
HOSPITAL
HUMPHREY SYSTEMS

Figure 5-14b.

6

Neurological Visual Field Loss

Perimetry is often a simple and cost-effective method of making neurological diagnoses because the visual system occupies or passes through so much of the brain.

NEUROLOGICAL DISEASE is an important area for visual field testing. Before the advent of CT scanning and MRI, visual fields were often the best indicators of the location, and sometimes even the nature, of central nervous system disease. Even today perimetry is often a simple and cost-effective method of making neurological diagnoses. This is because the visual system occupies or passes through so much of the brain, from the optic nerve and chiasm to the optic radiation and visual cortex. When there is disease the resulting patterns of visual field loss are often specific for and vary with disease location. Modern practice emphasizes testing in the central field in assessing neurological visual field loss.

Neurological field loss has been shown in some cases to be more extensive when measured using static methods than with kinetic perimetry (Riddoch 1917), and thus static Humphrey perimetry may have some advantages over kinetic methods. Standard Humphrey perimetry also seems to identify neurological loss more reliably than perimetry based upon flickering stimuli (Johnson et al. 1998). SITA Standard has been found to be at least as

good as the older Full Threshold test in detecting optic neuropathies and hemianopias (Wall et al. 2001).

Optic Nerve Disease

As its name suggests, unilateral optic nerve disease produces field defects in the affected eye only. A central scotoma is the typical pattern of field loss for several types of optic nerve disease, e.g., optic neuritis *(figures 6-1a, 6-1b),* many toxic reactions, tobacco-alcohol amblyopia, and mechanical compression of the nerve. The size of the central defect varies, and reduced visual acuity is associated with larger scotomas. If the damage is small enough that visual acuity is still normal or only slightly depressed, the scotoma may be so small that sensitivity is only marginally depressed at some central points in the standard 30-2 or 24-2 test point patterns. Experience with computerized perimetry has shown, however, that optic neuritis can cause a large variety of visual field defects, some of which may even resemble those typical of glaucoma. Residual visual field defects remaining after an optic neuritis has resolved were seldom detected with manual perimetry, but they are frequently seen with computerized threshold perimetry; these include patterns with variable, mild, and multifocal depressions.

Anterior ischemic optic neuropathy results in sudden loss of visual function. The field loss is usually large with sizeable areas of absolute damage *(fig. 6-2)*. Many different patterns are possible, but altitudinal hemianopia is the most common. Just as with other hemianopias, those in optic nerve infarction are often not complete, and it is common to see areas with diminished function in the less affected hemifield as well.

Early phase optic disc edema produces only an enlargement of the blind spot, which becomes surrounded by a zone of relative loss of sensitivity *(fig. 6-3)*. This is of little diagnostic interest, since the diagnosis is usually made with ophthalmoscopy and not with perimetry. Patients

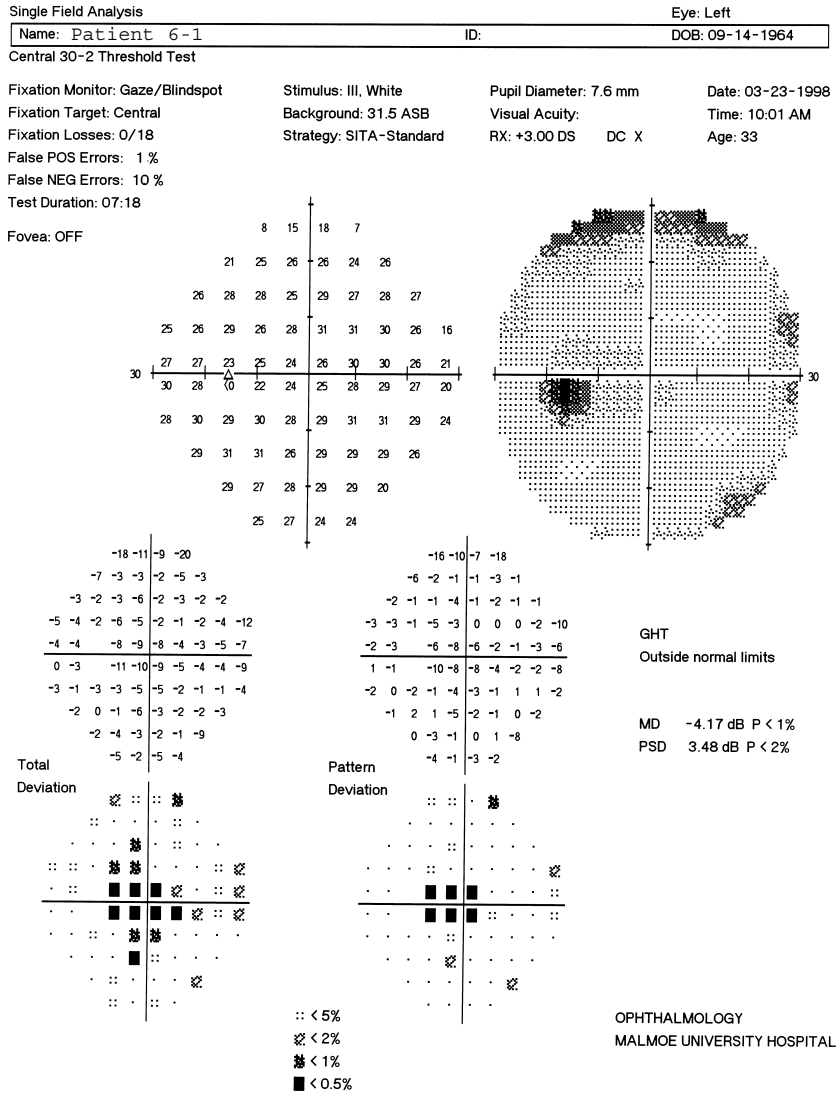


Figure 6-1a. Visual field of a 34-year-old patient with optic neuritis OS, and best corrected visual acuity of 20/80. Color vision testing was grossly abnormal, and the VEP examination of the left eye showed considerably decreased amplitudes and increased latency. The field shows significant reduction of sensitivity in paracentral points.

Figure 6-1. Optic neuritis

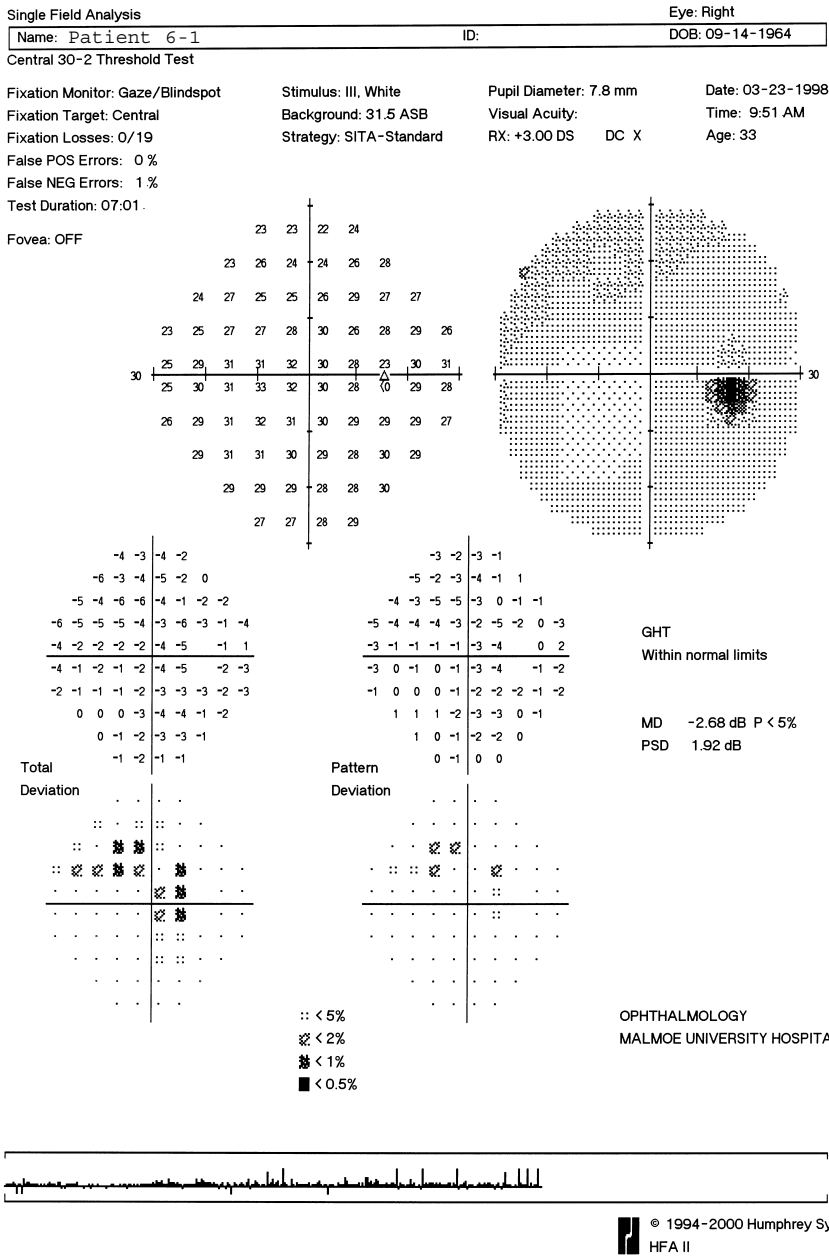


Figure 6-1b. Mild resolution defects after earlier optic neuritis in the right eye of the same patient as shown in Figure 6-1a. Visual acuity was 20/20-.

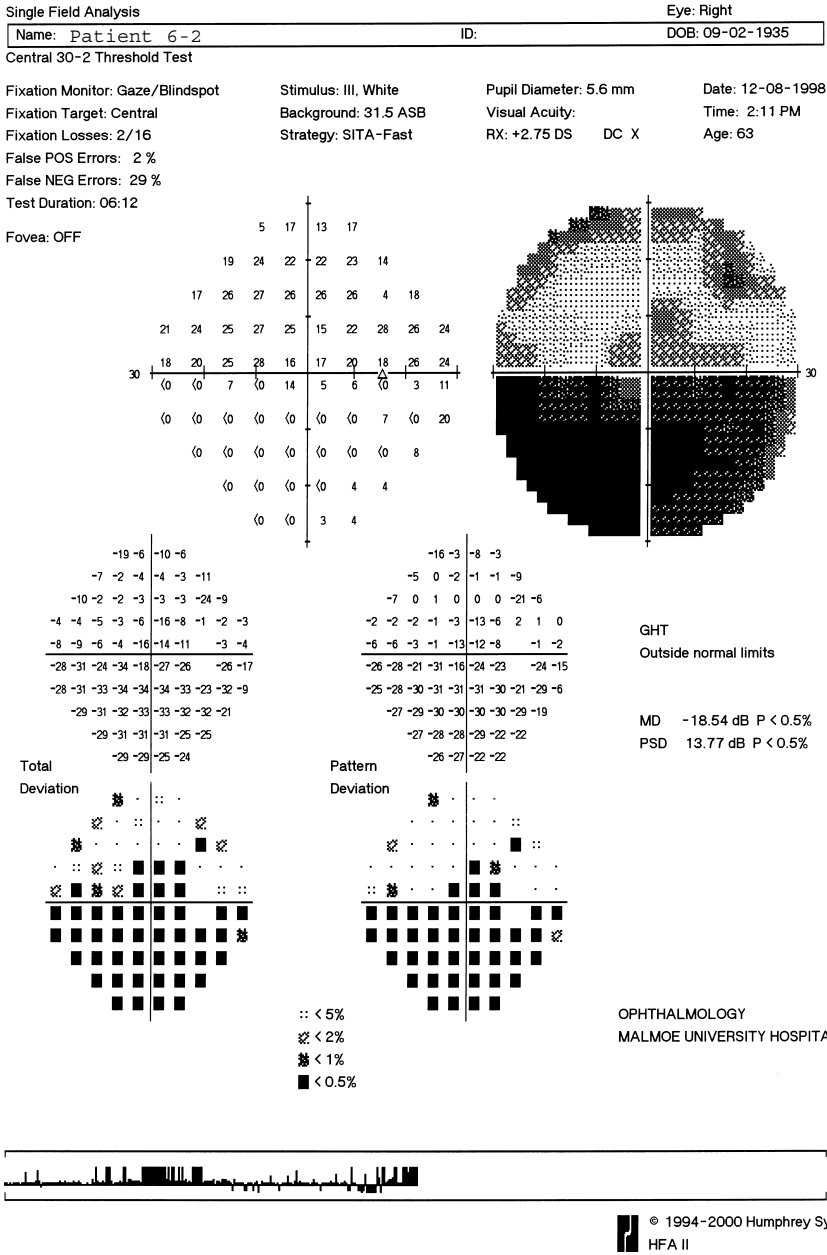


Figure 6-2. Acute ischemic optic neuropathy with typical altitudinal visual field loss. The patient was a 63-year-old woman who suddenly perceived a shadow in the lower field of the right eye, four or five days before seeking professional care. Ophthalmoscopy showed a swollen disk with some hemorrhages, and generally narrowed arterioles. During follow-up, the papilledema resolved, but the visual field defect remained unchanged.

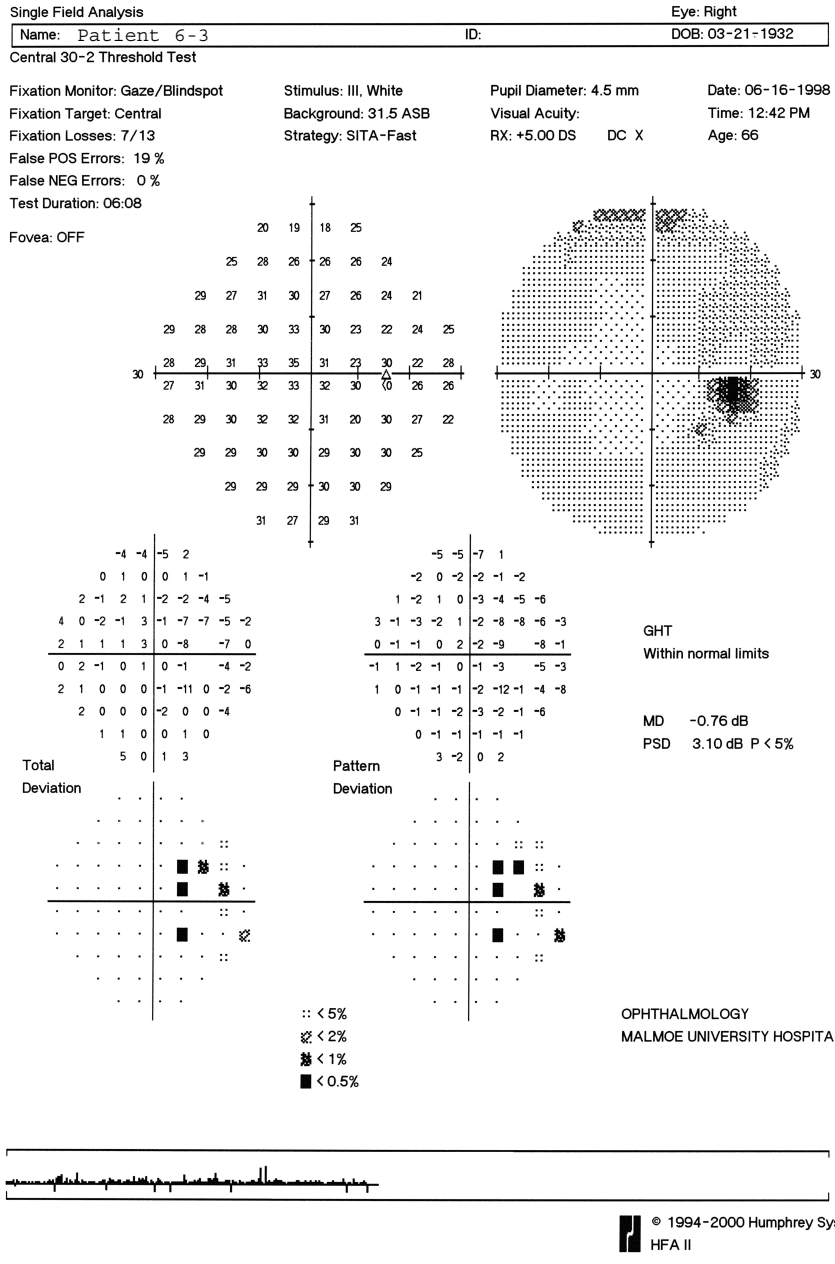


Figure 6-3. Enlarged blind spot caused by optic disk edema in a 66-year-old woman with benign intracranial hypertension. A few points around the blind spot show significantly depressed sensitivity values.

with optic disc edema should be regularly monitored with visual field testing, however, because longstanding optic disc edema can produce secondary optic atrophy, a serious condition that may lead to blindness if left untreated. Perimetry will show field loss in such cases, usually beginning in the nasal field *(fig. 6-4)*. Threshold tests using the 30-2 and 24-2 patterns are suitable for following these patients.

Drusen of the optic disk produces arcuate defects that may be indistinguishable from those caused by glaucoma *(fig. 6-5)*.

Serious thyroid ophthalmopathy causes field defects because of optic nerve involvement. Such defects occur primarily in the nasal field but are quite variable and, in contrast with glaucomatous defects, they will usually regress or even disappear upon successful treatment of the ophthalmopathy *(figures 6-6a, 6-6b)*.

Lesions of the Optic Chiasm

The optic chiasm may be damaged by pituitary adenomas, craniopharyngiomas, suprasellar meningiomas, or sometimes by aneurysms coming from the arterial circle of Willis. Crossing fibers are usually affected first, resulting in bitemporal hemianopias. In the beginning, defects caused by infrachiasmal lesions may be limited to the superior part of the hemifield, sometimes with wedge-like defects, which respect the vertical meridian. The involvement is often asymmetrical, with more damage occurring in one eye. With time, the defects grow and can become complete *(figures 6-7a, 6-7b)*, or even involve the nasal hemifield. Resolution defects—i.e., defects remaining after surgery or other treatment—can spare the most central field while being clearly visible in the midperiphery, i.e., in the peripheral two rings of the test points in 30-2 pattern *(figures 6-8a, 6-8b)*.

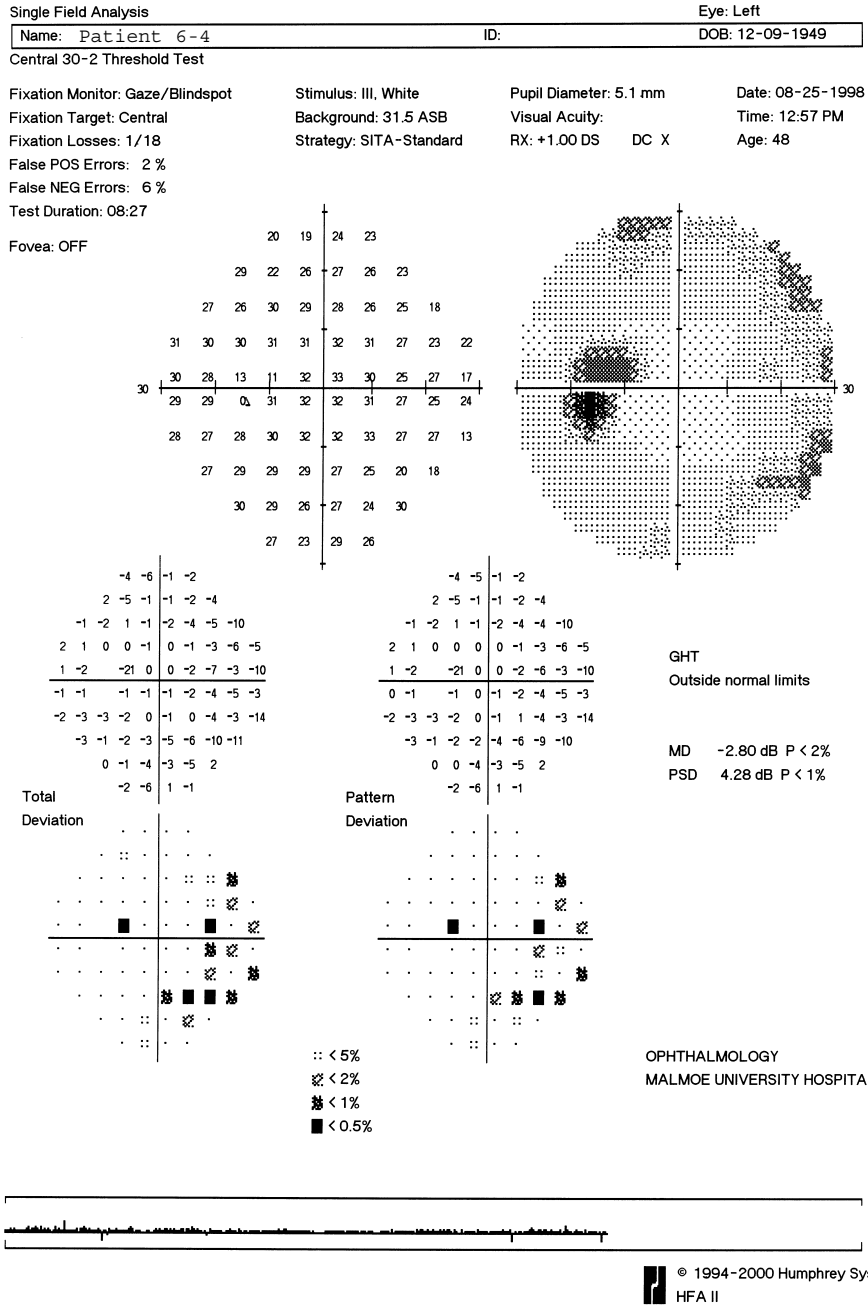


Figure 6-4. Early secondary optic atrophy in a patient with longstanding papilledema. Testing shows shallow, predominately nasal field defects.

Post-Chiasmal Lesions

Post-chiasmal disease of the optic pathways results in homonymous hemianopic defects, i.e., matching defects in the same hemifield of both eyes. Matching defects in the left half of both visual fields would be an example. Such hemianopic defects tend to respect the vertical meridian even if they affect only part of the hemifield, e.g., hemianopic wedge-like defects, quadrantanopias, and homonymous hemianopic scotomas *(figures 6-9a–6-9d and 6-10a, 6-10b)*. A large lesion involving all postchiasmal nerve fibers whether it is found in the optic tract, the lateral geniculate body, the optic radiation, or the whole visual cortex on either the left or the right side of the brain will lead to a complete homonymous hemianopia.

If parts of the hemifields are spared, the congruity of defects may be used to help localize the lesion. Postchiasmal visual field defects are more congruous when they are caused by lesions situated further back toward the occipital lobe visual cortex. Damage to the visual cortex should, in principle, result in perfectly congruous defects in the two eyes *(figures 6-11a, 6-11b)*.

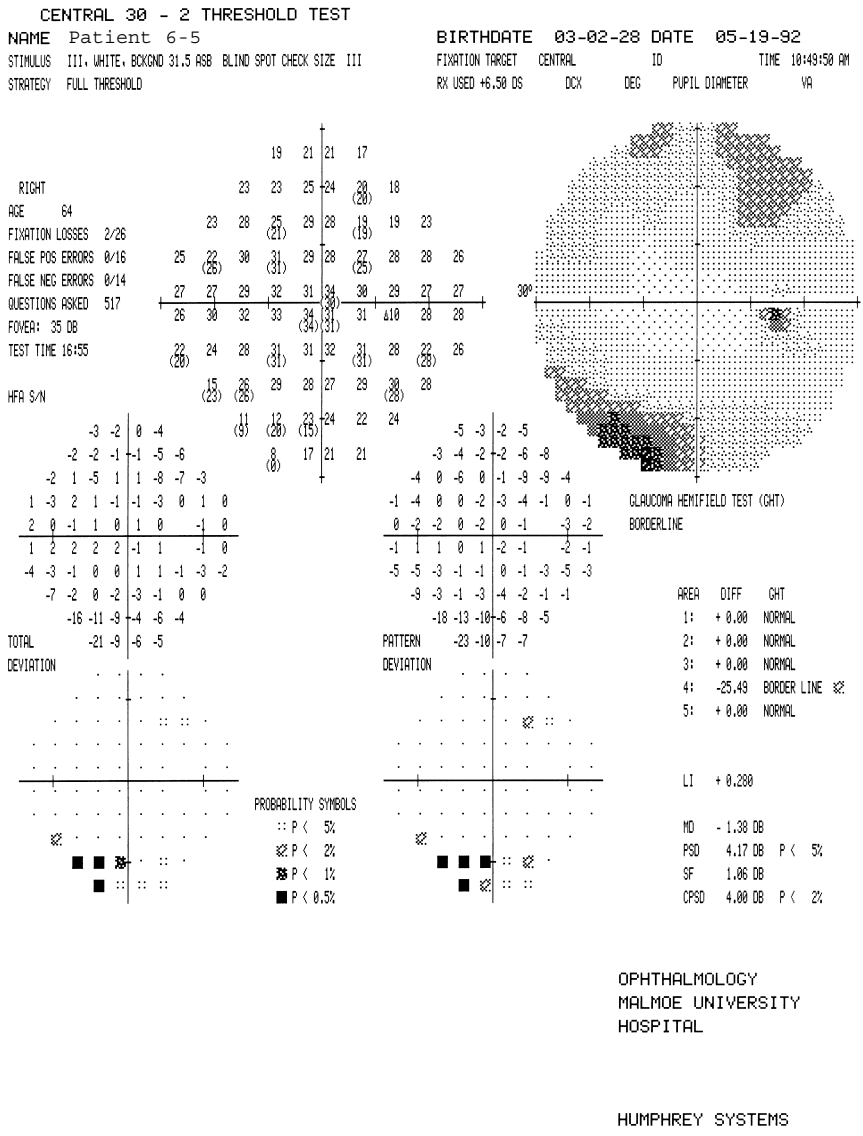


Figure 6-5. Visual field defect in an eye with optic disk drusen

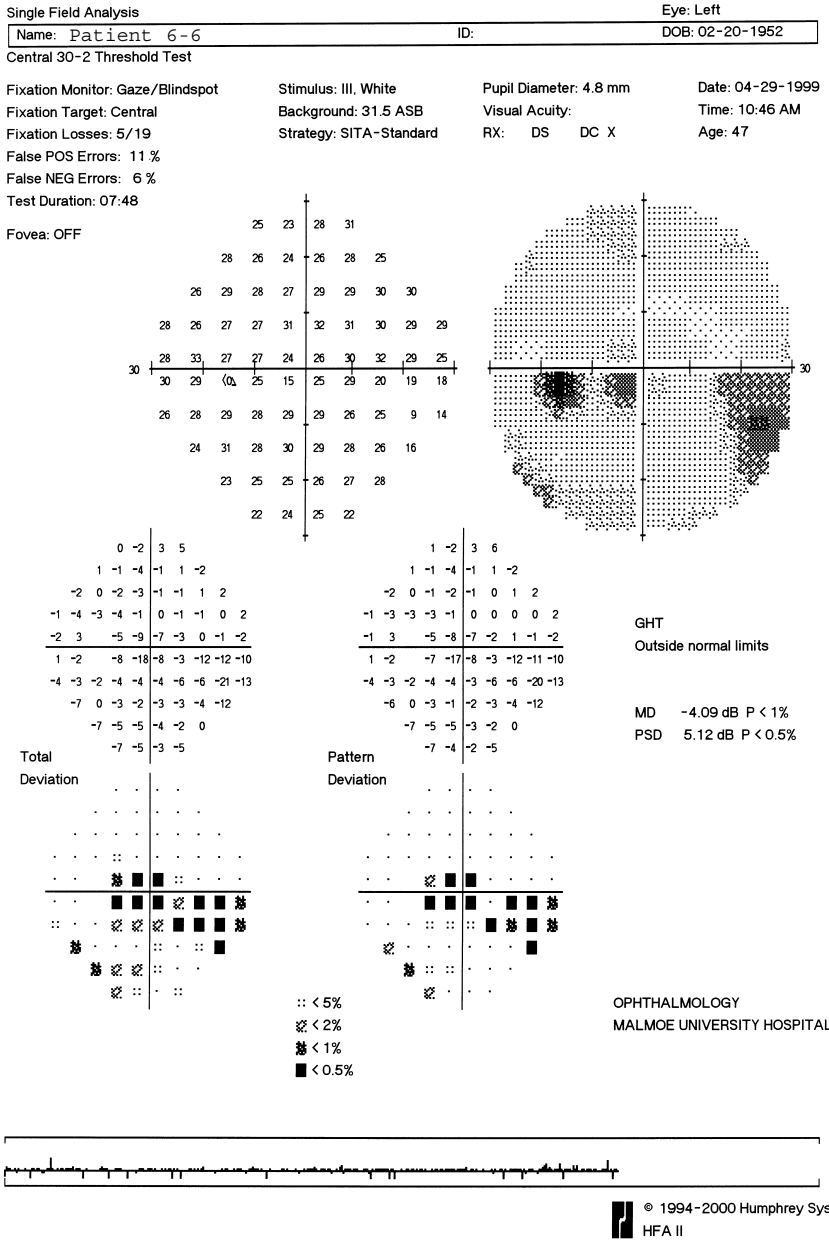


Figure 6-6a. Left eye

Figure 6-6. Bilateral field loss with absolute sensitivity loss OD in a 47-year-old woman with advanced steroid-treated thyroid ophthalmopathy. Exophthalmometry showed 26 mm OD and 25 mm OS. Visual acuities were 20/30 OD and 20/20 OS. Both optic disks were slightly edematous.

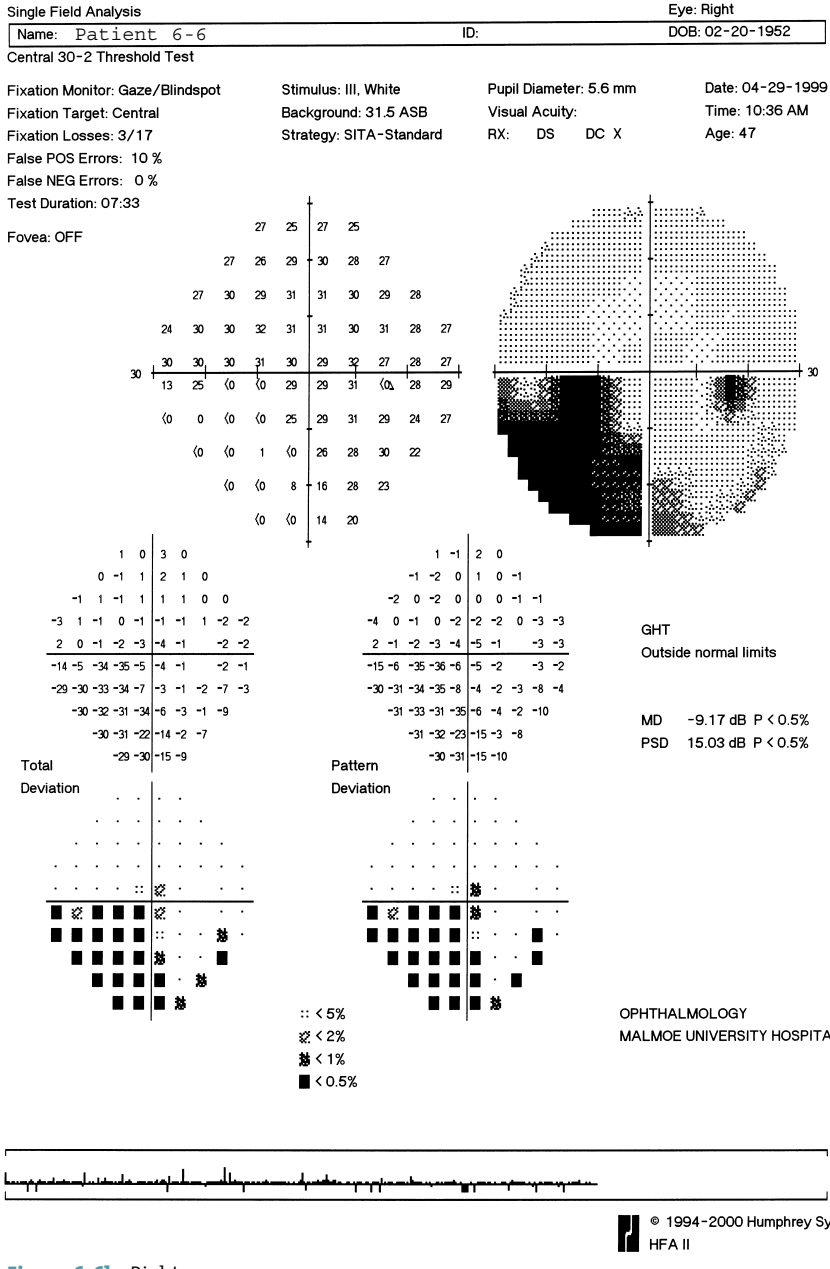


Figure 6-6b. Right eye

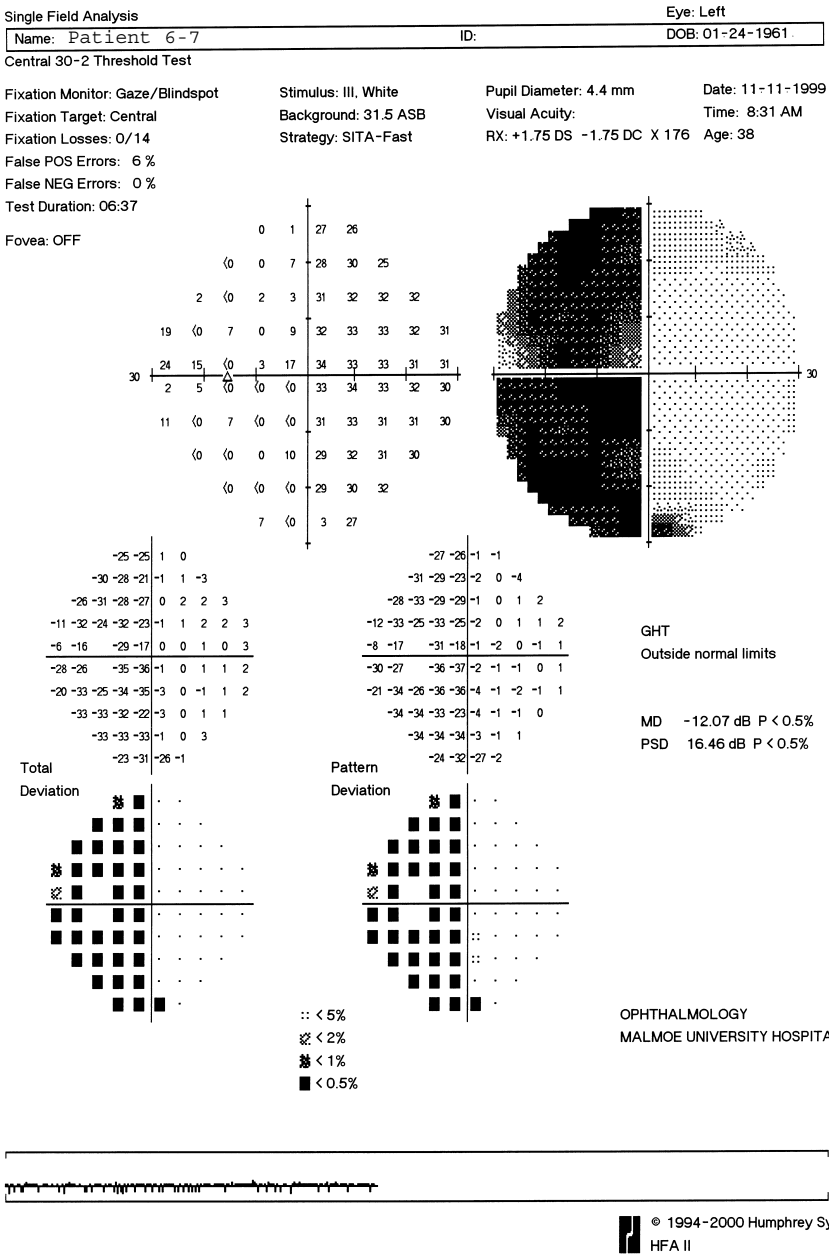


Figure 6-7a. Left eye

Figure 6-7. Thirty-eight-year-old woman with nearly complete bitemporal hemianopia secondary to cystic pituitary adenoma. Patient had noticed reduced vision for one year prior to presenting for care; visual acuities were 20/30 OD and 20/40 OS.

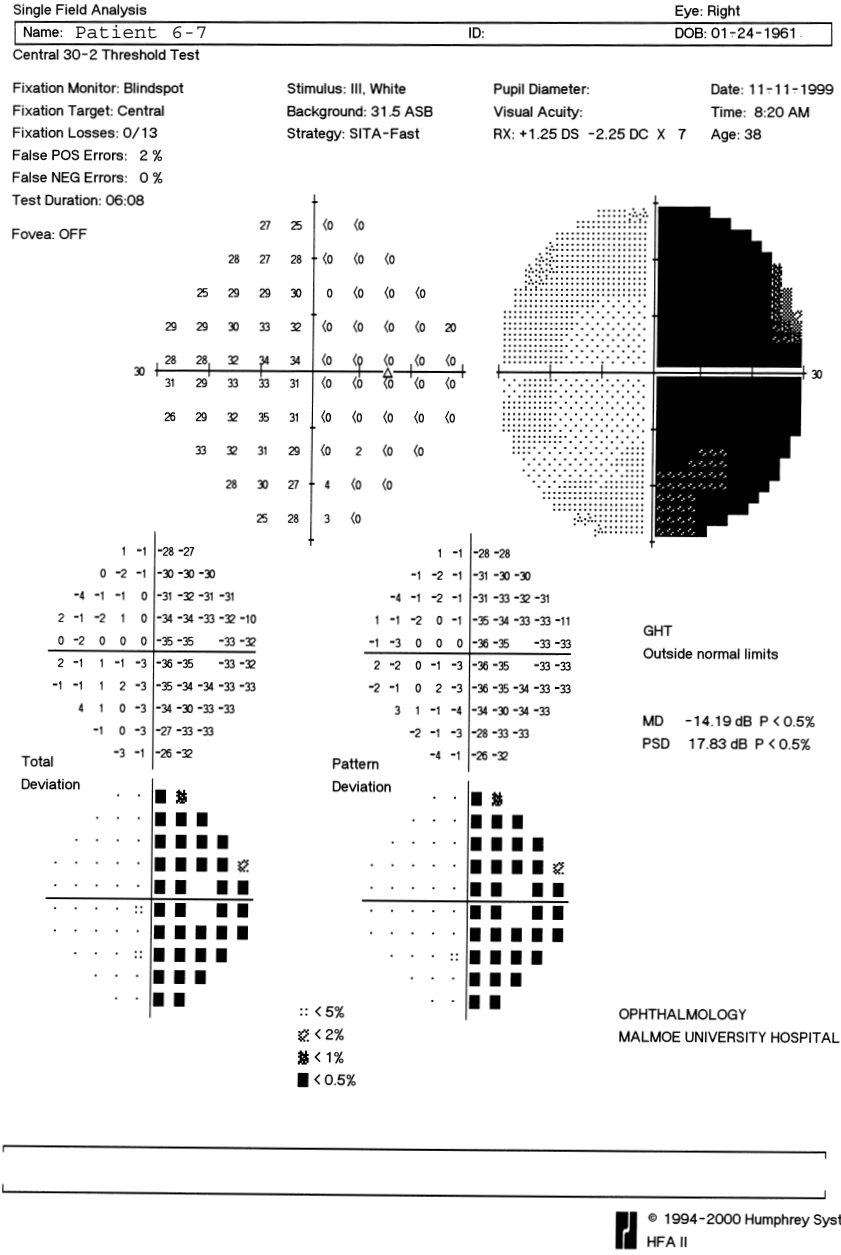


Figure 6-7b. Right eye

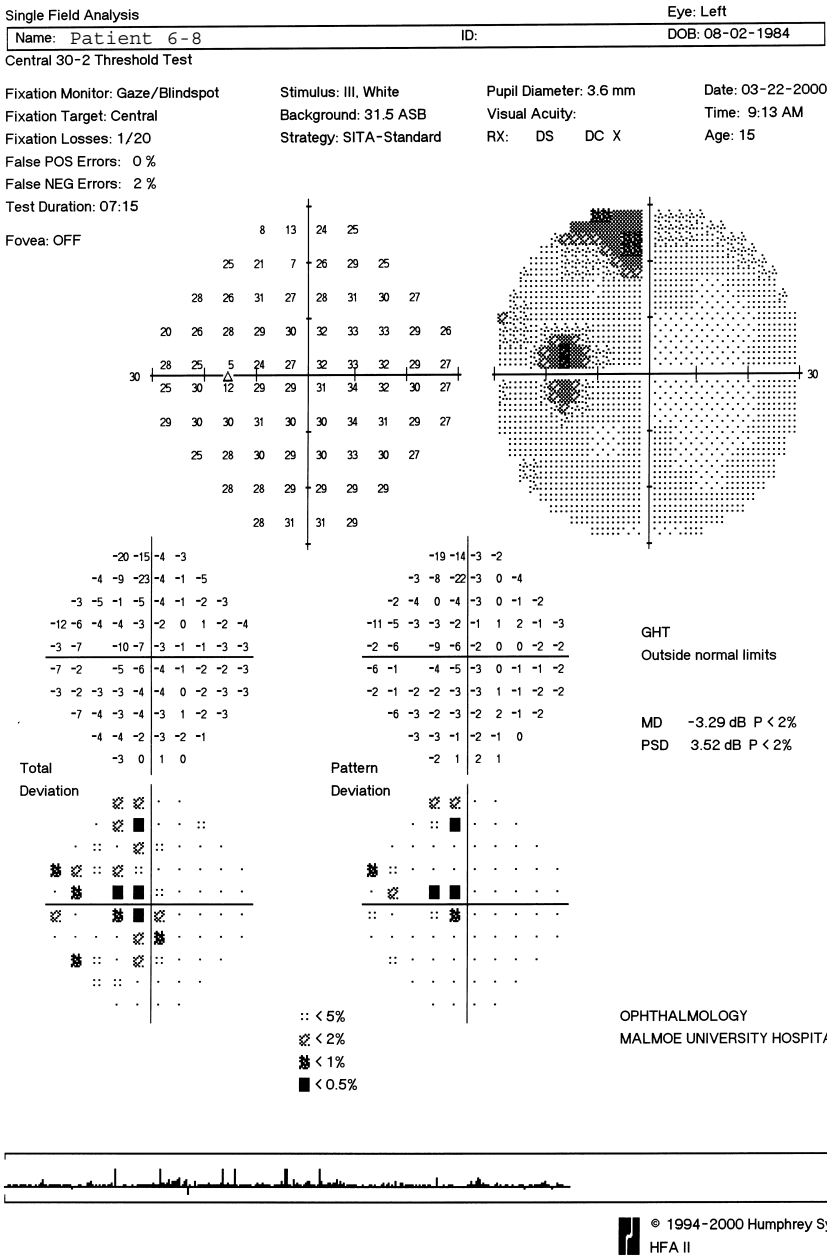


Figure 6-8a. Left eye

Figure 6-8. Bitemporal resolution defects in a 15-year-old girl. The patient had undergone surgery for craniopharyngioma several years prior to these field tests.

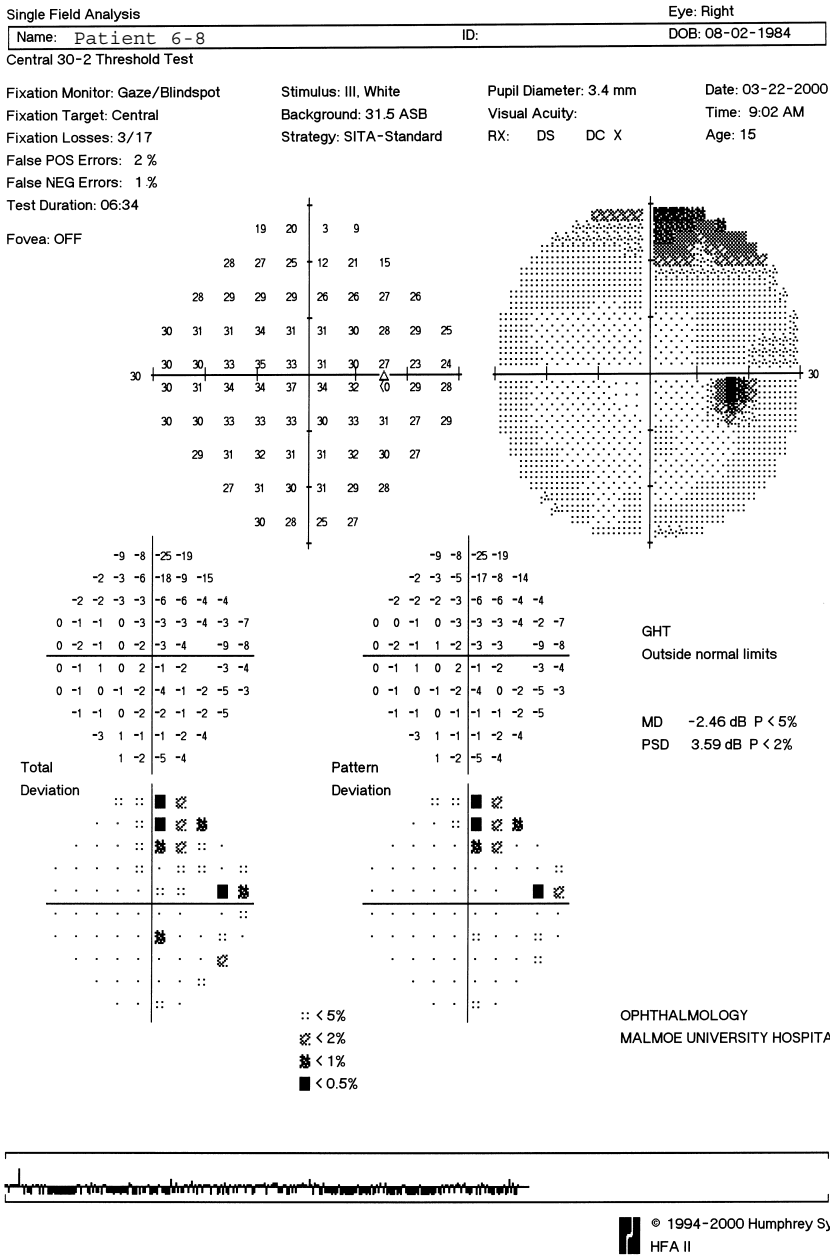


Figure 6-8b. Right eye

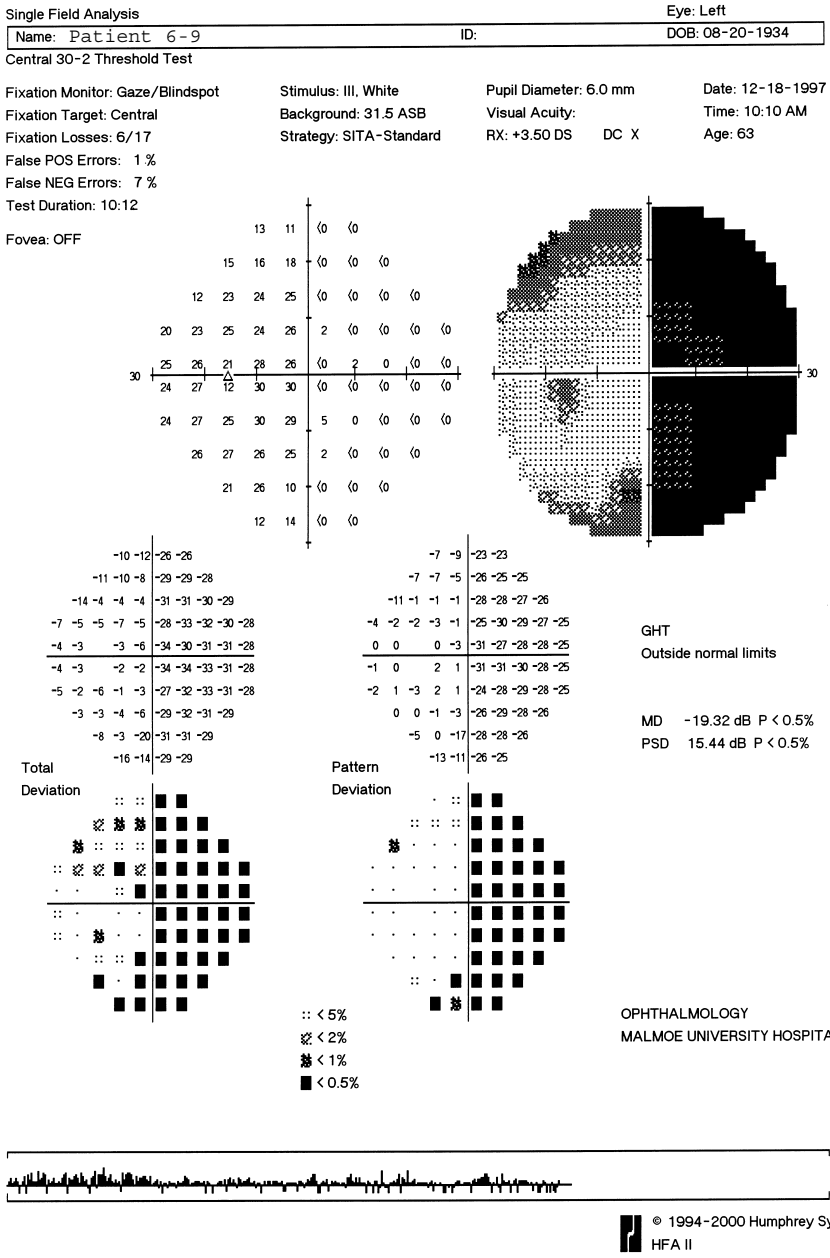


Figure 6-9a. Deep hemianopic defects, left eye. Initial testing showed right homonymous hemianopia secondary to occipital lobe hemorrhage.

Figure 6-9. Baseline and follow-up testing in a patient with homonymous visual field loss

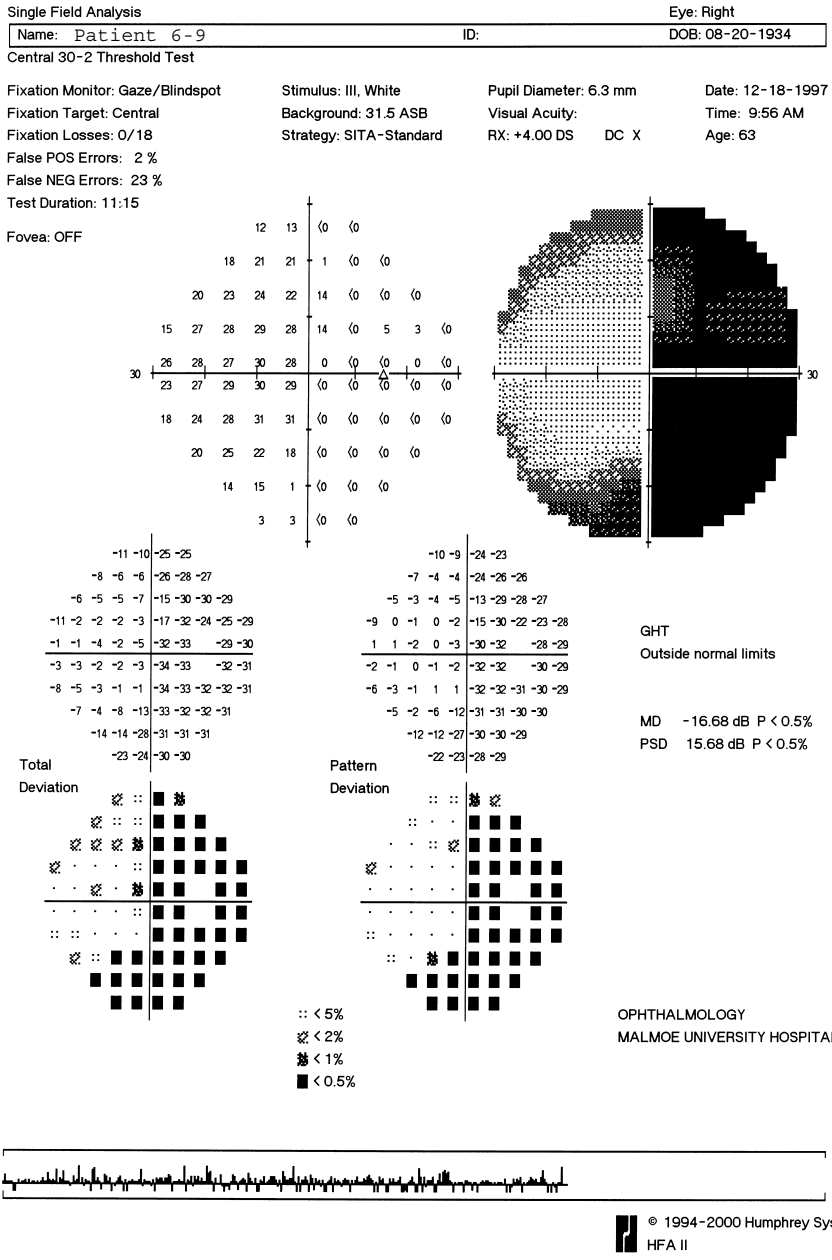


Figure 6-9b. Right eye

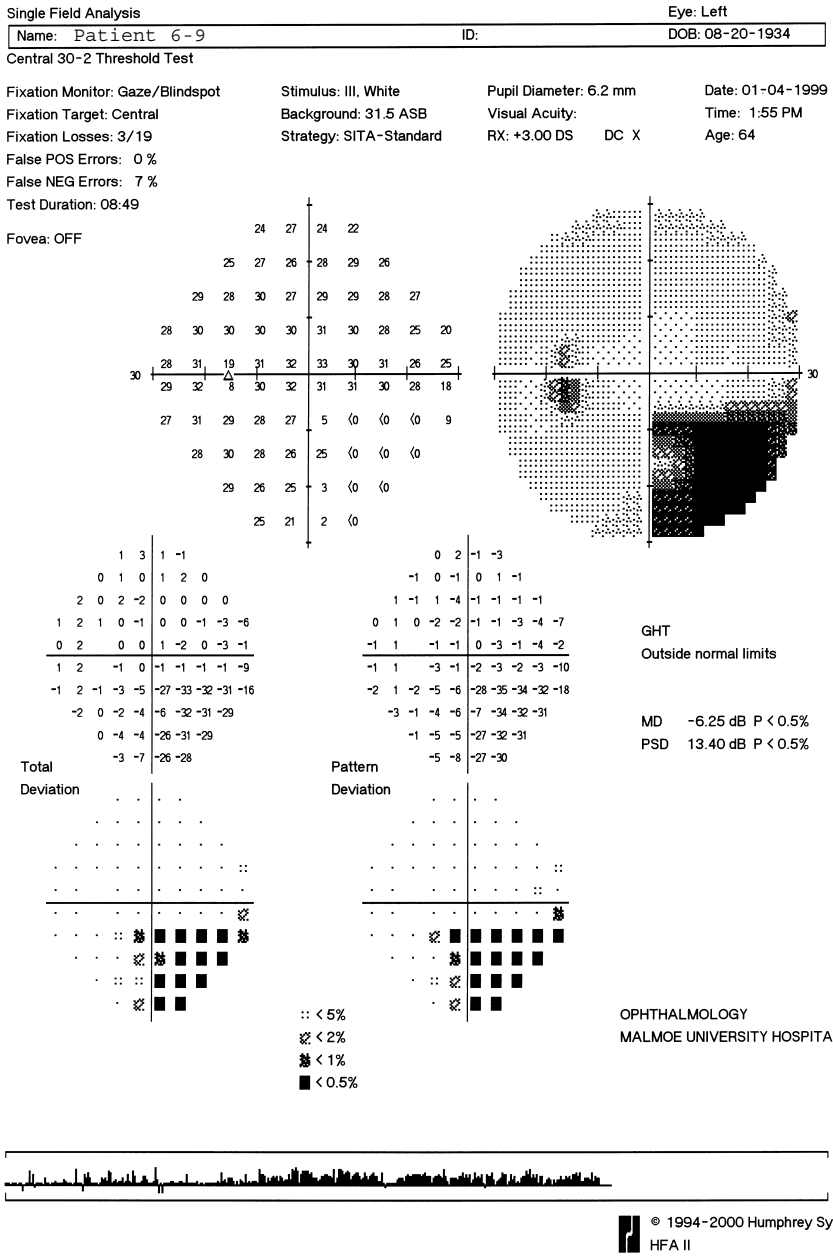


Figure 6-9c. Left eye. Follow-up testing 13 months later showed resolution to a right inferior quadrantanopia.

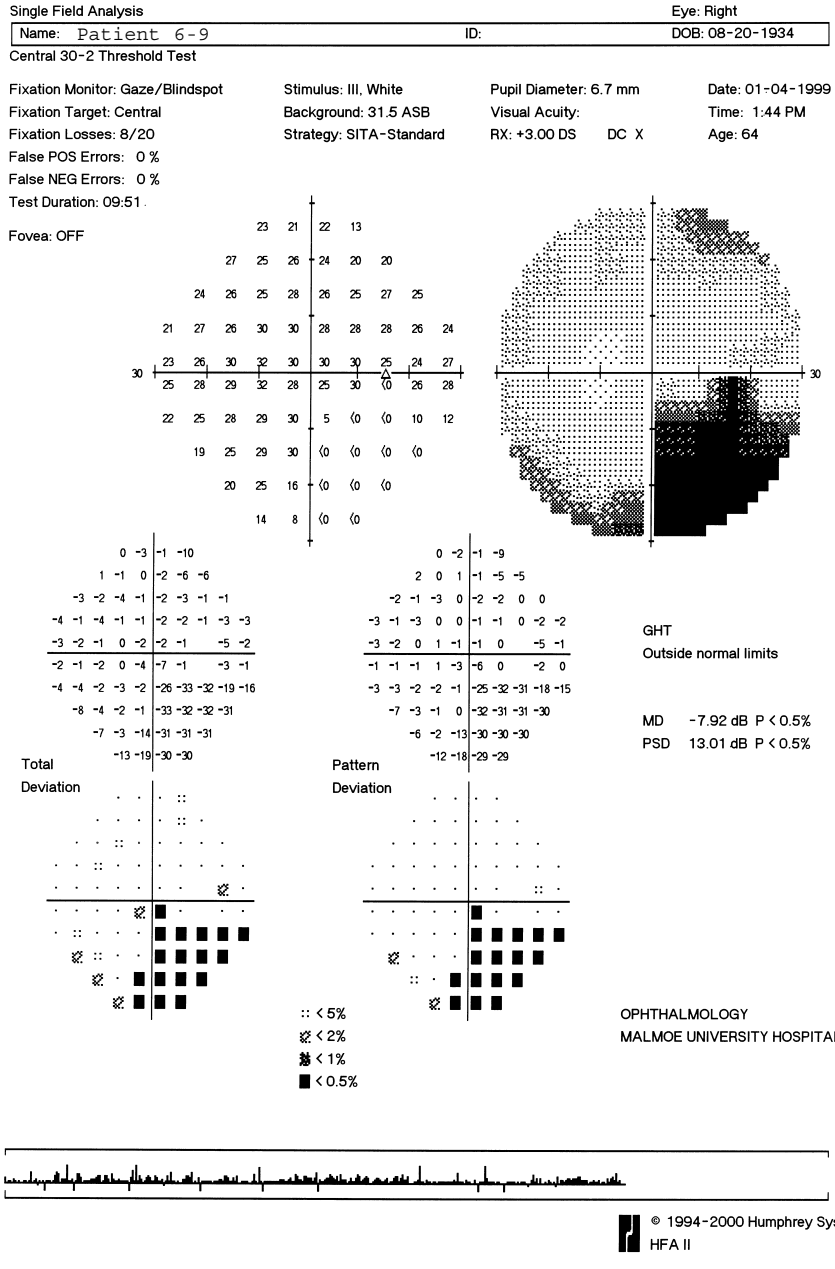


Figure 6-9d. Right eye

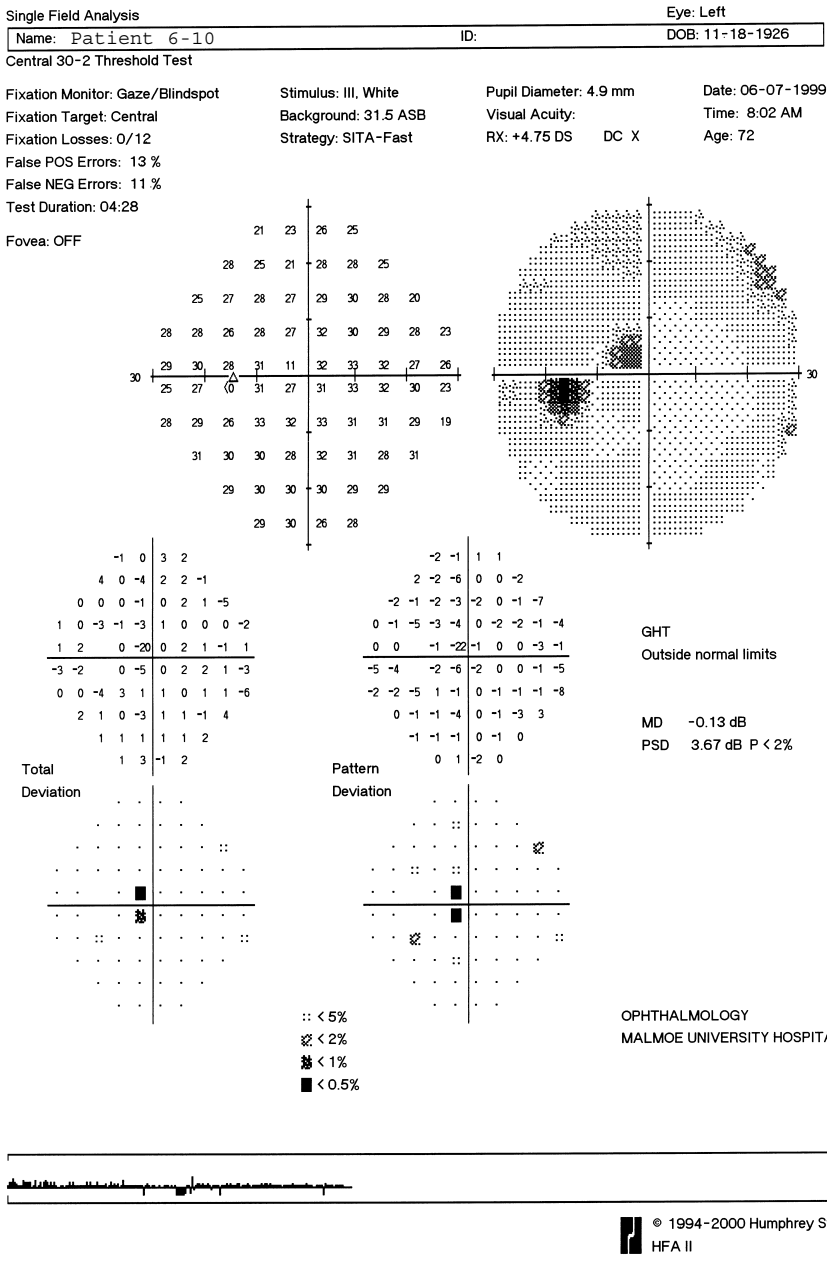


Figure 6-10a. Left eye

Figure 6-10. Homonymous hemianopic scotomas in a 72-year-old man. The patient suddenly noticed decreased vision on the left side in conjunction with a coronary angiography.

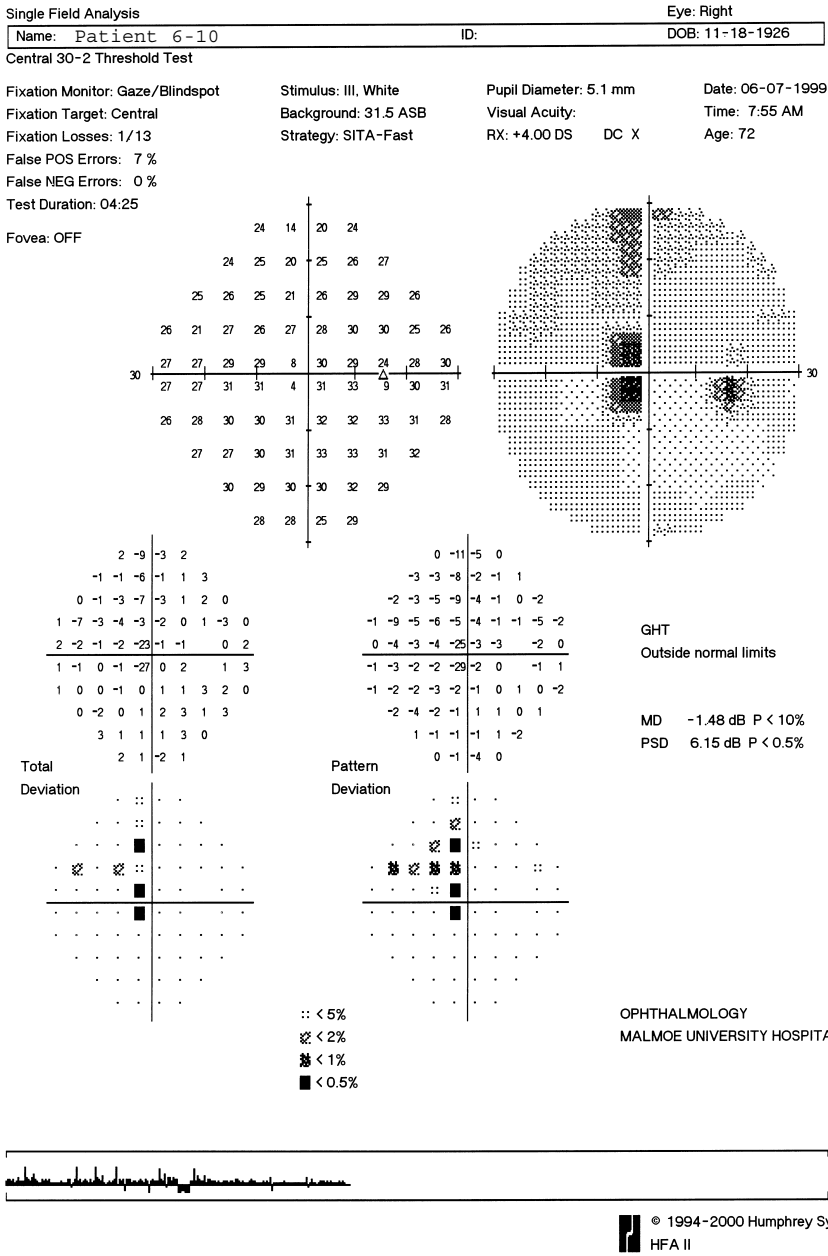


Figure 6-10b. Right eye

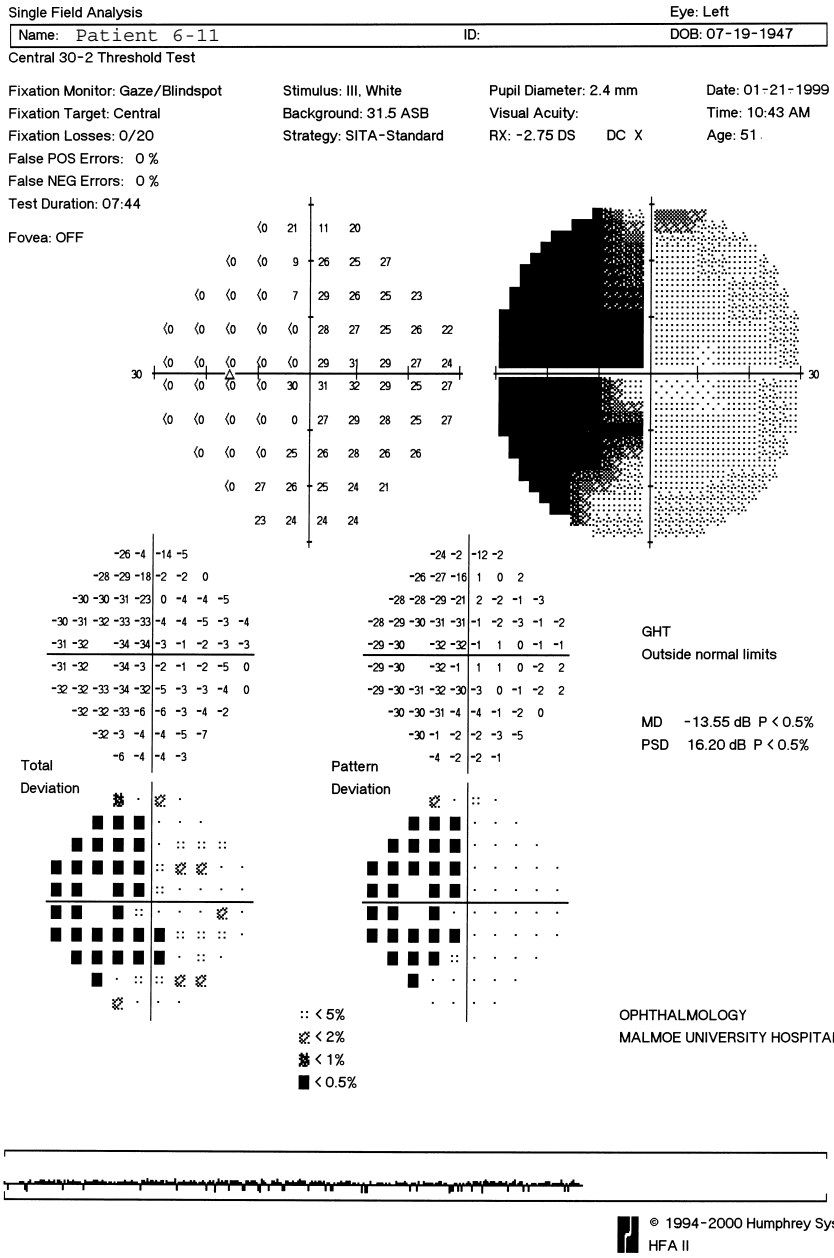


Figure 6-11a. Left eye

Figure 6-11. Highly congruous left homonymous hemianopia in a 51-year-old man, secondary to a 2 cm metastasis in the right occipital lobe from prostatic carcinoma.

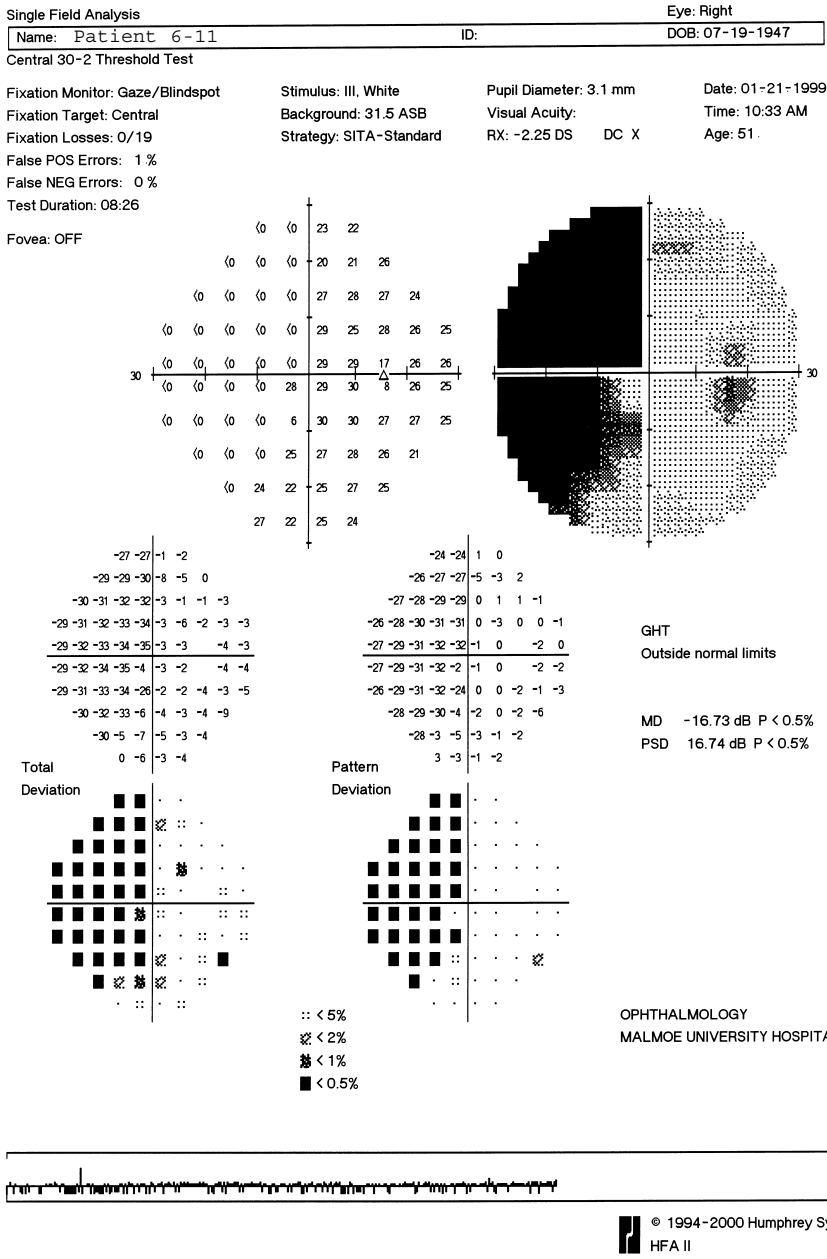


Figure 6-11b. Right eye

7

Visual Field Loss in Retinal Diseases

DOCTORS RELY PRIMARILY on ophthalmoscopy in diagnosing or monitoring retinal disease because most lesions are visible on ophthalmoscopy. Nevertheless, it is important to have some knowledge of the visual field defects caused by retinal lesions. Sometimes retinal disease can be identified because of field defects found accidentally. Often, several diseases coexist in the same eye, e.g., glaucoma and retinal disease, and it becomes important to determine whether encountered field loss is caused by one disease or the other.

A common field defect caused by retinal disease is the central scotoma associated with age-related macular degeneration. Just a few affected test point locations may be identified in many cases if a standard grid with 6 degree resolution is used *(fig. 7-1)*. A higher density 10-2 test will show a more detailed picture. Patients with macular degeneration or central vision loss caused by other disease should be tested with the large diamond fixation target if they are having difficulty seeing the standard fixation LED.

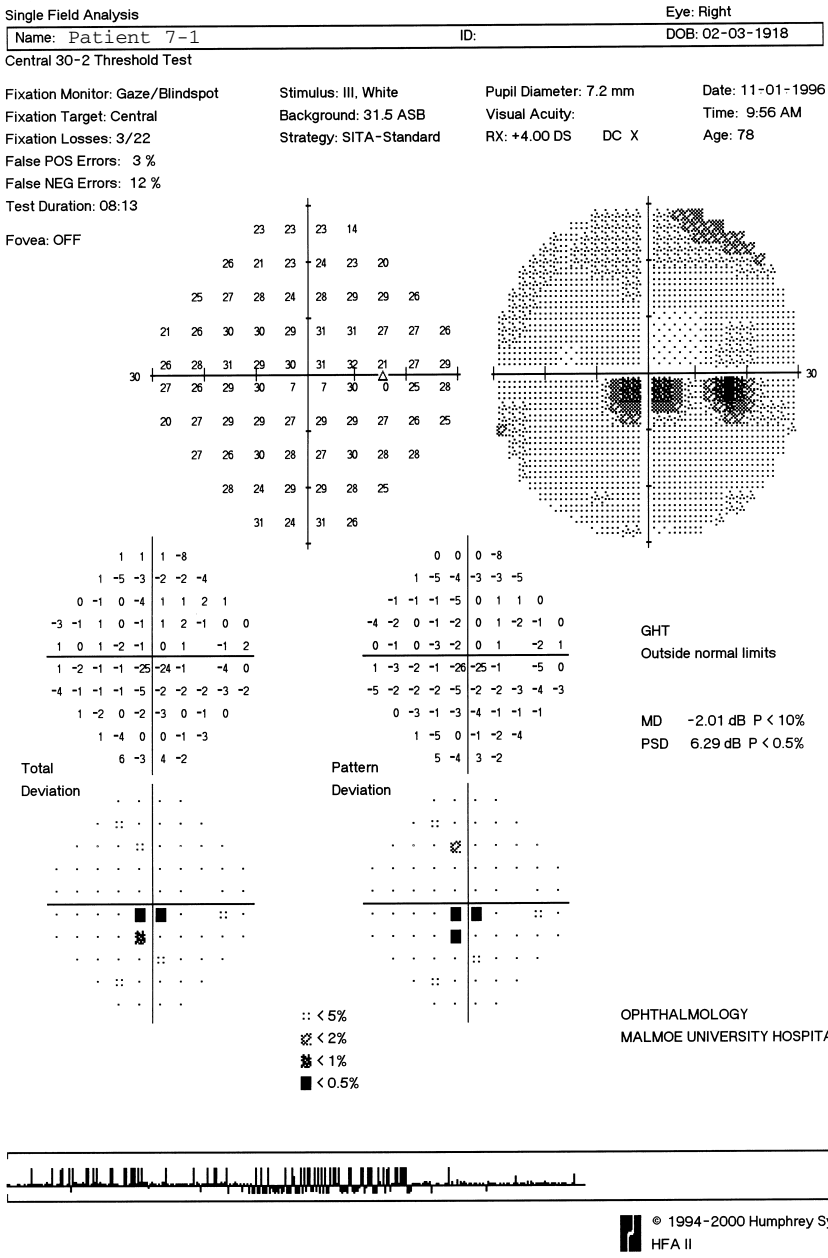


Figure 7-1. Central scotoma due to exudative age-related macular degeneration in a 78-year-old woman. Visual acuity was 20/200-.

Central serous retinopathy also results in reduced central visual function, and therefore in central scotomas. Visual acuity is often only moderately reduced, and the resulting field loss may be discrete and visible only on probability plots *(fig. 7-2)*.

Retinochoroiditis may cause arcuate or wedge-like defects that can be mistaken for glaucomatous lesions *(fig. 7-3)*. The cause of the problem becomes clear, of course, when lesions are seen during ophthalmoscopy. The visual field findings themselves offer some clues which may help refine the diagnosis. Field defects caused by retinal lesions are frequently deep and have sharp borders, and they tend to show much less variability from test to test than glaucomatous lesions of the same extent.

Field loss from diabetic retinopathy is, on the other hand, often relative and multifocal, giving the field a "mottled" appearance. Mild background retinopathy usually shows no field loss at all in standard perimetric testing using white targets; only in moderate and more advanced stages, 43 and higher in the ETDRS final scale, should one expect defects *(fig. 7-4)* (Henricsson and Heijl 1994). SWAP testing will usually show larger field loss than standard white-on-white perimetry in eyes with more than background diabetic retinopathy (Hudson et al. 1998a; 1998b) *(figures 7-5a, 7-5b)*.

Retinal detachments and retinoschises cause field defects, but since such defects are usually located in the peripheral field, they are often not seen in conventional tests involving the central 30 degree field. The central borders of the defects may be visible in the midperiphery, however. Retinal detachments then typically cause relative defects, while retinoschises naturally produce absolute defects with sharp borders because the inner and outer retinal layers are split apart.

Perimetry is also of value in diagnosing retinal degenerative diseases such as retinitis pigmentosa. Typical field loss in this disease is circular and initially located in the

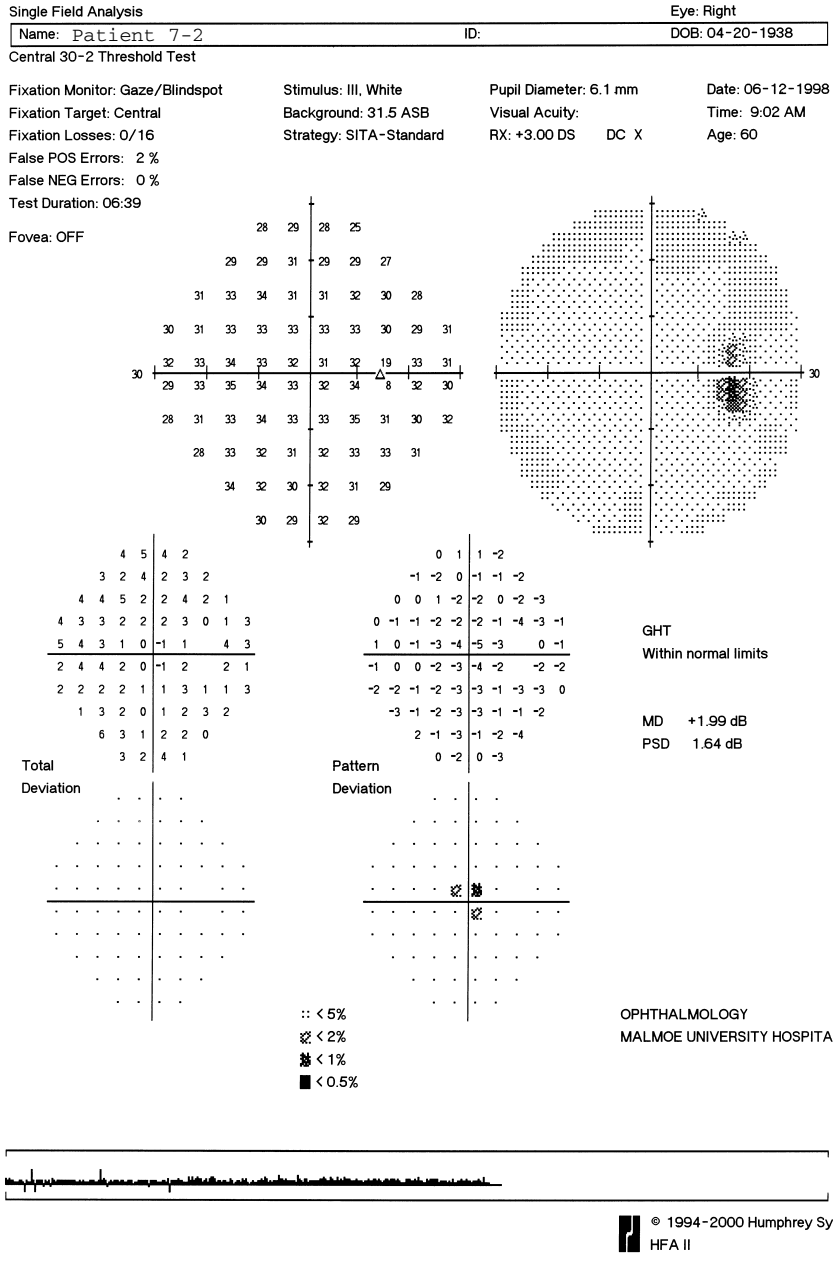


Figure 7-2. Mild reduction in visual field sensitivity secondary to central serous retinopathy is apparent only in the pattern deviation plots in this SITA Standard test taken by a 60-year-old man. Visual acuity was 20/60.

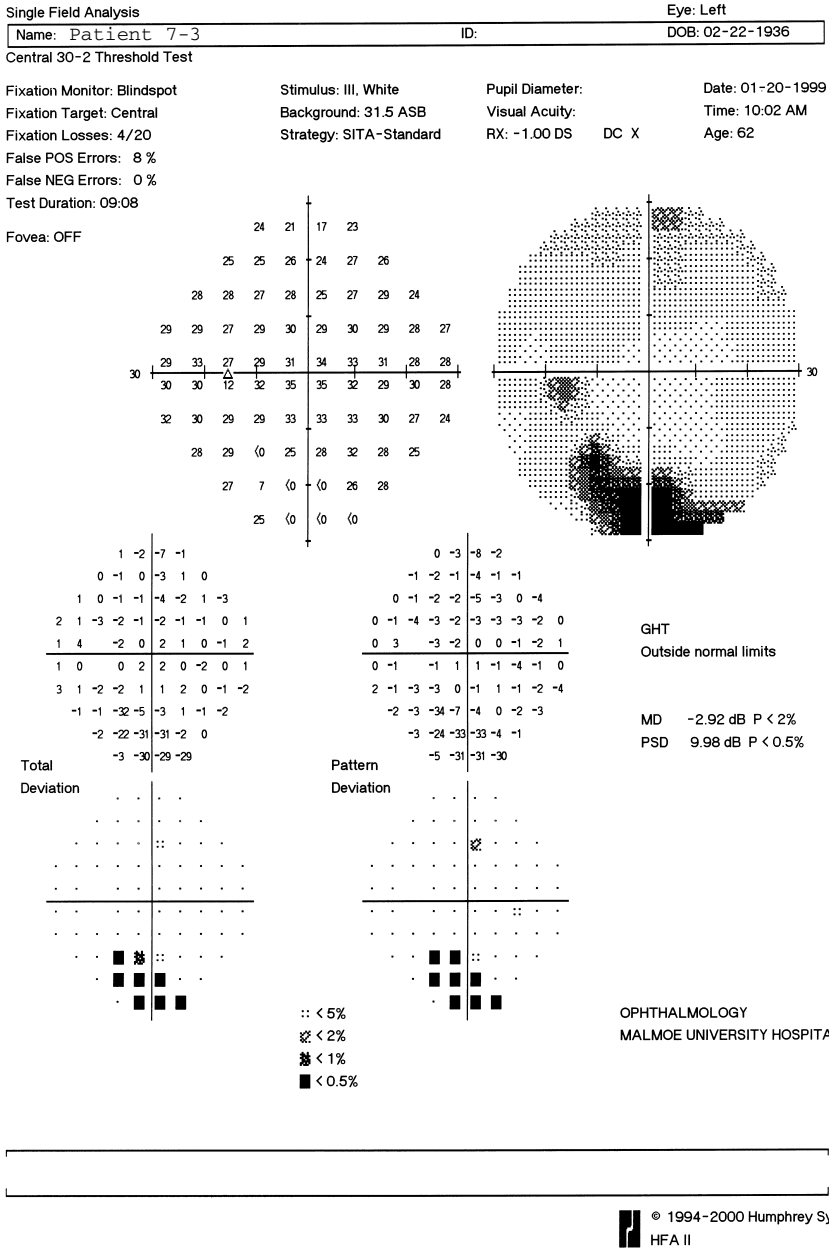


Figure 7-3. Old peripapillary retinochoroiditis, with a deep arcuate defect following the course of the retinal nerve fiber layer. Most defective points show absolute sensitivity loss.

midperiphery, but can progress to tunnel vision. Therefore, searching for visual field loss caused by retinitis pigmentosa is one of the few clinical situations where a standard threshold test using the 30-2 or 24-2 targets may be a good, but not the best, choice. A suprathreshold test that includes the peripheral field could be preferable, particularly because field defects there are often deep and easily identified.

Of course, retinal vascular occlusions are primarily diagnosed with ophthalmoscopy, but it is important when following patients with glaucoma to recognize that retinal vascular disease can cause field defects *(refer ahead to fig. 8-6b)*. Arterial occlusions typically result in absolute field defects, while venous occlusions produce highly variable field loss. Thus, eyes with small branch vein occlusions may have entirely normal fields, while central vein occlusions may sometimes be associated with profound and widespread field loss.

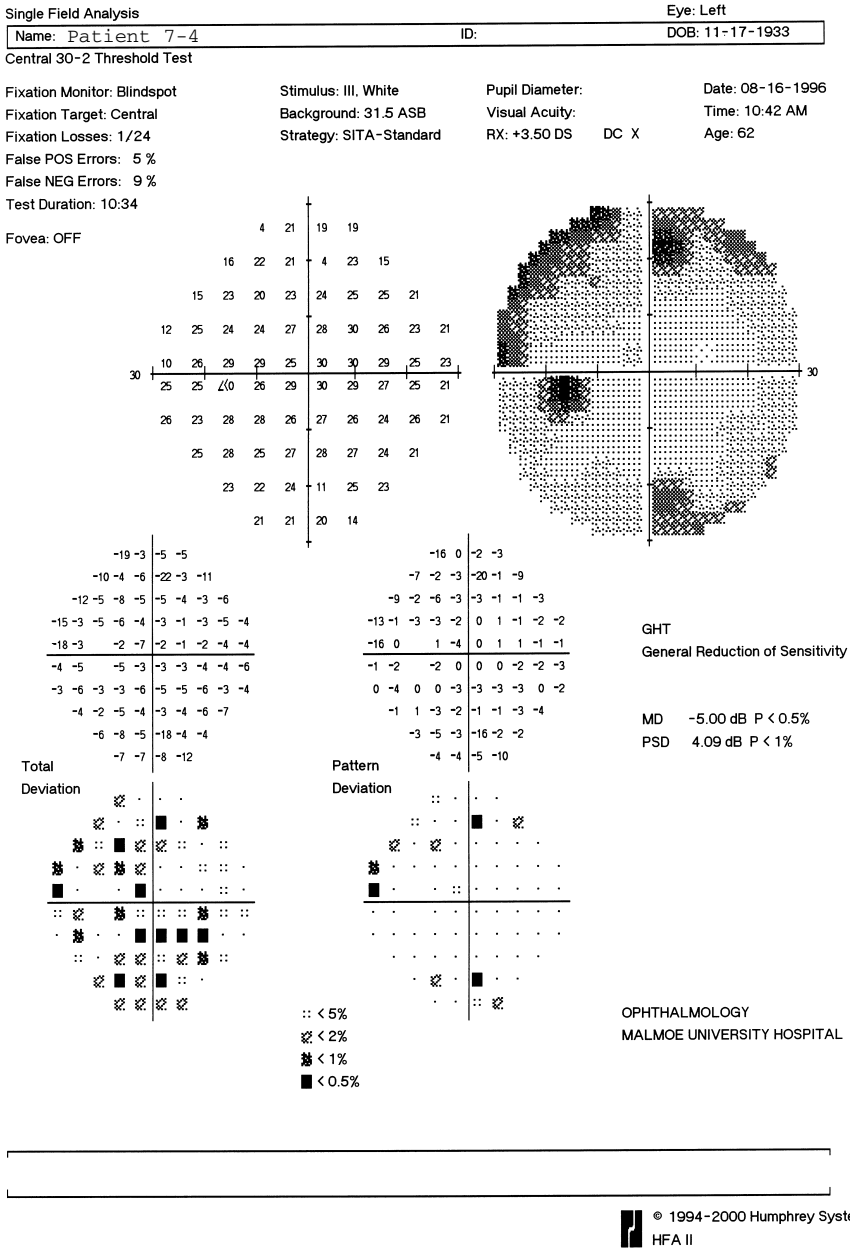


Figure 7-4. Visual field from a 62-year-old woman with diabetic retinopathy. The field shows a mottled pattern of loss, with an overlying generalized depression secondary to concomitant posterior sub-capsular cataract.

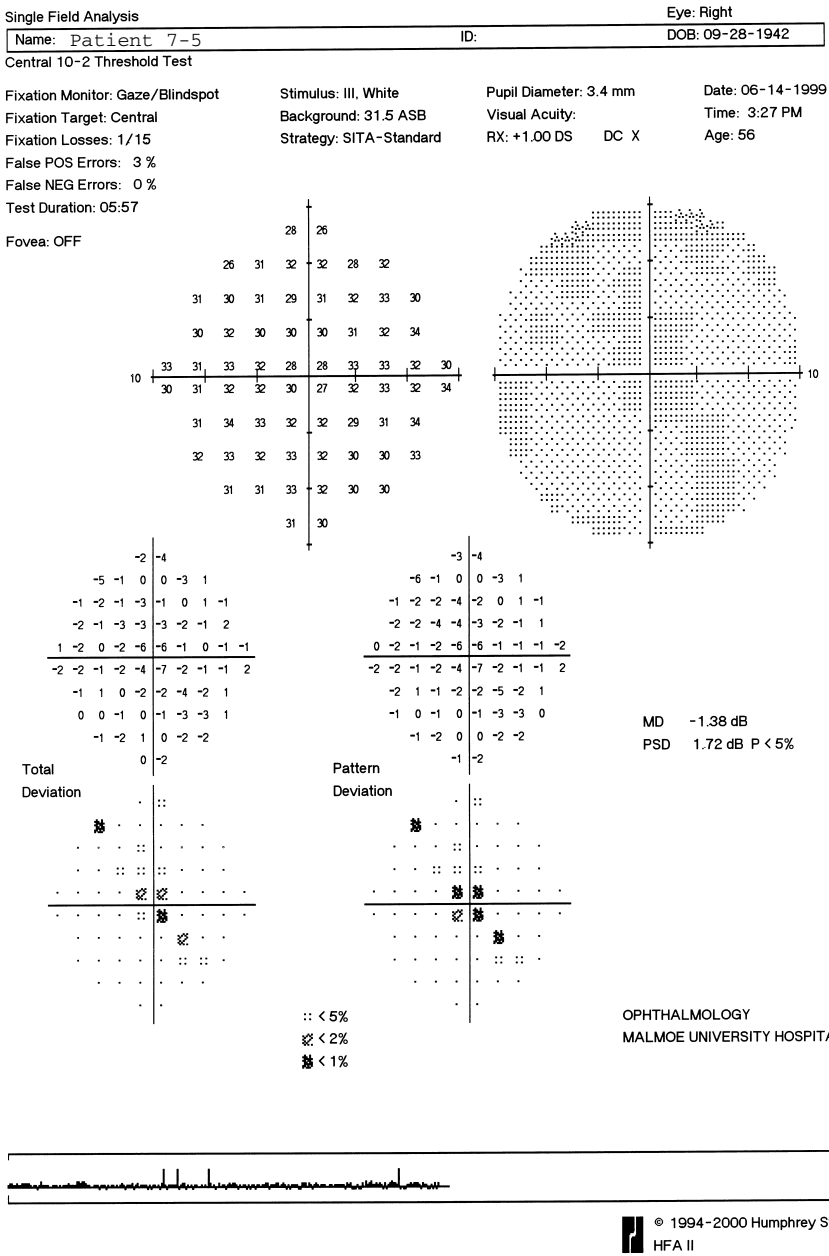


Figure 7-5a. Standard white 10-2 field showing mild central depression in clinically significant macular edema in an insulin-dependent 56-year-old patient with diabetes and systemic hypertension. Visual acuity was 20/20.

Figure 7-5. A comparison of SWAP and white-on-white testing in a patient with diabetic macular edema

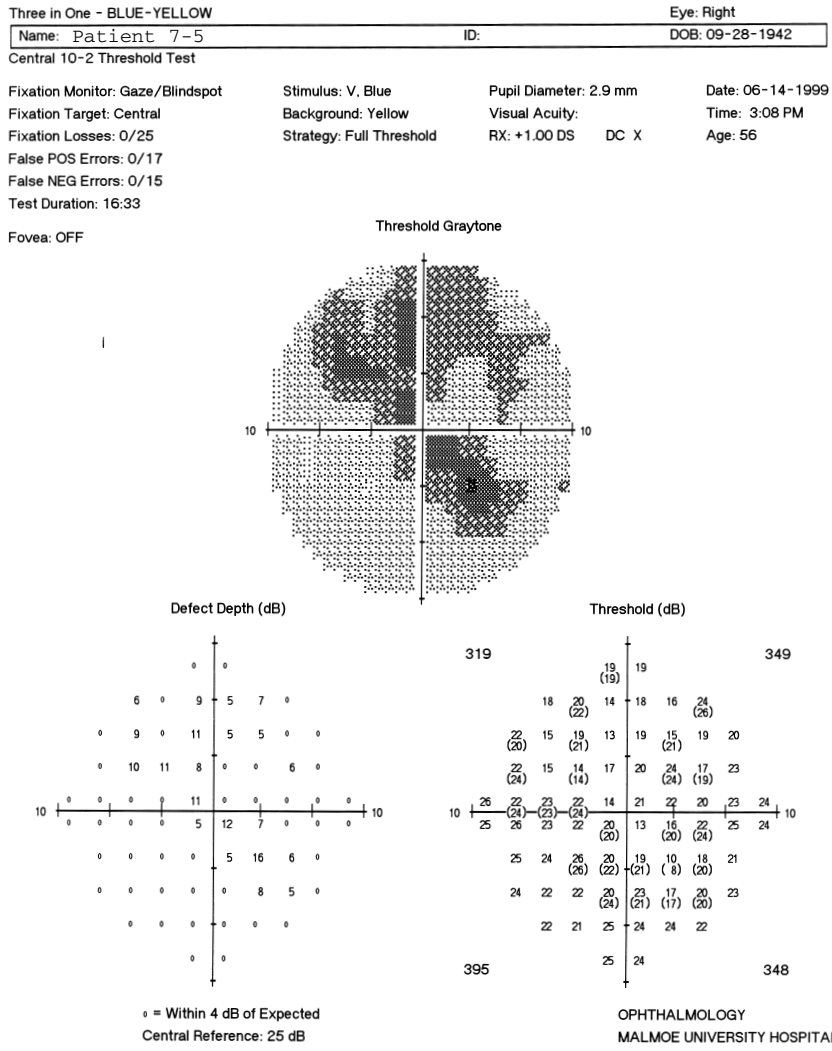


Figure 7-5b. The SWAP 10-2 field taken on the same day shows considerably larger areas of depressed sensitivity than were found by conventional perimetry as shown in figure 7-5a.

8

Common Patterns of Artifactual Test Results

PATIENTS DO NOT ALWAYS produce reliable visual field tests. Fortunately, artifactual results are often easily recognized. This allows the perimetrist to intercede and get the patient back on track in order to obtain useful test results. Common false patterns may be caused by the patient's lack of previous perimetric experience, droopy eyelids or prominent eyebrows, misaligned correction lenses, lack of proper operator instructions and supervision, and patient anxiety.

The Untrained Patient and Perimetric Learning

Some patients exhibit perimetric learning, i.e., their field test results improve after their first test (Heijl, Lindgren, and Olsson 1989; Wild et al. 1989, 1991; Heijl and Bengtsson 1996b). Thus, a large minority, probably 10% to 20%, of patients with a normal visual field do not produce an entirely normal test result on their first test. Typically, such fields show depression of sensitivity in the mid-peripheral area 20 to 30 degrees from fixation, while the very central field is normal *(figures 8-1a–8-1d)*. If the test

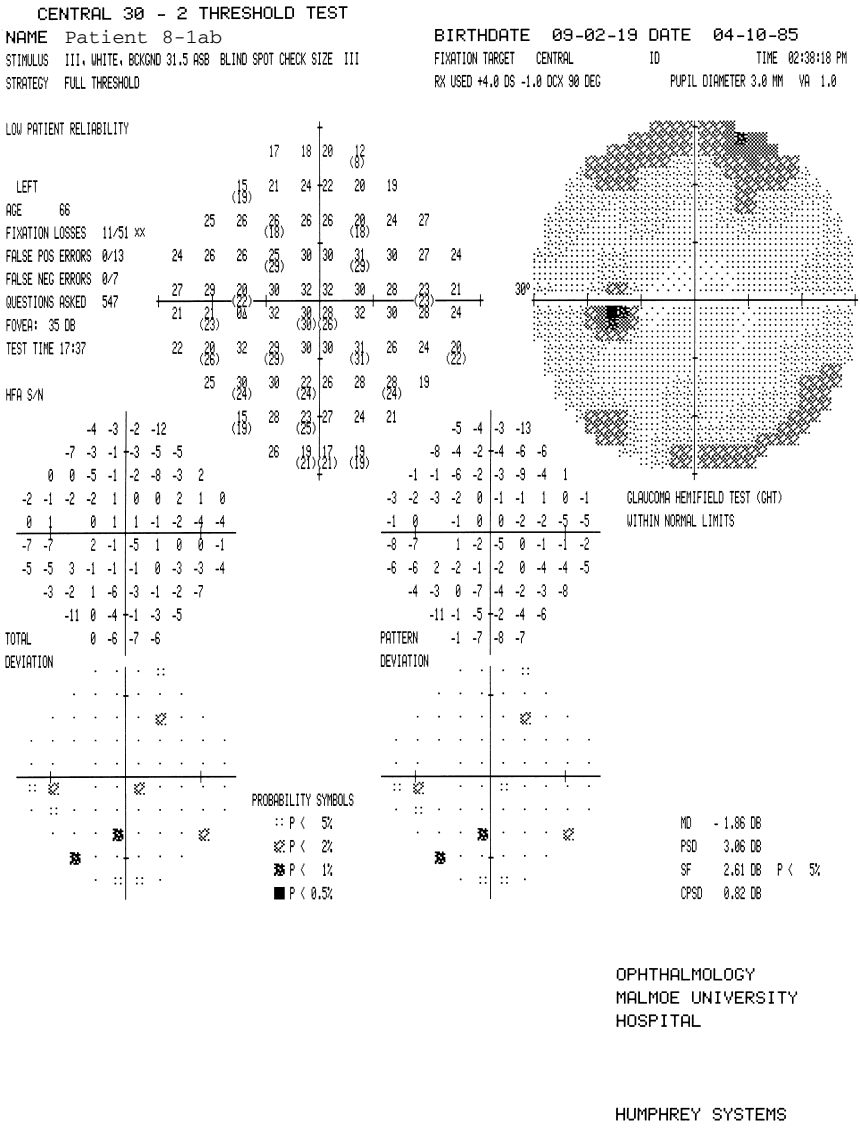


Figure 8-1a. Typical pattern of visual field test produced by an untrained patient with mid-peripheral depression of sensitivity

Figure 8-1. Perimetric learning effects

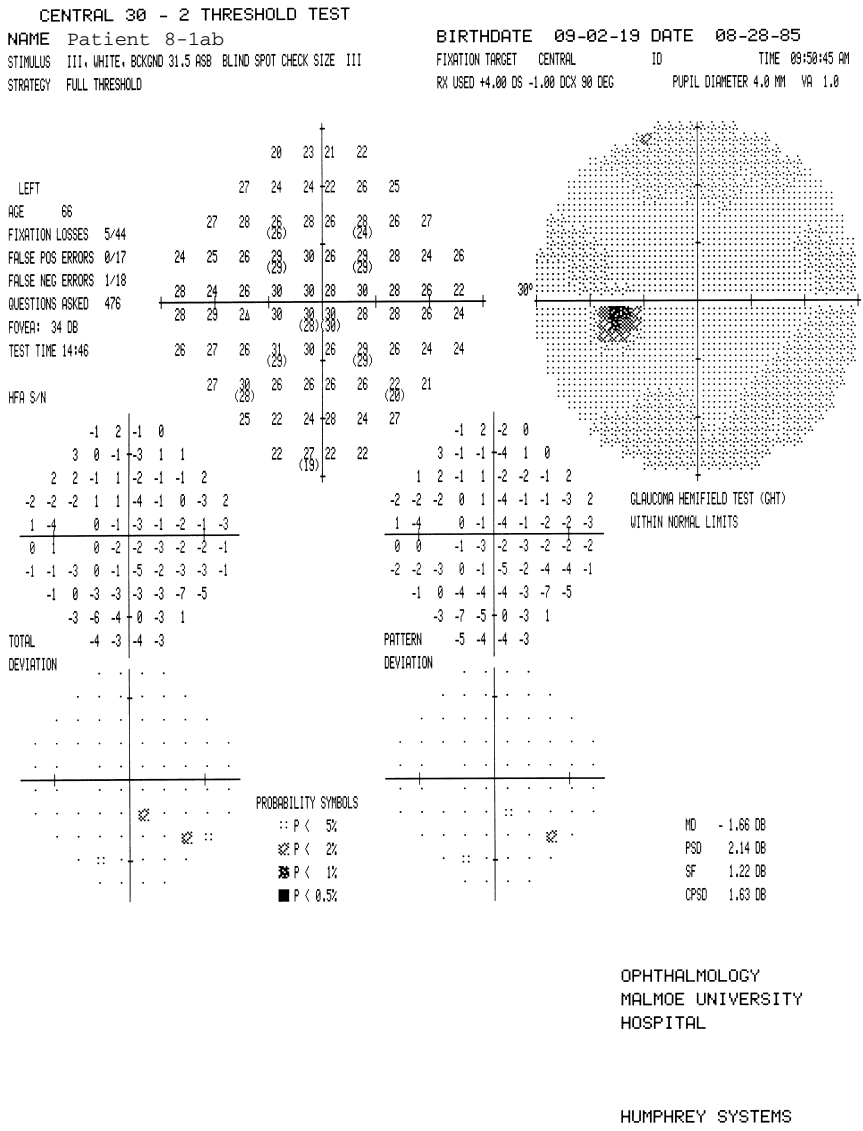


Figure 8-1b. Retesting of the patient shown in figure 8-1a. The midperipheral depression is much less apparent than in the first test.

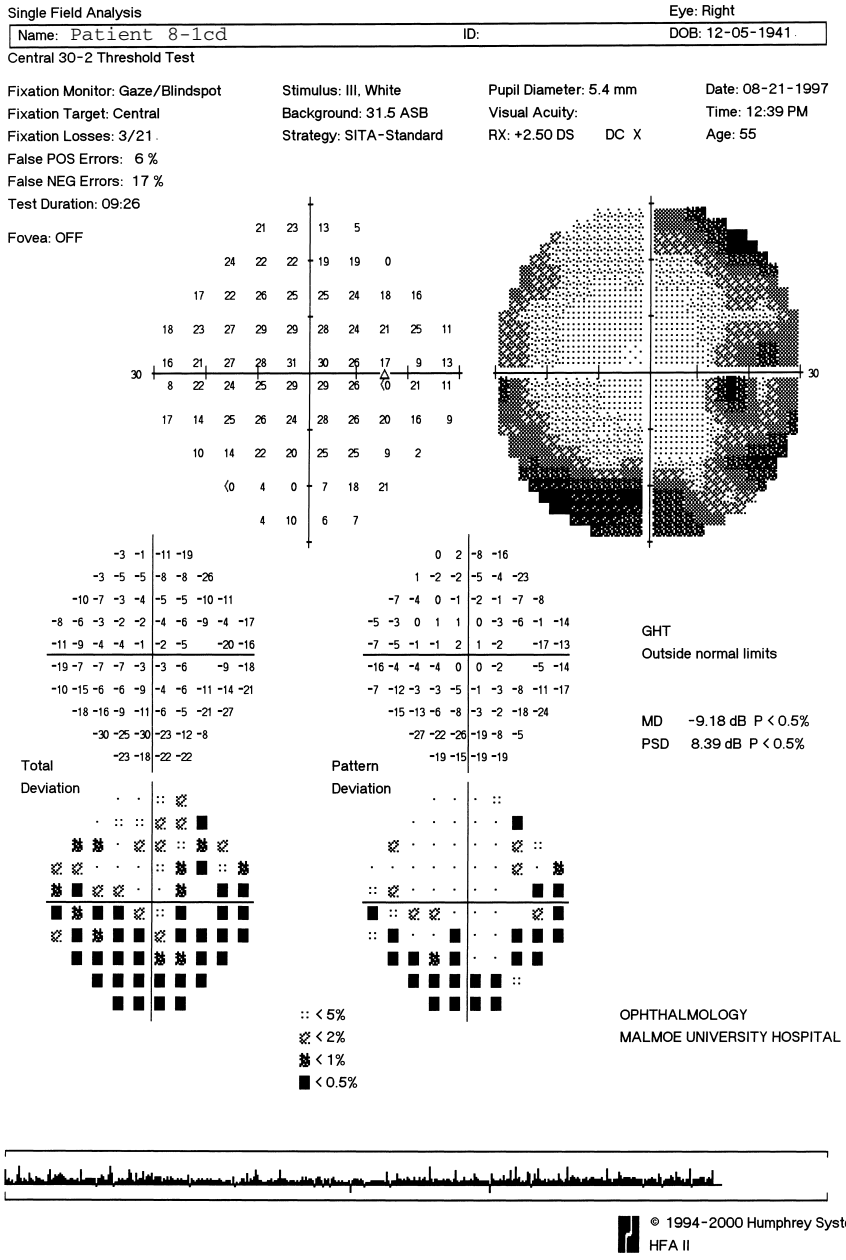


Figure 8-1c. A more extreme example of the pattern of midperipheral loss frequently seen with untrained patients, some of which remained even on the second test (8-1d). Some patients require more than one follow-up test to reach stable levels.

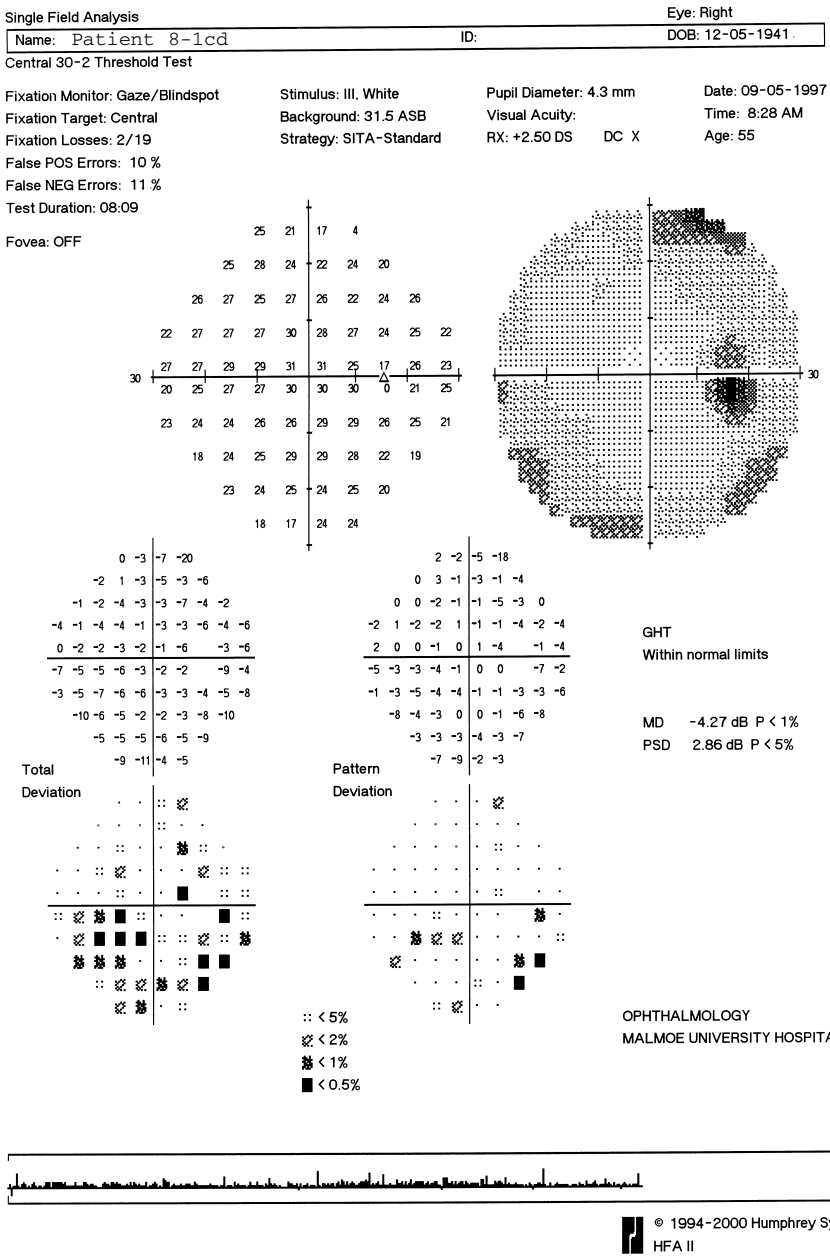


Figure 8-1d. Retest of the patient shown in figure 8-1c. The pattern of midperipheral loss typical of inexperienced patients sometimes persists beyond the second test.

is repeated, the results will usually be normal, or at least much improved. This pattern is characteristic enough to be worth remembering; it occurs less commonly with the shorter SITA tests than with tests performed using the other strategies.

It is also important to know that perimetric experience gained with one type of perimetric testing may not be transferable to another test modality. Thus, a perimetric learning curve may still be encountered in SWAP (blue-yellow perimetry) testing of patients who have extensive previous experience with standard white-on-white testing (Wild and Moss 1996).

Midperipheral constriction due to inexperience is less apparent in the smaller 24-2 test point pattern than in the larger 30-2 pattern. It is also less common when patients are tested using the shorter test strategies.

Perimetric learning is even more significant in glaucomatous than in normal eyes and is therefore of importance in perimetric follow-up of glaucoma patients. In one study, the majority of newly diagnosed glaucoma patients showed obvious improvement with repeated testing (Heijl and Bengtsson 1996b).

Eyelid Artifacts

Partial ptosis is quite common, even in normal subjects, and frequently produces artifactual field defects. Such defects are accentuated on the grayscale printout because they add to the normal reduction in perimetric sensitivity in the superior portion of the central field. As a result, patients with somewhat droopy eyelids will often produce grayscale results that look relatively dark superiorly *(figures 8-2a–8-2d)*. That this type of pattern is common and normal is obvious from the probability plots, where it usually does not result in readings indicating high statistical significance.

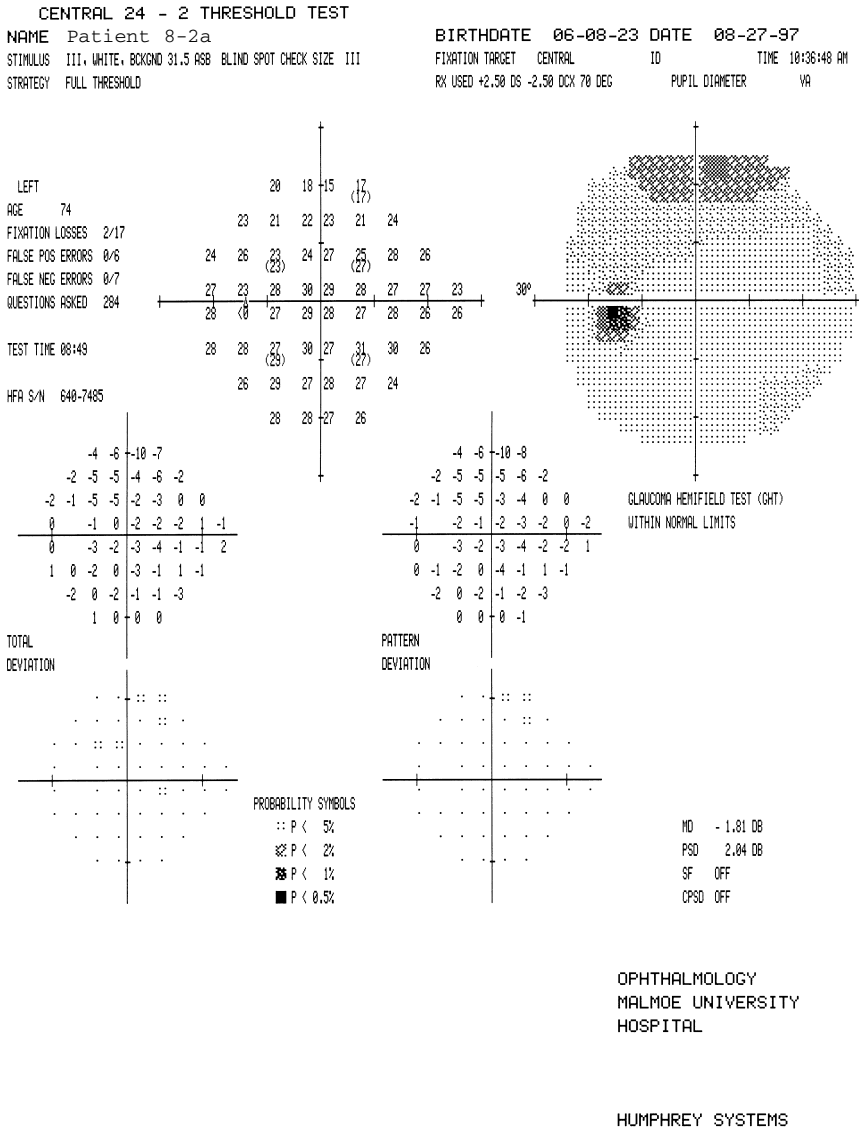


Figure 8-2a. This lid artifact is marked enough to appear on the grayscale result in a 24-2 test pattern. Still, the probability plots indicate that the test result falls with the range of normal variation on this Full Threshold Test.

Figure 8-2. Eyelid artifacts

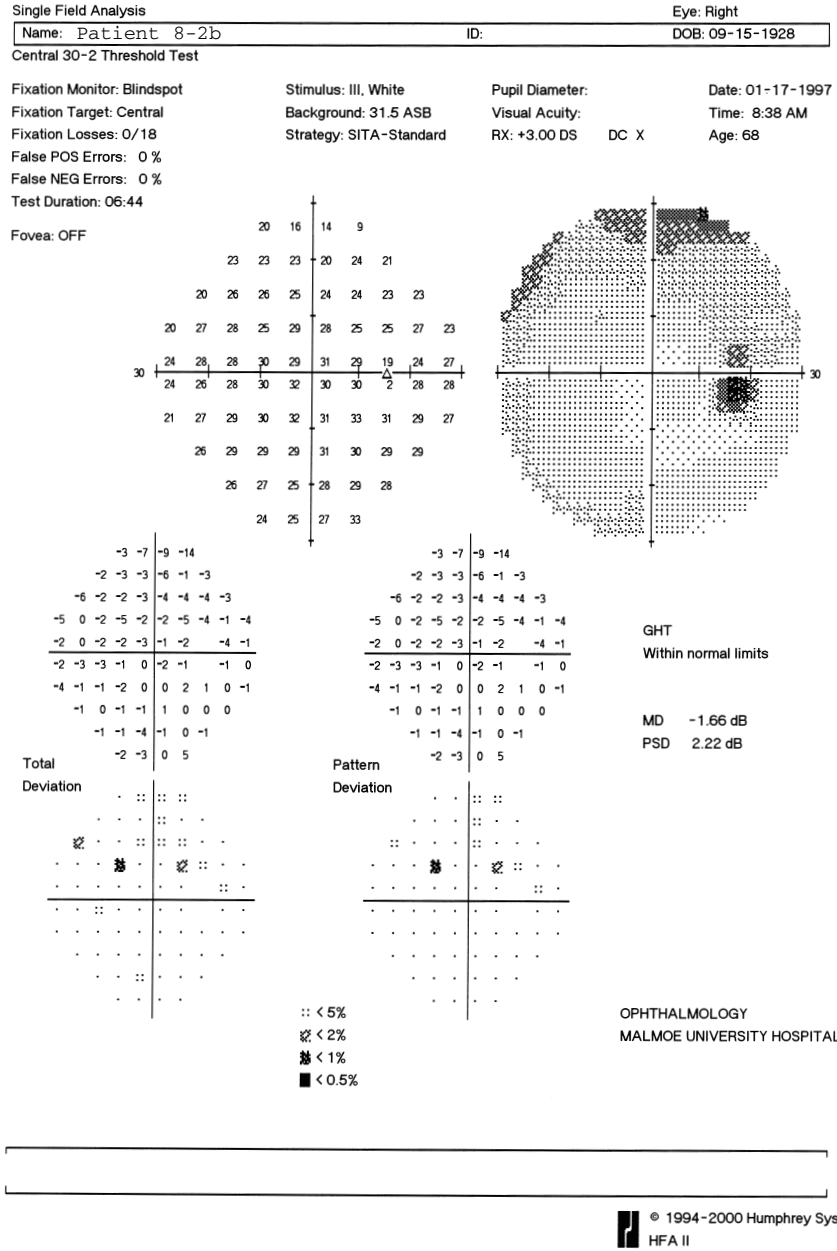


Figure 8-2b. This SITA Standard test shows a less pronounced grayscale lid artifact, which is not significant on the probability plots.

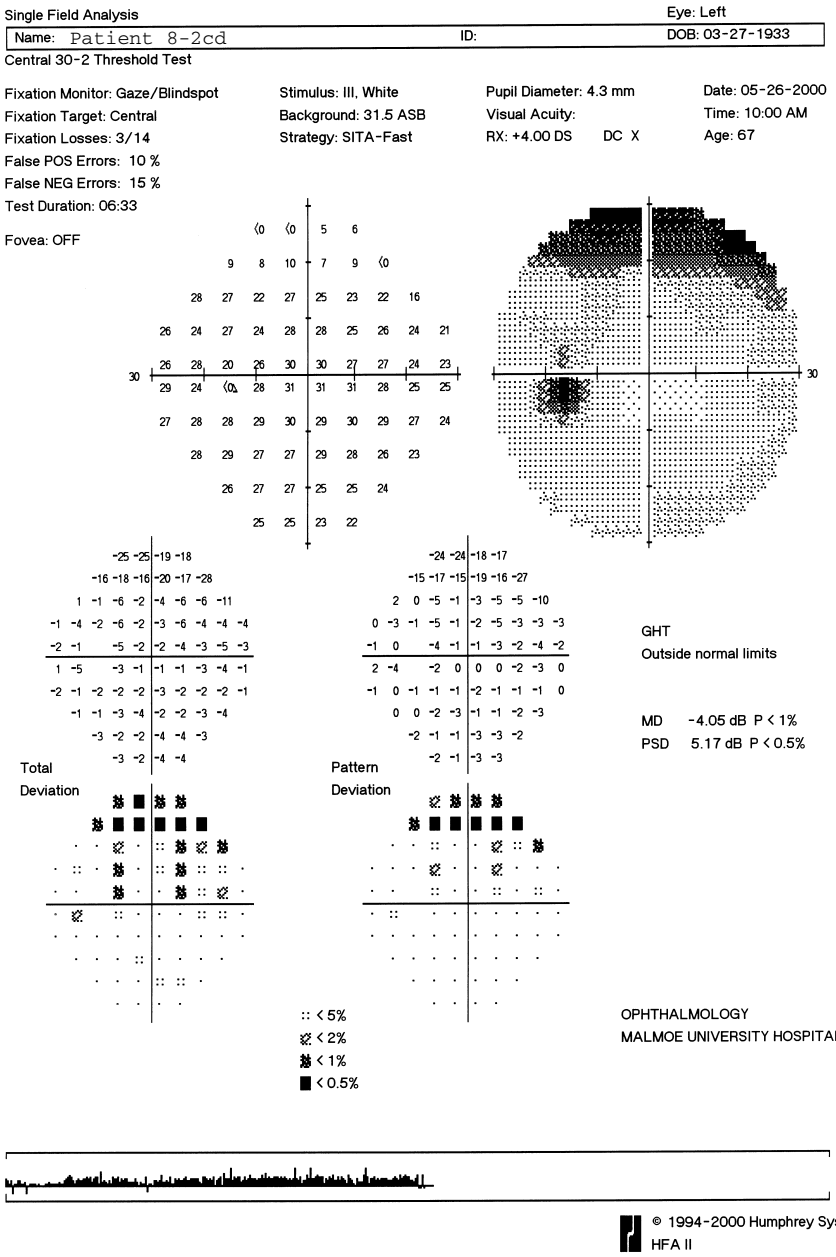


Figure 8-2c. In this case, more marked ptosis has produced a lid artifact that is so deep it also appears on the probability plots.

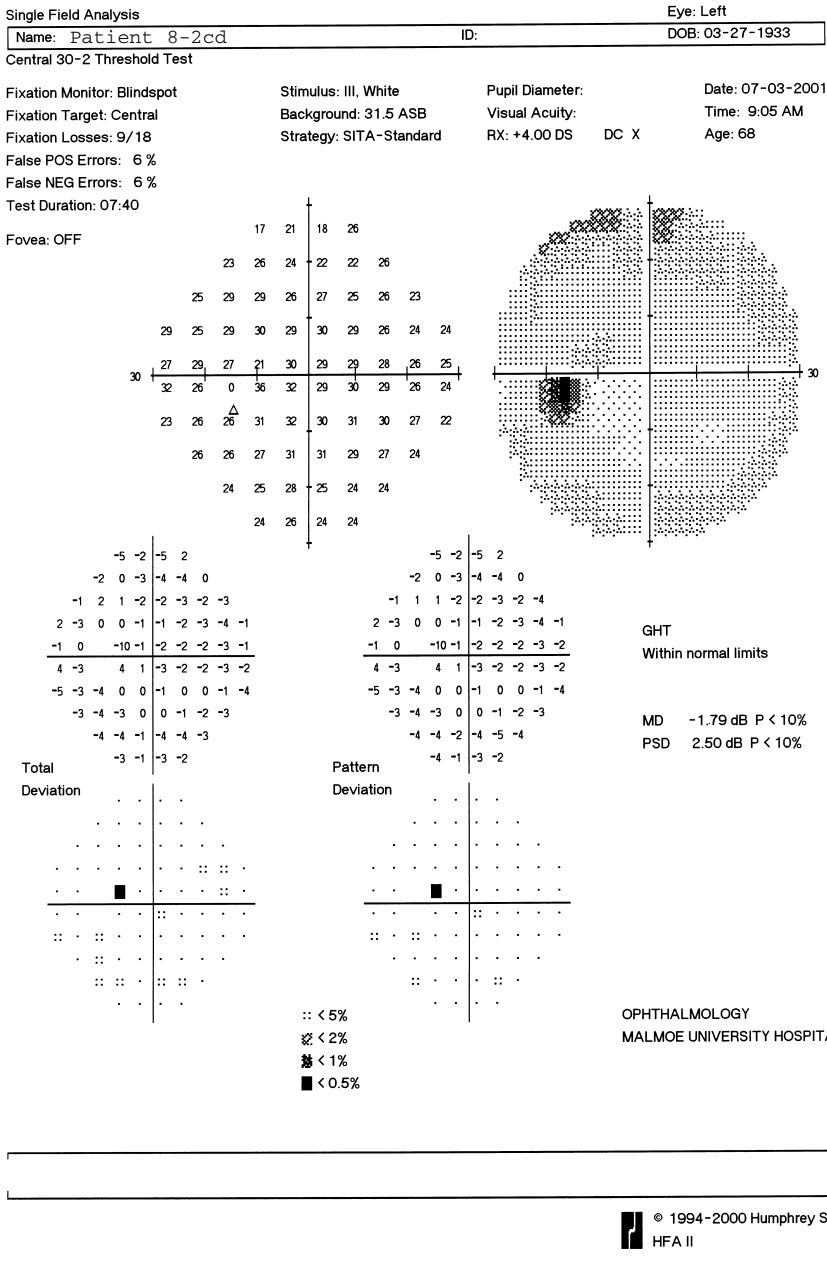


Figure 8-2d. Re-test of the patient shown in figure 8-2c after taping the lid.

Correction Lens Artifacts

With patients who have strong positive correction lenses, the visual field may be concentrically contracted so that the peripheral points of a 30-2 pattern show reduced sensitivity *(fig. 8-3)*. This will not happen with well-aligned lenses of lower power, but with misalignment even weak lenses or their rims may create artifactual patterns. Such patterns are usually easy to recognize: they involve a series of points in the periphery of the tested field with low sensitivities, and the resulting false defect has sharp borders. Six mm of decentration will produce a trial lens artifact when using a +3D correction at a vertex distance of 15mm. With a +10 D lens, only 3mm of decentration can be allowed. Naturally, these artifactual patterns caused by the correction lens are likely to disappear on a subsequent test.

The Cloverleaf Field

The cloverleaf field is a very characteristic artifactual pattern *(fig. 8-4)*. In this pattern, threshold values are normal or near normal at and sometimes around the four primary points where the test begins in all Humphrey threshold programs, but they are much reduced at other locations where the threshold is measured later in the test. This pattern occurs when the patient has responded more or less appropriately during the first part of the test, and then given up. Usually, this results from a misunderstanding on the part of the patient, or sometimes a lack of motivation. The patient may have asked the operator if the test was over or how to respond, and if the operator was no longer in the room, the patient did not know what to do and chose to do nothing.

If you see many cloverleaf fields in your practice, it may be a sign that your staff needs more training in how to perform computerized perimetry, that is, to instruct and supervise patients.

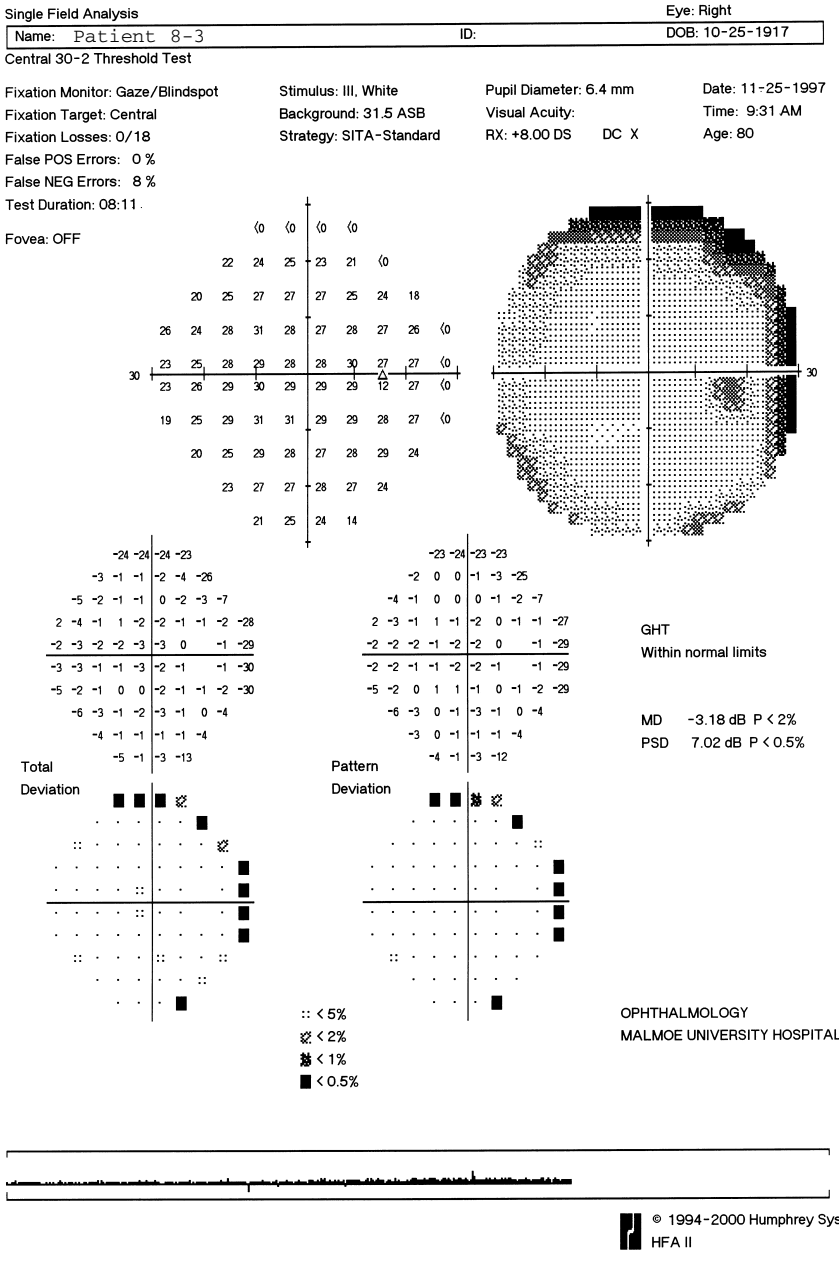


Figure 8-3. This trial lens artifact associated with use of a +8 diopter corrective lens demonstrates the importance of carefully maintaining the alignment of the patient during the test, especially when using strongly positive lenses.

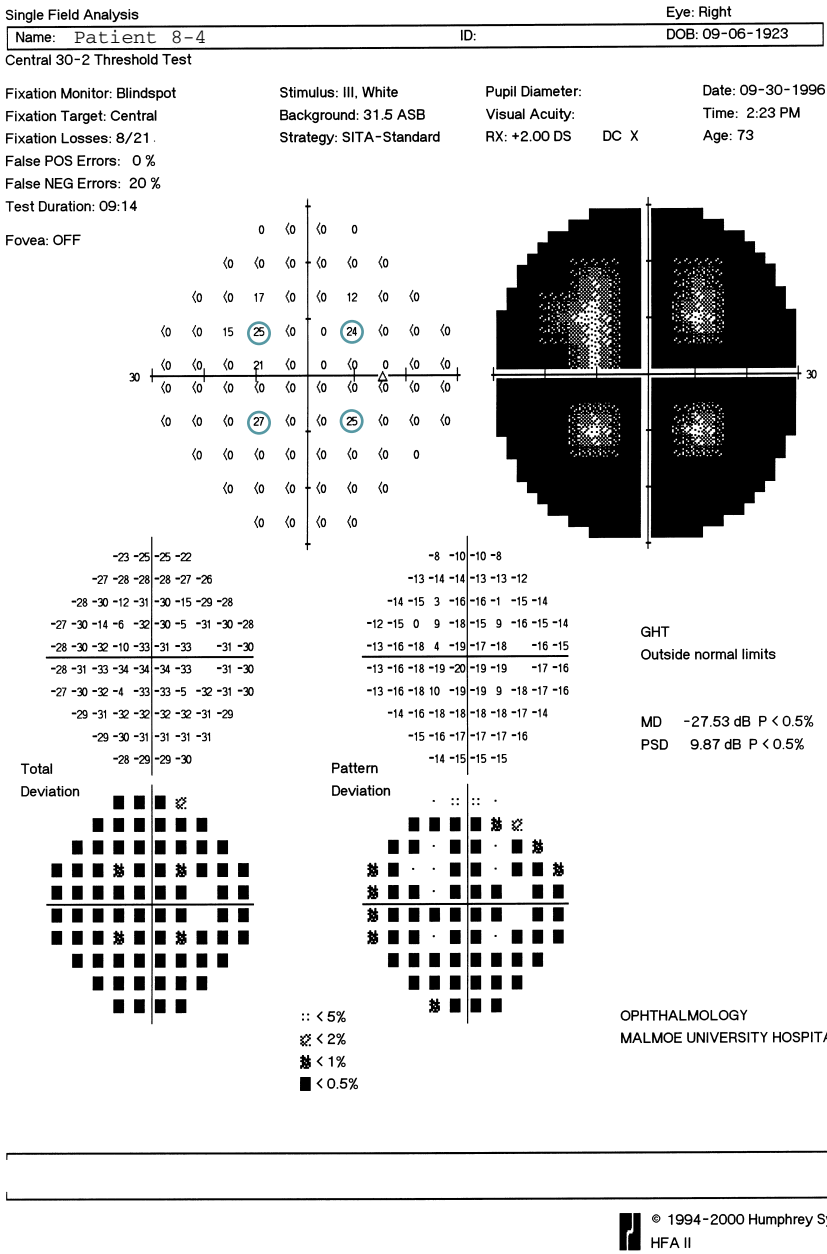


Figure 8-4. The cloverleaf artifact pattern occurred because the patient stopped paying attention shortly after testing began. Points circled in blue are the primary points, that is, the first points tested in each quadrant.

The "Trigger-Happy" Field

Some patients, particularly if they are anxious, will be eager to see most or even all stimuli during a test. They will then press the response button as often as possible, resulting in large numbers of false responses given when, in fact, the patient has not seen the stimulus. This will push up measured threshold values at some points to levels that no human can see. The result is a classical "trigger-happy" field, characterized by patches of abnormally light or even entirely white tones in the grayscale presentation *(refer back to fig. 4-5.)* Often, the measured frequency of responses to false-positive catch trials is high. The Glaucoma Hemifield Test will usually display the "Abnormally High Sensitivity" message, indicating the same problem.

The SITA programs calculate the rate of false positive answers more precisely and are therefore more likely to identify this type of patient than the older programs, which had to limit the number of false positive catch trials in order not to prolong the test time unnecessarily. The SITA programs can also partially correct for false positive answers. Therefore, the full-blown "trigger-happy" fields with very light grayscale patches occur less frequently with SITA than with older threshold programs.

Sudden and False Change

Diseases followed over time with repeated visual fields often have a slow and protracted course. The most common example is glaucoma, of course, but there are many other such conditions, e.g., pituitary tumors and retinal dystrophies. Even if the disease does not really change or progress, biological variability will result in slightly different fields from test to test. True disease progression is

If the clinician finds a large difference between two consecutive fields obtained within a reasonable time period, the changes are usually not the result of progression of the chronic disease but of some other new condition.

best identified by analyzing a series of visual fields instead of only two or three consecutive tests.

If the clinician finds a large difference between two consecutive fields obtained within a short time period, the changes are usually not the result of progression of the chronic disease but of some other new condition. A sudden and large change in a glaucoma patient is often due to a stroke, or perhaps retinal vascular occlusion *(figures 8-5a, 8-5b, 8-5c, 8-5d)*. A stroke can be suspected when the new field loss respects the vertical meridian, at least to some extent. This may be difficult to see if there is also considerable glaucomatous field loss. The diagnostic clue in such situations is provided by the fact that postchiasmal field loss is bilateral and homonymous, and there will be evidence of sudden and similar worsening in both of the patient's visual fields. In contrast, sudden progression caused by retinal vascular catastrophes will be unilateral, but the cause will be seen on ophthalmoscopy *(figures 8-6a, 8-6b)*.

In any case, it is wise to look for other and previously undiagnosed disease any time that large and sudden apparent field progression is found when following patients who have chronic disease.

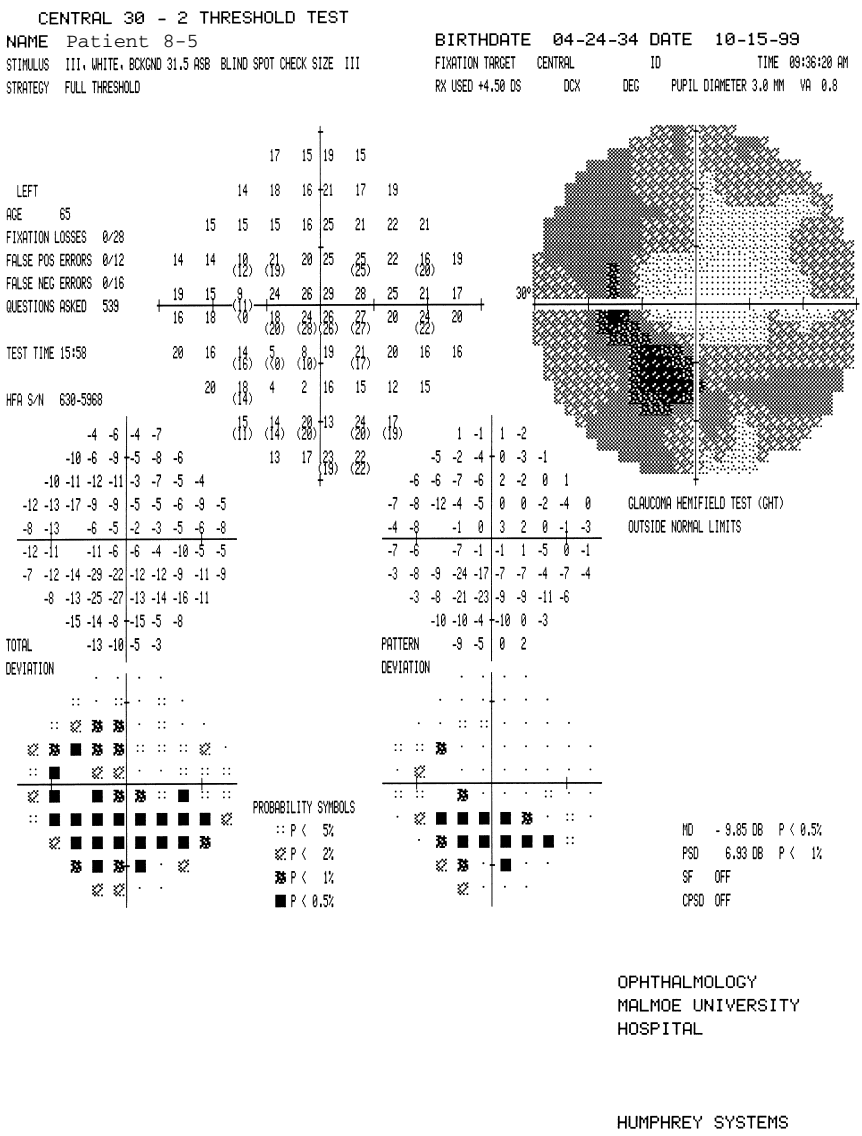


Figure 8-5a. Left eye, October 1999

Figures 8-5a, b, c, d. This patient with the moderate glaucomatous field loss shown in figures 8-5a and 8-5b suddenly developed considerably larger field defects in both eyes between two visits just over three months apart. The new loss, shown in figures 8-5c and 8-5d, was mainly in the left halves of both fields, at least partially respecting the vertical meridian, and was caused by a stroke.

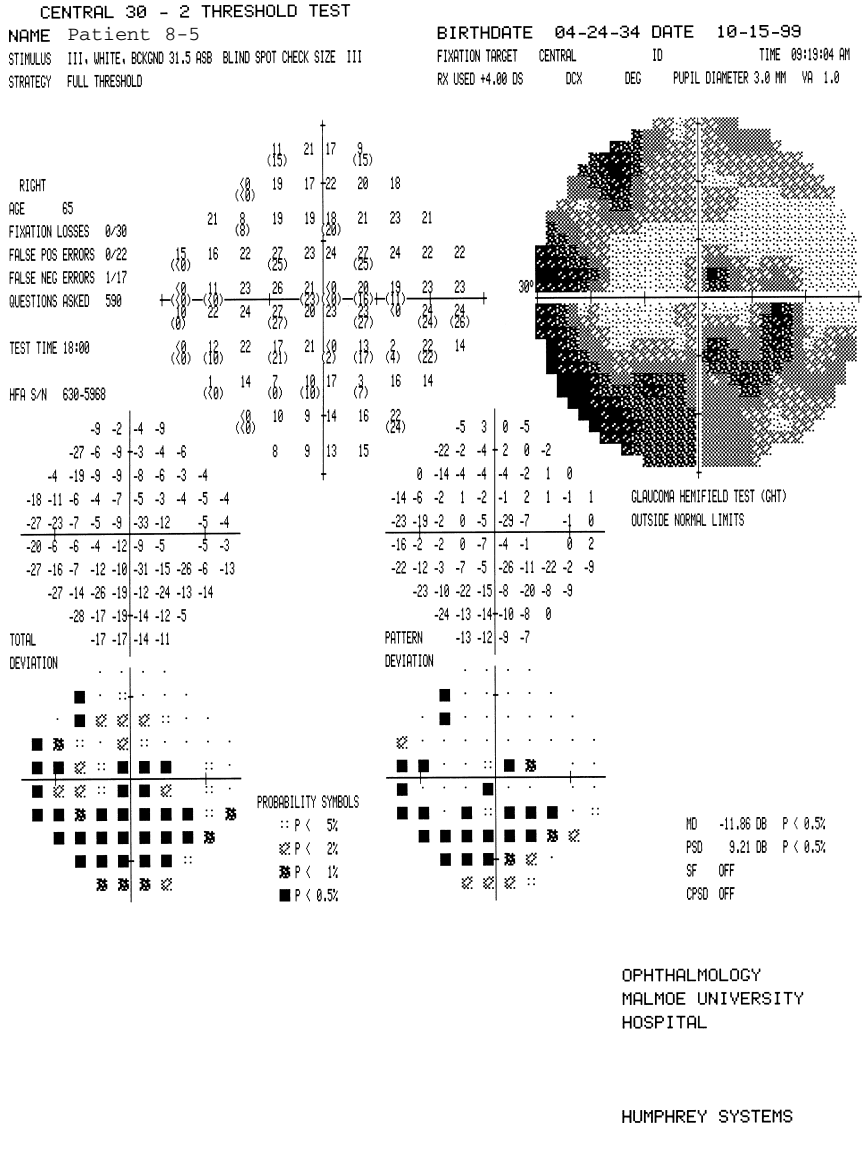


Figure 8-5b. Right eye, October 1999

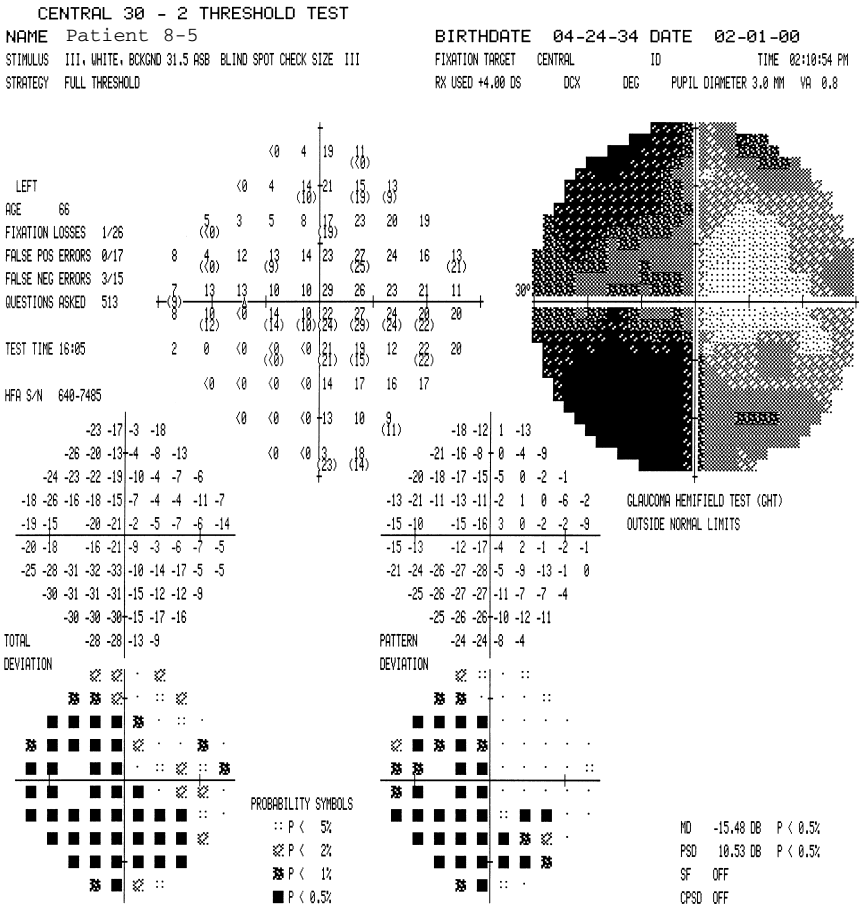


Figure 8-5c. Left eye, February 2000

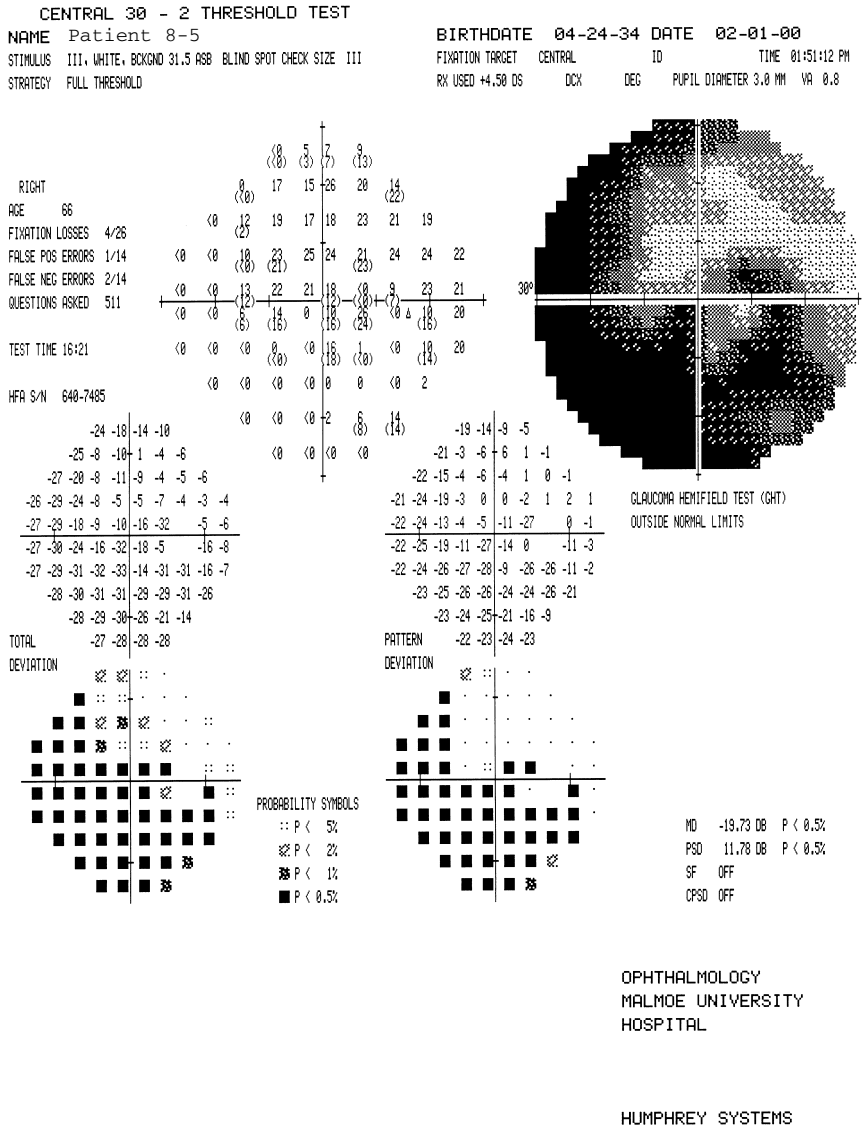


Figure 8-5d. Right eye, February 2000

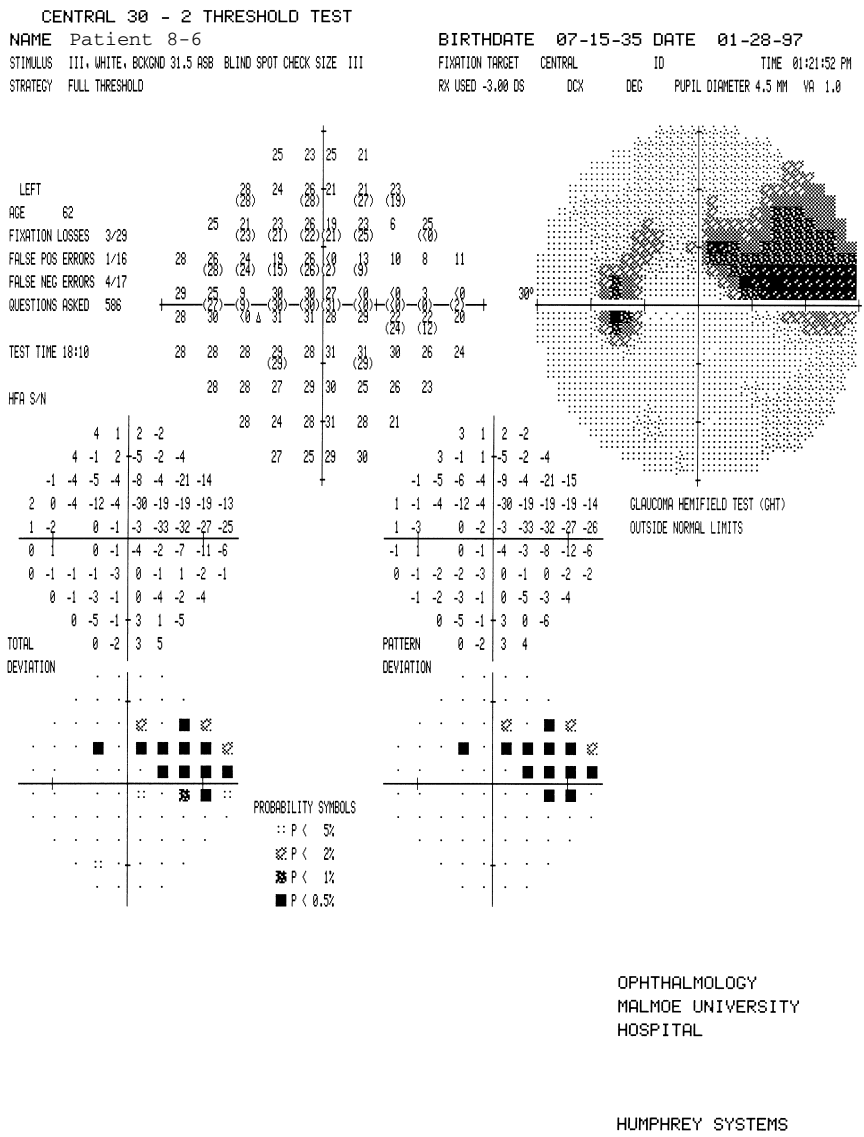


Figure 8-6a. Baseline glaucoma field. Compare with the follow-up test shown in figure 8-6b.

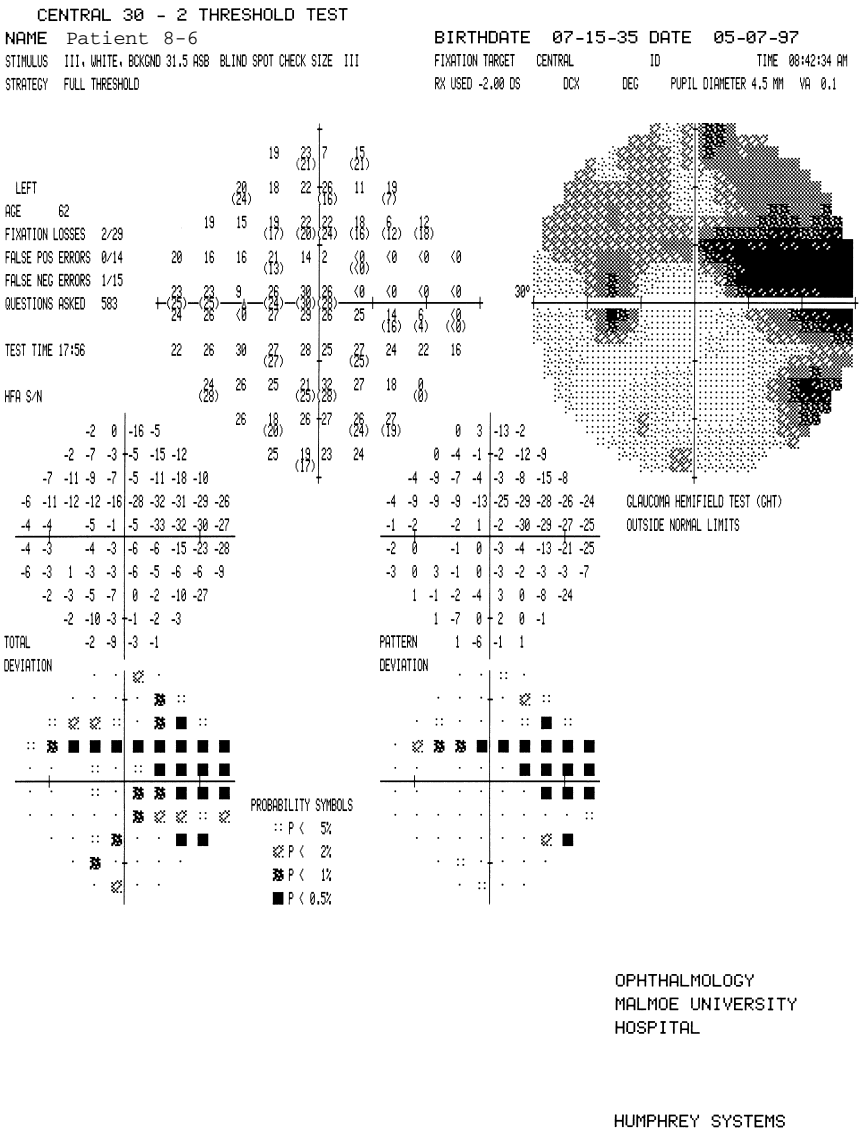


Figure 8-6b. Follow-up test. What looks like a sudden change in the visual field status of this glaucoma patient was actually caused by a central vein occlusion, resulting in the apparent extension of an existing defect in the superior field.

9

The Hardware

THE HUMPHREY FIELD ANALYZER (HFA II) consists of four basic elements: the bowl or projection surface, the optical system, the central processor, and the patient interface. The overall design goal was to combine accurate and consistent perimetric testing with ergonomic features that provide as much patient comfort as possible.

The Bowl

The bowl of the HFA II is a patented, aspherical, or bullet-shaped, surface upon which stimuli are projected. This is a departure from earlier hemispherical designs, such as the original Goldmann perimeter, and was adopted because it improves patient ergonomics and reduces instrument size. The distance from the eye to the center of the bowl is 30 centimeters—the same as the original Goldmann perimeter. The amount of asphericity was chosen such that the surface departs negligibly from the traditional spherical shape in the central 30 degrees; HFA II test results are entirely comparable with those of the original Humphrey perimeter, now known as HFA I

(Johnson et al. 1997). This curvature also assures that the refractive correction needed for clear vision in the center of the bowl is proper even at the edge of the central visual field. Outside the central visual field, the bowl's asphericity causes stimuli to be somewhat closer than is the case in a standard hemispherical bowl. The effect is corrected for by making small adjustments in stimulus brightness. The bowl surface is textured to provide an almost perfectly matte finish known as a Lambertian surface. Lambertian surfaces provide almost no direct or specular reflections but instead scatter light diffusely and equally in all directions. Thus, stimuli projected on this surface will seem equally bright regardless of viewing angle.

The Optical System

The Humphrey perimeter's optical system provides stimuli of known brightness for a known amount of time in a known location, and against a background of known brightness. All five standard Goldmann stimulus sizes (I through V) are available, although most testing is done with the size III. Stimuli are presented by aiming a projection system at the particular location to be tested, adjusting a set of neutral density filters to obtain the correct stimulus brightness, and then opening a mechanical shutter for a fixed time, usually 200 milliseconds. Background brightness—the brightness of the bowl surface itself—is checked at the beginning of each test, and constantly during testing. Stimulus brightness is checked every time the instrument is started up. Stimulus brightness is finely adjusted just before each stimulus is presented, based upon the local background brightness measured at each test location. This fine adjustment is done with the goal of keeping stimulus contrast constant in spite of any local variations in bowl brightness, such as those that might be caused by shadows falling on the bowl from an open door.

The Central Processor

The Humphrey perimeter's central processor not only fulfills many of the functions commonly seen in a standard desktop computer, it also must control the optical system as well as make complex, split-second strategy adjustments based upon each patient response. The development of modern, high-speed microprocessors has made it possible to incorporate the computation-intensive, maximum-likelihood calculations of the SITA strategies into everyday clinical practice. The system has a hard disk for program and data storage, a disk drive, and a video screen. As with any computer system, all clinical data must be safeguarded by frequent backing up. A printer is also available so that visual field test results may be printed for future reference.

The Patient Interface

The patient interface consists of a chin rest, a forehead rest, a trial lens holder, the patient response button, and the instrument table and chair. The chin rest and forehead rest are powered by a small electric motor and are moved horizontally as a unit. A second motor is used to adjust the chin rest up and down to center the tested eye behind the lens holder.

The trial lens holder is used to hold standard 37 mm ophthalmic trial lenses in place in front of the patient's eye in order to assure clear vision of the stimuli presented. Trial lens correction is used only when necessary for clear vision in central field testing; trial lenses are never used for testing outside of 30 degrees because the lens and its holder will produce an area of deep artifactual field loss where they block the patient's vision of the periphery. When it is not in use, the trial lens holder can be folded down and out of the way.

An optional feature on the Humphrey perimeter automatically adjusts the chin rest and forehead rest in minute (0.3mm) increments—right-left and up-down—in order to keep the patient's eye centered relative to the trial lens. An automatic vertex distance monitor also sounds an audible alarm if the patients backs away from the lens holder. These features are intended as adjuncts to proper patient instruction and supervision, not as replacements.

The patient response button is designed for maximum comfort for elderly patients, especially those whose hands have been weakened by arthritis, for example.

The instrument table is designed to allow the patient comfortable and unimpeded access to the perimeter when sitting in a standard office chair or even a wheelchair. The combination of the highly accessible table and the small-profile aspherical bowl allows the patient to sit upright comfortably.

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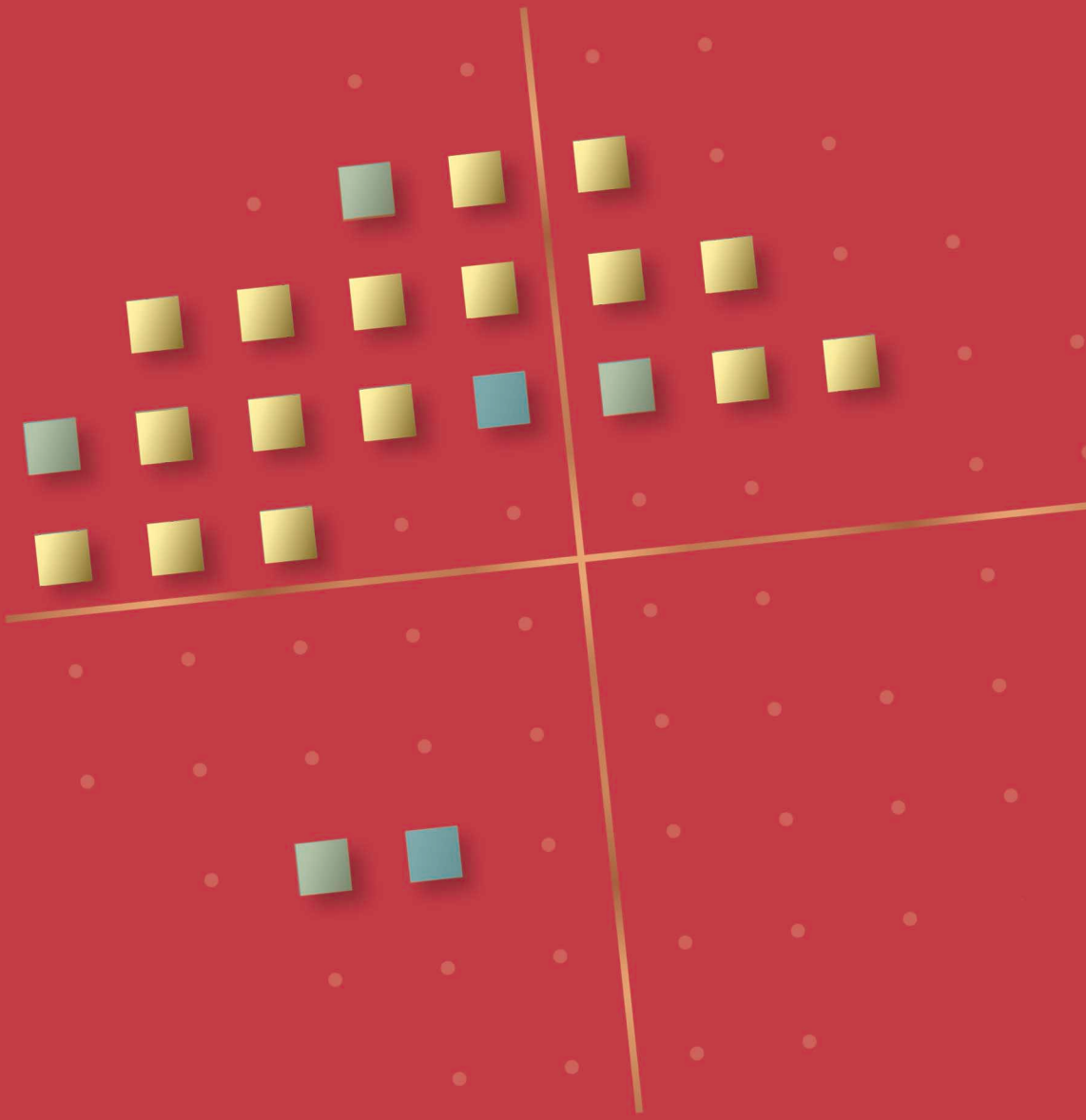

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