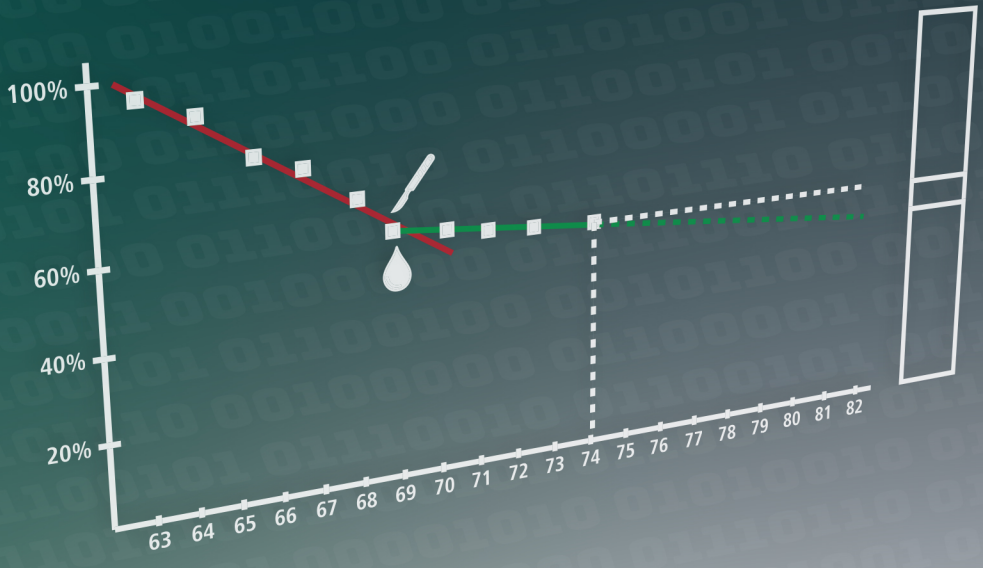
THE FIELD ANALYZER PRIMER FIFTH EDITION

Excellent Perimetry



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ISBN 978-0-9884795-1-7

March 2021

en-INT_31_010_0080I.

Cover design: Johan Heijl
Photos: Johan Heijl
Text design and composition: Seventeenth Street Studios
Illustrations and infographics: Johan Heijl
Index: Sandi Schroeder

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Foreword to the Fifth Edition

IN THE LATE 1960s, during my residency, I was taught how to test the visual field at the tangent screen, a test done by the physician himself. In the next decade, Goldmann's well-engineered manual perimeter, which could be operated by a trained technician, introduced standard quantifiable conditions of background illumination and stimulus size/intensity. Stephen Drance and I conducted courses in the 1970s to train clinicians and their technicians to use this perimeter effectively and to interpret the results. The teaching material for those courses became a textbook (*Testing the Field of Vision)*. Soon thereafter, computerized perimeters were developed, which further standardized perimetric testing and better quantified the patient's visual status. Automated perimetry became the focus of sequels to that book.

We obtained one of the first computerized Humphrey Field Analyzers (HFAs) in 1983. This book is written by the expert trio who invented that device and who orchestrated the development of improvements to the HFA over the ensuing years. Their combined expertise spans clinical care, engineering, and the research skills needed to develop thresholding algorithms and diagnostic analyses.

This "primer" will serve to provide experienced clinicians with the recent advances in perimetry and how to apply them to practice. Some aspects of the material presented are specific and unique to the HFA. However, the general principles—why perimetry is done, how the tests are conducted, and the approach to interpreting the results—apply to any method of perimetry.

Because of the generalizable nature of the information, this primer will also be useful to those training to become ophthalmologists or optometrists. This introduction to the use of perimetry clinically, particularly as it is applied to the management of glaucoma, is quite valuable, given the present-day scarcity of up-to-date textbooks or other instructional material on this topic.

Of particular importance to both the practitioner and the perimetrist is the guidance in chapter 4 on how to prepare the patient and how to conduct the testing in order to get the best results. The rest of the primer guides selection of testing strategy and interpretation of the test result according to the clinical context in which the test is conducted.

Visual field testing has become more and more important in managing glaucoma, and today most perimetry is done in that context, while perimetry's role in neurological diagnosis has become less important. However, even when testing for glaucoma, it remains crucial to be familiar with the characteristics of nonglaucomatous visual abnormalities (chapters 10 and 11) and artifacts (chapter 12), so they can be recognized for what they are when encountered and not be incorrectly attributed to glaucoma.

In the present age of rapid advances in technology and in medical knowledge, books rapidly become out of date. In this manual, you have the latest guidance regarding perimetry, written by those who have been at the forefront of automated perimetry. Read it. Keep it for reference. Make sure those entering the profession have a copy to read. It will be a while before anyone so broadly skilled and experienced will offer an equivalent manual.

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Foreword to the Fourth Edition

THIS NEW EDITION OF *The Field Analyzer Primer* is timely. Since the previous edition, there have been improvements in perimetric software, but more importantly, we now have a better understanding of the meaning of certain results. Test results, for example, no longer should be viewed as either reliable or unreliable but as falling on a continuum from highly reliable to marginally informative, sometimes containing useful information even when indicators of reliability are not optimal. We now understand that False Positive responses—when the patient presses the response button even when no stimulus has been seen—are more destructive to interpretation than formerly believed, that the gaze tracker probably provides more accurate measures of patient fixation stability than does the blind spot method, and that False Negative responses are to be expected in distinctly abnormal fields, even when patients have been highly attentive to the test.

In a similar way, progression is no longer viewed as simply being present or absent, but careful evaluation will consider the rate of change as well as the degree of certainty that change really has occurred. Both diagnosis and management now can be better than ever before when a modern automated perimeter is used in an astute manner by a well-informed practitioner.

The first two editions of this primer—published more than 20 years ago—concentrated on perimetric technology, however complex. The third edition, written in 2002, looked more at how to simplify and standardize the clinical process. This new edition seeks to emphasize the insights of the past decade, including not only those just mentioned but also the importance of human interaction during testing and the importance of quantifying change as a rate rather than simply as an event, when a change from baseline can be recognized.

The reader has the good fortune that this primer has been written by the people who have been largely responsible for the development and continual improvement of the Humphrey perimeter. You should not pass up the

opportunity to learn from them by reading this work and using it for reference from time to time. In the modern world, most of us operate new computerized devices by intuition, without ever reading the instruction manual. However, when using a modern perimeter, it often is important to understand the workings of the instrument, as well as the nature of visual defects from disease (and artifacts). This primer was written to address these essentials, but experience and further study also will help the reader achieve and maintain up-to-date expertise.

I remember when testing of visual fields was performed manually, most typically by the physician himself, at a tangent screen, with an effort by some to carefully calibrate the room illumination level and to record results quantitatively, in terms of the size of the round white bead contrasting with the black background. Then came manual perimeters designed by people like Aulhorn with Harms in Tübingen, and Goldmann in Bern, with carefully calibrated illumination of the stimulus and background. John Lynn may have been the first to attempt to have the test conducted automatically, using emerging technology that was primitive by today's standards. Quite a number of automated perimeters were developed, with increasing sophistication. In the decades since, we have seen improved test accuracy, shortened test times, and the addition of statistical analyses to help with both diagnosis and monitoring for change. Lost in that process is the art of performing the test and, just as importantly, the practitioner's thoughtful involvement as the test is being conducted. It need not be so with automated perimetry, if the perimetrist and practitioner each undertake their tasks insightfully.

For the conduct of the test, chapter 2 is particularly important, because it explains how the perimetrist can improve test results, even when using a highly automated instrument. The perimetrist should not simply stand by and watch the machine conduct the test but should perform the test using the instrument. With that mind-set, the perimetrist ensures that the patient understands what the test is going to be like, is positioned correctly, has the proper lens correction in place, is comfortable and alert, is maintaining fixation centrally, and so on. A brief word of encouragement from time to time keeps the patient alert and attentive to the task. The quality of the examination is highly dependent on the perimetrist, and experienced expert perimetrists routinely recognize when adjustments are needed, or when the patient needs a brief pause for rest.

The practitioner, for his part, should have undergone perimetric testing at least once to appreciate the nature of the task performed by the patient and to understand the sources of artifacts, both to instruct the perimetrist and to

recognize artifacts mixed within the diagnostically useful information on the printed report, which includes increasingly helpful statistical analyses.

Please reward yourself and your patients by absorbing the contents of this primer, growing further in your expertise with experience, and staying current with even newer information as it becomes available.

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October 2012

Preface

WRITING THIS FIFTH EDITION of the Humphrey primer has reminded us of just how much visual field testing has evolved since the days when we wrote each of the previous editions. The first two editions introduced Humphrey perimetry itself (in 1986) and the internationally based normative data application we called Statpac (in 1987). The 2002 third edition focused on the then new Swedish Interactive Thresholding Algorithm (SITA) testing strategies, and the fourth edition (in 2012) emphasized the importance of careful patient management during testing. We also have realized that all four of these earlier editions were written primarily for the use of practicing ophthalmologists and optometrists, with little thought given to the needs of young trainees.

In this edition, we have sought to make the book more suitable for use in residency and in optometric training programs. Thus, we have expanded the basic principles section (chapter 2) to briefly teach topics that we previously had assumed that our audience already understood. We have also expanded the chapter on the use of perimetry in glaucoma management (chapter 9), providing increased emphasis on practical ways of using perimetric data to address common and important patient care questions. We hope that those additions will also help experienced eye professionals take better advantage of perimetric data in their management of patients with glaucoma.

A second area of emphasis comes from our recent work to further shorten testing times, which resulted in the introduction of the SITA Faster testing algorithm. We undertook this project in order to encourage and facilitate more frequent visual field testing in recently diagnosed glaucoma patients.

Our third point of emphasis is embodied in a new chapter (chapter 8) covering the use of server-based analysis software in order to provide user access to the Humphrey Statpac and Glaucoma Progression Analysis applications on desktop computers. We believe that this software approach has truly come of age and, perhaps more importantly, also can now facilitate quicker and more effective patient care decisions by serving as a summing point for other clinical data, such as automated imaging results, clinical observations, surgical events, and pharmaceutical regimens.

This fifth edition celebrates 38 years of collaboration between its three authors in the development of clinical perimetry. We wish to recognize and thank those who have helped us along the way, a list too long to be recorded here. We especially wish to recognize Professor Douglas R. Anderson, who has been our collaborator, mentor, and friend for almost all of those years. We also wish to celebrate the memory of Professor Stephen M. Drance, who, during his long life, helped us immeasurably.

We wish to thank those who have helped us with this new edition of the *Field Analyzer Primer*: Lee Alward, Douglas R. Anderson, Sabina Andersson-Geimer, Anders Bergström, Dimitrios Bizios, Thomas Callan, Buck Cunningham, Thomas Fitzmorris, William Gustafson, Björn Hammar, Aiko Iwase, Eric Larson, Gary Lee, Christopher Leung Kai Shun, Georg Lindgren, Steven A. Newman, Marina Pekelis, Dorothea Peters, Catarina Villalba, Michael Wall, and Claudia Wasch. These colleagues have generously given us their best advice, and each of them has helped us improve this book in important ways. However, none of them has endorsed or approved what we have written.

Each of the authors serves as a perimetry consultant to Carl Zeiss Meditec Inc. Zeiss has helped us publish this book but has had no editorial influence or control over the book's contents.

Anders Heijl, MD, PhD
Mike Patella, OD
Boel Bengtsson, PhD
March 2021

How to Use This Primer

THIS BOOK IS INTENDED to serve as an introduction to clinical automated perimetry and particularly to visual field testing using the Humphrey perimeter.

It has been written as a concise introduction and reference that may be used by busy practitioners and in training programs.

Because of its purpose, this primer does not follow the outline of most textbooks. For example, the bare essentials of modern practical perimetry are covered in a very condensed form in chapter 1. Chapter 2 has been written primarily with residents and optometry students in mind; it describes normal and abnormal visual fields and how visual field testing works.

Those who only have time for absolutely basic information may choose to read only chapter 1 and to refer to the other chapters as the need may arise. We do, however, strongly recommend that you also read chapter 4. This chapter addresses what we believe to be the single most fertile area for improving clinical perimetry—the management and training of patients and technical staff.

1

The Essentials

THIS CHAPTER PROVIDES A brief summary of essential perimetric facts and methods. The topics presented here are treated more fully in later chapters.

What Is Standard Automated Perimetry?

Standard Automated Perimetry (SAP) quantifies the sensitivity of a patient's peripheral vision by testing at specific peripheral test locations, using efficient and standardized testing and analysis methods. While SAP perimeters usually are also capable of performing suprathreshold testing, in which the only goal is to detect peripheral vision areas where visual function is well below the normal range, the primary function of SAP devices is precise, standardized quantification of visual field sensitivity.

Most SAP testing is done in what is called the central visual field, that is, within 30° of the fovea. Perimetry performed peripheral to the central visual field is often referred to as *peripheral visual field testing, as distinct from central visual field testing.*

When Is Perimetry Called For?

Perimetry is essential in glaucoma management. It also is frequently useful in diagnosing and managing neurological diseases, and it has a role in the diagnosis and management of some retinal diseases. Perimetry also is used to certify visual function, such as quantifying a patient's level of visual impairment or ability to drive.

GLAUCOMA

Perimetry is fundamental in glaucoma diagnosis and management. Perimetric test results that reproducibly demonstrate visual field loss remain the most conclusive contributor to glaucoma diagnosis. Even now, as we enter the third decade of the 21st century, the most precise method for quantifying glaucomatous progression remains careful and disciplined visual field testing. Imaging-based measurements of the optic disc, retinal

nerve fiber layer, and ganglion cells are nevertheless increasingly important and provide information that clearly does not replace but is complementary to perimetry.

NEUROLOGICAL DISEASE

Field testing is not as crucial when managing neurological disease as it is in glaucoma management; neuroimaging often can replace perimetry. Nevertheless, visual field testing may sometimes provide an inexpensive and noninvasive complement to neuroimaging and a way of documenting changes in visual function.

RETINAL DISEASE

Visual field testing has a role in the diagnosis and management of some retinal diseases, but clinical observation and imaging of the fundus usually are of greater value. Perimetry then becomes one of many ancillary tests.

What Are We Looking For?

VISUAL FIELD LOSS DUE TO GLAUCOMA

The pattern of glaucomatous visual field loss reflects the anatomy of the damage caused by the disease. Field loss frequently occurs first in the so-called Bjerrum areas, which follow an arcuate course from the blind spot, broadening as it courses above or below the macula, and ending at the temporal raphe (Figures 7-3 to 7-5). Early glaucomatous field defects most often take the form of localized relative scotomas, that is, small areas of decreased sensitivity. Defects in the nasal field are particularly common, and sensitivity differences across the nasal horizontal meridian often are diagnostically informative (Figures 7-5 and 7-6).

Perimetric testing of glaucoma patients is seldom done outside of the central 30° field. Only a small percentage of glaucomatous fields have defects in the peripheral field alone, and testing the central 24°–30° field is preferred in glaucoma management today.

Considerable test-retest variability is a hallmark of areas of visual fields affected by glaucomatous visual field loss; variable sensitivity reductions occurring in the same area, but not always at the same test point locations, commonly precede clear-cut glaucomatous field defects (Figure 7-11). Although a reduction in overall visual field sensitivity frequently is seen in combination with localized glaucomatous loss, purely homogeneous reductions are more commonly associated with cataract and are rare and nonspecific in glaucoma (Figures 5-3, 7-7, and 7-8).

VISUAL FIELD LOSS DUE TO NEUROLOGICAL DISEASE

Nonglaucomatous lesions of the optic nerve typically produce either central scotomas or defects that follow the pattern of nerve fiber damage, similar to those caused by glaucoma. Neurological field defects caused by postchiasmal lesions are hemianopic, that is, they tend to affect either the right half of the visual field or the left, without crossing the vertical meridian, characteristically in both eyes (Figure 2-3). Some disease conditions may affect the chiasm along with the optic tract or optic nerve, or both, producing a mixed configuration of visual field damage. As with glaucoma, the great majority of defects start in the central 30° of the visual field, and thus central visual field testing is preferred here as well (chapter 10).

VISUAL FIELD LOSS DUE TO RETINAL DISEASE

Field defects caused by localized lesions of the outer retina are often deep, with steep borders (Figure 11-2). Lesions of the inner retina may produce visual field damage in the shape of the affected nerve fiber bundles. In the case of branch vascular occlusions, the shape of the field defect may reflect that of the ischemic area.

COEXISTING DISEASE

Because glaucoma patients frequently also develop retinal and neurological disease, it is important to be able to recognize the development of retinal and neurological field defects, even if those diseases are not primarily managed using perimetry.

Selecting a Test

Threshold testing is usually the best choice, and in ophthalmic clinical settings it is almost always to be preferred over suprathreshold screening tests. Threshold testing can detect the earliest visual field changes and is also the standard of care for following patients who have established field loss.

We recommend use of the 24-2 test pattern and the Swedish Interactive Thresholding Algorithm (SITA) Faster thresholding strategy for most patients. The 24-2 pattern tests the central visual field at 54 locations and has become the most commonly used testing pattern worldwide (Figure 3-2). The recently developed SITA Faster strategy offers testing times ranging from 2 to 4 minutes, while providing reproducibility that is similar to the two original SITA testing strategies (Figure 3-1).[1-12] SITA Faster is not available in the older HFA2 instruments, in which case our first choice would be SITA Fast. In either instance, a good alternative is SITA Standard.

Kinetic testing is also available in the Humphrey Field Analyzer (HFA) but nowadays is very seldom used in routine clinical care (chapter 3).

Perimetric Follow-Up

Perimetry's most important role is in management of patients who already have a diagnosis of glaucoma, and the primary goal of each encounter with such patients, is to determine whether current therapy is adequate or must be changed. If a patient is consistently examined with the same test pattern, then tests can be more effectively compared by using standardized progression analyses (chapter 6). The three SITA testing strategies (SITA Faster, SITA Fast, and SITA Standard) may be freely intermixed in the Humphrey perimeter's updated Guided Progression Analysis program.

Perimetry Outside the Central Visual Field

While the Humphrey Field Analyzer has complete capabilities for testing outside the central visual field, automated testing peripheral to 30° from fixation is rarely performed for diagnostic purposes. Testing outside the central 30° is mostly done to assess visual function, such as to certify the vision of automobile drivers or to certify visual disability for insurance purposes. Note that the goal in such certification testing is quite different from the usual goals when doctors are diagnosing and managing disease. Certification testing usually is done in order to detect a specified degree of loss of visual function, while perimetry performed for health care purposes usually seeks to detect and quantify subtle defects and small amounts of vision change over time in order to make timely diagnostic and therapeutic decisions. Testing of the peripheral field is one of few situations in which kinetic testing may be considered (chapter 3).

Other Testing Options

In severe or end-stage glaucoma (Table 7-1), it may be helpful to shift from the 24-2 to the 10-2 test pattern, which tests only the central 10°, but with a more detailed 2° grid of test points (Figure 3-3), or to change to a larger Size V stimulus (Figure 3-6). There is continuing research regarding the use of 10-2 testing in earlier stages of glaucoma (chapter 3).

Interpreting Test Results

The Humphrey perimeter provides two groups of interpretation aids. One group, called Statpac, can help identify visual fields that fall outside the normal sensitivity range and is helpful for analyzing visual field damage, regardless

of cause. A second group, called Guided Progression Analysis (GPA), can help identify patients with statistically significant visual field progression and determine the rate of such progression, primarily in patients with glaucoma.

Useful Statpac Analyses

The following description identifies important Statpac features (Figure 1-1). Further suggestions for interpreting these results are found in chapter 5.

NUMERICAL THRESHOLD SENSITIVITIES

This presentation simply shows the measured decibel sensitivity at each tested point and is the basic information upon which all the other analyses and printouts are based (Figure 2-5).

GRAYSCALE PRESENTATION OF THRESHOLD SENSITIVITIES

The grayscale is an intuitive way of presenting numerical threshold sensitivities, with darker areas indicating regions having lower sensitivity than lighter areas. However, because the data are not compared to normal ranges, clinically significant loss may not be recognized in this presentation (Figures 5-2, 7-11, 9-4, and 9-5). An important use of this presentation is as an aid in identifying artifactual findings (chapter 12), but it is also useful in immediately identifying typical disease-specific visual field defect patterns in eyes with well-established visual field loss.

TOTAL DEVIATION MAPS

For each tested point, any deviation from age-corrected normal sensitivity is quantified in the Total Deviation numerical plot. More importantly, the associated Total Deviation probability map highlights deviations that fall outside the statistical range of normal sensitivity.

PATTERN DEVIATION MAPS

Pattern Deviation maps highlight localized loss after first correcting for any overall change in the height of the hill of vision, such as that caused by cataract. Sensitivity deviations from expected values are quantified in decibels in the upper plot, while the statistical significance of those deviations is shown in the accompanying probability map. The Pattern Deviation probability map may be the single most useful Statpac analysis, simply because it displays the statistical significance of defects, their location, and their shape, after correcting for cataract effects.

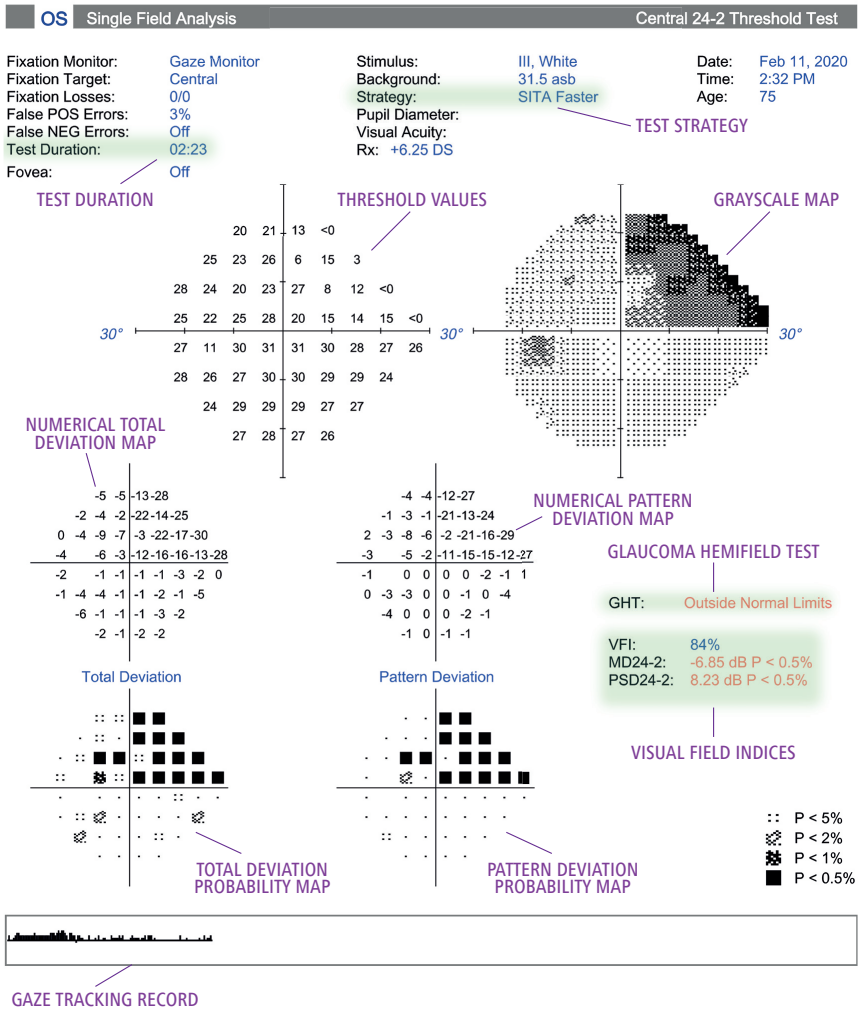

Figure 1-1
Statpac Single Field Analysis.

THE GLAUCOMA HEMIFIELD TEST

The Glaucoma Hemifield Test (GHT) is an artificial intelligence application that produces plain-language analyses of threshold test results. It has been reported to detect glaucomatous visual field loss with both high sensitivity and high specificity and presents its analysis in plain language (Figure 5-5).[13,14,17,18] For eye professionals who are not highly experienced at visual field analysis, this may be the single best place to look when judging whether a test result in a glaucoma patient or suspect is normal or pathological. The

GHT was not designed to be sensitive to neurological or retinal field loss but may also fall outside normal limits in these conditions.

VISUAL FIELD INDICES (MD, VFI, AND PSD)

Mean Deviation (MD) is a weighted average of the values presented in the Total Deviation numerical plot, with an MD of zero indicating no deviation from normal and large negative values being associated with advanced field loss. Visual Field Index (VFI) is an enhancement of MD that is designed to be less affected by cataract and more sensitive to changes near the center of the field, in order to better correlate with ganglion cell loss. Normal vision is associated with VFI values near 100%, while perimetric blindness, in which the patient cannot see even the perimeter's brightest stimuli, produces VFI values approaching 0% (Figure 6-7). Pattern Standard Deviation (PSD) summarizes localized loss in a single index while ignoring generalized depression. PSD is low for normal fields, for uniformly depressed fields, and for nearly blind or blind fields, and is highest in moderate to advanced localized loss.

These three indices are much less helpful for diagnosis than are the probability maps and the GHT. However, VFI and MD are very helpful for disease staging and following patients over time, the newer VFI being preferable.

Progressive Visual Field Change

Glaucoma management relies heavily on the quantification of visual field change over time. The Guided Progression Analysis, discussed in chapters 6 and 9, has been designed to help ophthalmologists and optometrists identify and quantify visual field progression. GPA has two types of analyses: Glaucoma Change Probability Maps and the VFI trend analysis. These two analyses are presented together in standardized GPA reports. Our preferred is the GPA Summary Report (Figure 1-2 and 9-10).

Glaucoma Change Probability Maps are designed to identify statistically significant progression events. These maps show areas of the tested field that have changed by more than the range of testing variability typically found in glaucoma patients (Figures 2-12 and 2-13). Reproducible statistically significant changes may be associated with glaucomatous progression. GPA automatically produces a plain-language analysis of series of field tests, called a GPA Alert, based upon change probability findings (chapter 6).

On the other hand, regression analyses over time of summary parameters such as VFI or MD are trend analyses that help differentiate between patients who are progressing at dangerously rapid rates and patients who may be progressing so slowly as to not require more aggressive therapy. Over the years, we have found regression analysis of the VFI values of threshold visual fields

to be the most helpful analytic tool for assessing the adequacy of each glaucoma patient's therapy. See chapter 9 for details.

Over the past decade, a paradigm shift has occurred in glaucoma management. While perimetric follow-up used to focus primarily on whether or not visual field progression had occurred, we now are more interested in determining the patient's rate of progression. The reason for this shift is that long-term studies have shown that most treated glaucoma patients do progress, and that progression usually will be evident if perimetric testing has been performed at reasonable test intervals for a number of years. Today, we try to differentiate between patients who, given their life expectancy and

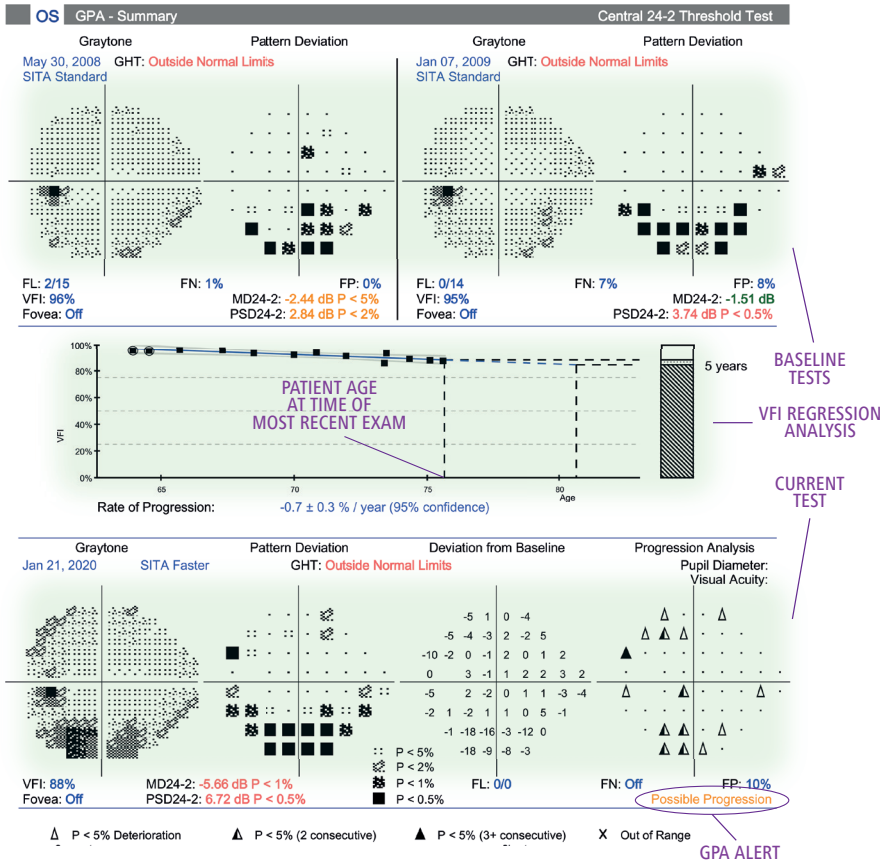

Figure 1-2

Guided Progression Analysis (GPA) Summary Report from a 76-year-old patient with progressive glaucomatous field loss.

the severity of their field loss, are progressing rapidly and dangerously—and who thus may need increasingly aggressive therapy—and patients who are progressing so slowly that a change in therapy is neither necessary nor desirable.[15,16]

Overview reports assemble abbreviated summaries of multiple test results, all in one report, and can facilitate qualitative review of many tests over time (Figure 6-10).

Artifactual Test Results

Several typical patterns of artifactual test results are worth recognizing. These include fields from eyes with partial ptosis or prominent brows and examinations in which the trial lens holder has blocked the patient's peripheral vision and produced false field defects.

Another type of artifactual test result is seen when patients anxiously press the response button even when no stimulus was seen—"trigger-happy" fields. This behavior is associated with test results showing unusually high threshold values that may mask areas of visual field loss.

Patients sometimes show what are called learning effects, that is, artifactually reduced sensitivity the first time they take a visual field test compared to later tests, but the effects typically are small. A minority of patients may produce results characterized by peripheral reduction of sensitivity, compared to the most central visual findings. These and other artifactual features of the test results are discussed more fully in chapter 12.

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2

Review of Basic Principles

THIS CHAPTER DESCRIBES NORMAL and abnormal visual fields and how visual field testing works.

Human Peripheral Vision

When looking at something of interest, we can also see other objects in our peripheral vision. Even though we cannot see these objects clearly, our peripheral vision constantly informs how we respond to our world and how we move through it. Every point on the retina corresponds to a certain direction in the visual field, and because the image formed on the retina is inverted, just like a camera, the nasal retina sees objects in the temporal visual field and vice versa. Likewise, the superior retina corresponds to the inferior visual field and the inferior retina corresponds to the superior field.

Visual information from all parts of the retina is transmitted via retinal nerve fibers, which join together to form the optic nerve, and because the optic nerve head itself contains no photoreceptors, the area it occupies on the retinal surface constitutes a physiological blind spot. Since the optic nerve head is located about 15° nasal of the fovea, the physiological blind spot is located in the temporal visual field, about 15° temporal of the point of gaze. Blind spot size varies from person to person but typically subtends an angle of about 5° in the horizontal and about 7° vertically.

The Normal Visual Field

The normal field of vision extends more than 90° temporally, 60° nasally and superiorly, and about 70° inferiorly, relative to the point of gaze, which is also called the fixation point. For a number of reasons, most diagnostic visual field testing concentrates on the area within 30° of fixation, called the *central visual field.* The area beyond 30° is often called the *peripheral visual field*. The central visual field is where most of the eye's retinal ganglion cells are located. When making diagnostic and disease management decisions, the central field also provides visual sensitivity measurements that are considerably more precise and informative than measurements in the peripheral visual field.

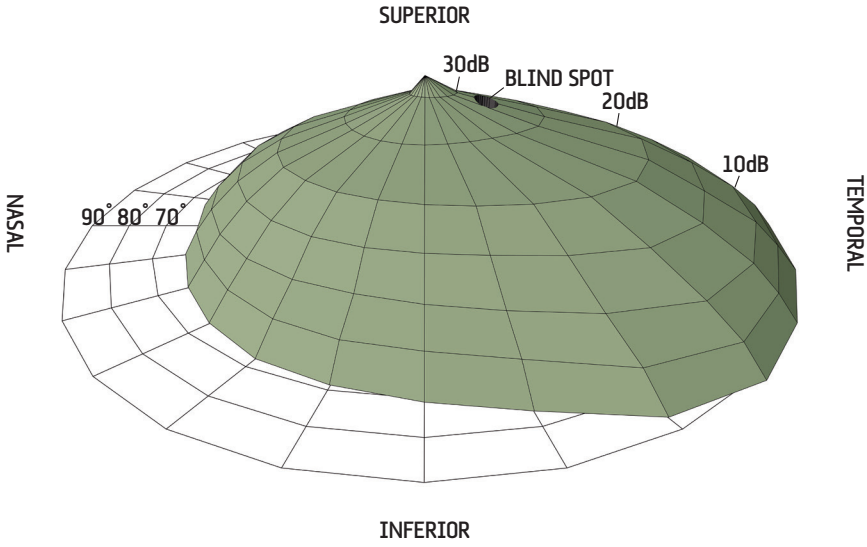


Figure 2-1

Hill of vision for the right eye of a normal 51-year-old person tested with a Goldmann Size III stimulus. Peripheral vision normally extends more than 90° temporally and less in other directions. The height of the hill of vision represents the eye's sensitivity, which is highest at the point of fixation and gradually decreases toward the periphery. Most clinical testing is performed in the central visual field, within 30° 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 (Figure 2-1). The height or sensitivity of the normal hill of vision is affected by age, the general level of ambient light, stimulus size, and stimulus duration.

The Abnormal Visual Field

A visual field defect is any statistically significant depression of visual sensitivity compared to the normal hill of vision. For the Humphrey perimeter, estimates of the statistical significance of threshold sensitivity findings are provided by the Statpac analysis program (chapter 5).

Field defects may be localized or general. Localized field defects can be described in terms of both size and the amount of sensitivity loss, which is also referred to as the *depth* of the loss. Quantification of the size and depth of defects is important in differentiating between normal and pathological findings, in staging the amount of visual field damage, and also in detecting and quantifying change over time. An abnormal area of the visual field

where the patient still has some remaining vision but where sensitivity is below the normal range is called a *relative visual field defect*, while an area where even the most intense available perimetric stimulus is not seen is termed an *absolute defect*.

Except for defects very near fixation, peripheral vision losses that are quite evident on perimetric test results are unlikely to be perceived by the patient if the damage is in the cones and rods or farther back in the neurological system. This is due to the so-called filling-in effect[1-5] (Figure 2-2), and such field defects are called *negative field defects*. This is why patients seldom tell us about visual field loss and why we must rely upon visual field testing to detect such damage. Field loss occurring from lesions in front of the photoreceptors and the neural system, e.g., a macular hemorrhage, will be very clear to the patient, as a brown or dark spot in the central visual field.

Anatomic Basis of Peripheral Vision Loss

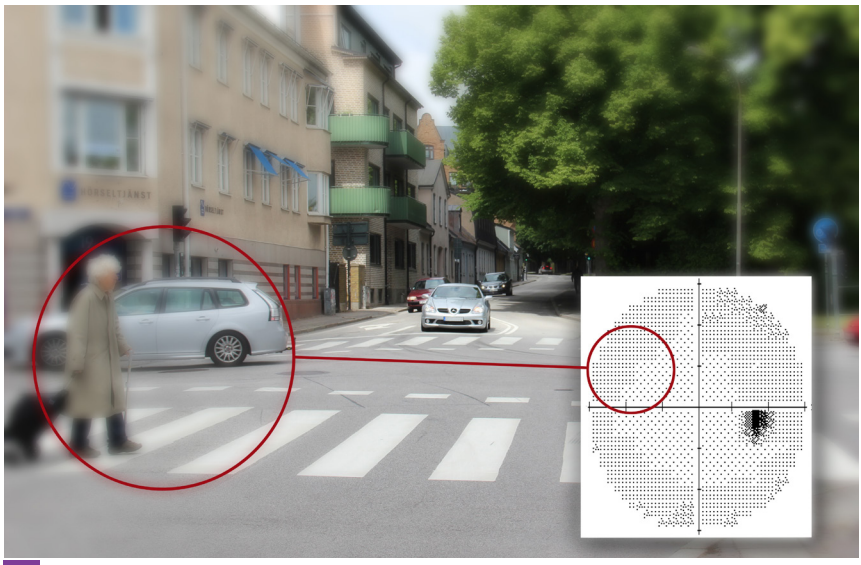
Visual field loss can be caused by disease processes occurring in the eye itself or anywhere along the visual pathway from the eye to the occipital cortex (Figure 2-3). Lesions occurring between the eye and the chiasm will produce visual field damage that is specific to the involved eye or optic nerve. Lesions affecting the postchiasmal visual pathway—between the chiasm and the primary visual cortex—produce similar but not necessarily identical visual field damage in both eyes. Lesions directly affecting the nerve fibers crossing at the chiasm itself tend to produce defects in the temporal visual fields of both eyes.

FIELD DEFECTS CAUSED BY PRERETINAL CONDITIONS

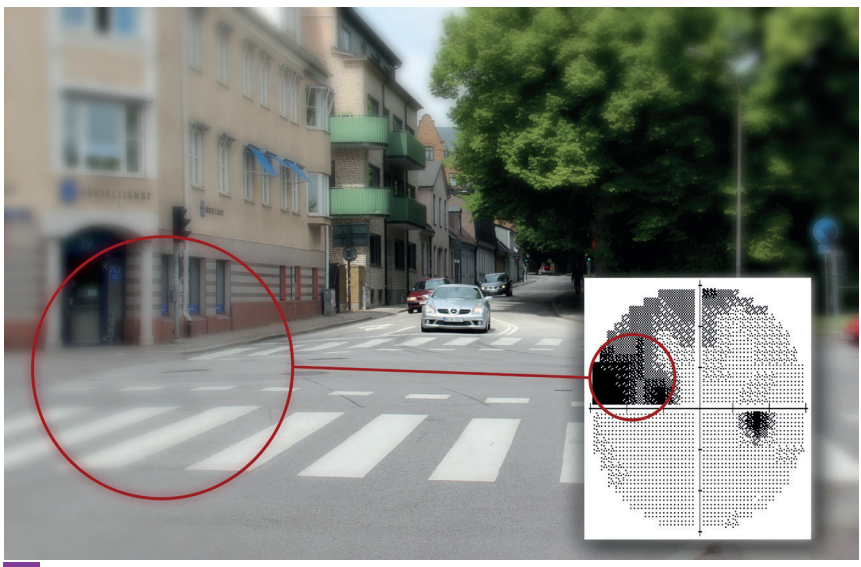
Field defects caused by preretinal conditions include cataract and corneal clouding, which reduce perceived stimulus contrast. These and other forms of cloudy ocular media result is a general, or diffuse, reduction of visual field sensitivity (Figures 7-7 through 7-10). A general depression also can be caused by uncorrected refractive error. A lesion close to the retina preventing light from reaching the photoreceptors, such as a preretinal macular hemorrhage, will cause a localized scotoma, which will be visible to the patient as a positive field defect.

FIELD DEFECTS CAUSED BY DISEASE OR ABNORMALITIES IN THE OUTER RETINA

Damage to the retinal pigment epithelium or to photoreceptors can produce corresponding areas of visual field loss. For example, age-related macular degeneration can cause a central scotoma, visual field loss in retinitis pigmentosa is often deepest in the midperiphery of the visual field, and



A



B

Figure 2-2

Filling-in phenomenon. Most field defects are negative, which means that they will not be perceived as, for instance, dark or blurred areas. Instead, the brain will cause so-called filling-in, thus creating an inaccurate but believable image in the part of the patient's visual field that is defective. A patient with a nasal field defect may therefore fail to see the pedestrian and the car shown in A (depicted as seen by a normal eye), but instead will perceive a believable image of the intersection, such as that depicted in B. Note that both the normal and the damaged visual field simulations illustrate the lower resolution that is typical of peripheral vision compared to central vision.

photocoagulation scars will each produce a small scotoma. Such defects do not respect the vertical or horizontal meridian and, if bilateral, are not identical in the two eyes.

FIELD DEFECTS CAUSED BY INNER RETINAL DISEASE AND CONDITIONS OF THE OPTIC NERVE

These defects constitute the third category of prechiasmal disease conditions that affect the visual field. Glaucoma is the most common disease that affects this segment of the visual pathway, and other conditions in this anatomic region may produce field defects that mimic those seen in glaucoma.

Field loss shape, size, and location are based on the visual field regions served by the affected ganglion cells or their nerve fibers. For instance, glaucomatous visual field loss associated with shallow or incomplete notching of the optic disc's neuroretinal rim can take the form of small localized scotomas (Figures 7-3 and 7-4). On the other hand, deep focal damage to the optic disc's neuroretinal rim can produce arcuate or curved field defects that follow the path of the damaged retinal nerve fibers (Figures 7-4 and 7-5). Such defects do not cross the nasal horizontal meridian. Optic disc drusen also can damage nerve fiber bundles, causing field loss that sometimes is indistinguishable from a glaucomatous visual field (Figure 10-5).

Nonglaucomatous prechiasmal conditions can cause central scotomas, as in optic neuritis (Figures 10-1 and 10-2), or field loss similar to that seen in glaucoma, as in ischemic optic neuropathy (Figure 10-3). Because retinal vessels track with the course of nerve fibers in the inner retina, vascular occlusions may cause paracentral or arcuate scotomas resembling glaucomatous field defects.

FIELD DEFECTS CAUSED BY DISTURBANCES AT THE CHIASM

Conditions such as pituitary adenoma can affect axons at the chiasm, some of which cross from one side of the brain to the other. Nerve fibers crossing at the chiasm originate in the nasal retina of each eye and cross to join the fibers of the temporal retina of the other eye. Thus, bilateral damage to crossing fibers can produce visual field loss in the temporal visual fields of both eyes, which in early stages of disease may be incomplete and asymmetric (Figure 10-7). Disease affecting the chiasm may be extensive enough to also affect the optic nerve or the postchiasmal optic tract, resulting in visual field abnormality that includes features of damage in these locations (Figure 10-8).

FIELD DEFECTS CAUSED BY LESIONS IN THE POSTCHIASMAL VISUAL PATHWAY

Tumors, vascular disease such as stroke, or head injuries occurring anywhere along the pathway from the optic tract to the visual cortex can damage either the right or left visual fields of both eyes; these defects are called homonymous hemianopic defects (Figures 10-9 and 12-11). Homonymous field defects may or may not be congruous, which is to say affecting both eyes similarly in shape and depth. In general, the more posterior a postchiasmal lesion, the more likely it is for field defects in the two eyes to be congruous.

SUMMARY

PRECHIASMAL CONDITIONS

- General depression of the visual field suggests preretinal cause, most commonly cataract, or optic nerve compression.
- Central scotoma suggests outer retina damage, such as that caused by age-related macular degeneration, or optic nerve disease, such as optic neuritis.
- Scotomas that reach but do not cross the horizontal nasal meridian, thus "respecting" the horizontal meridian, suggest disease of the inner retina or the optic disc, and sometimes of the optic nerve. Glaucoma is among these diseases and is the most common cause, but is not the only cause of such defect patterns.
- Scotomas in the arcuate Bjerrum region that become particularly wide or dense nasally are typical of glaucoma but can be caused by other optic disc or inner retinal disease.
- Most prechiasmal lesions have ophthalmoscopic signs, which can be subtle.
- Beware of unilateral prechiasmal defects that resemble glaucoma. Other conditions can cause both visual field defects and thinning of the retinal nerve fiber layer.

CHIASMAL AND POSTCHIASMAL CONDITIONS

- Bitemporal field loss respecting the vertical meridian suggests a lesion at the chiasm. Homonymous hemianopia suggests a lesion posterior to the chiasm.
- Greater congruity of hemianopia in the two eyes favors more posterior intracranial lesions, but there are exceptions. A complete homonymous hemianopia may be caused by lesions anywhere from the optic tract to the visual cortex.

- Beware of glaucomatous progression that is sudden, unexpected, or uncharacteristic. Stop to consider whether there is a newly developing comorbidity, perhaps of neurologic or ocular origin.

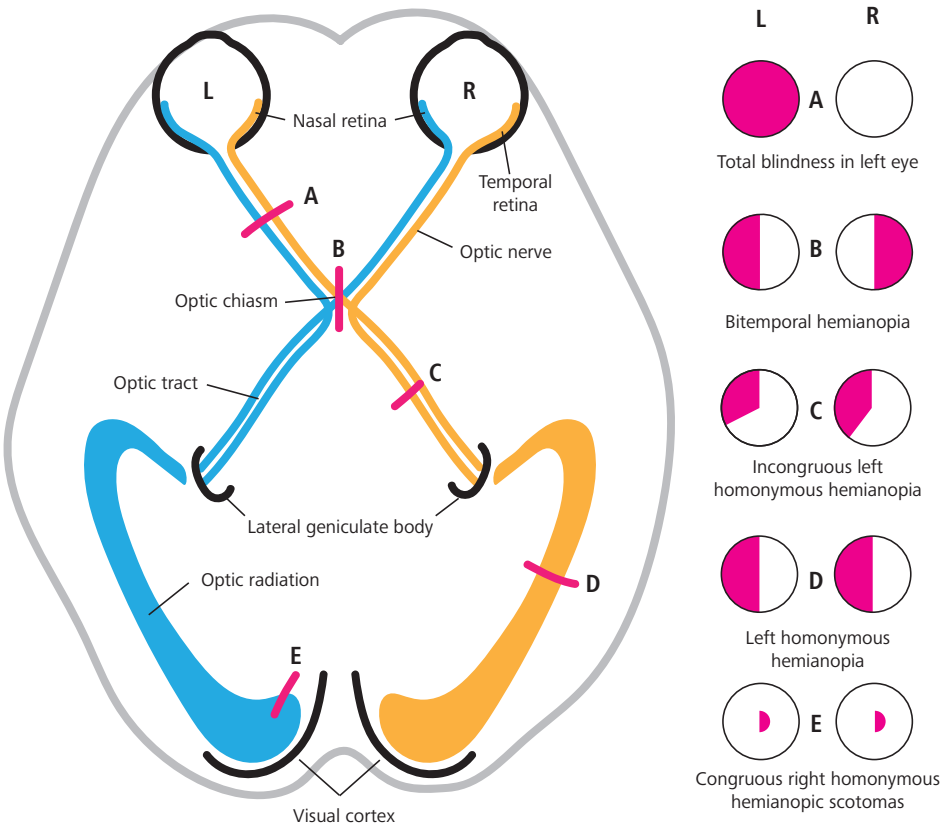


Figure 2-3

Anatomic basis of peripheral vision. Signals from the right halves of the visual fields of both eyes end up in the left visual cortex, and the left halves of the visual fields of both eyes end up in the right visual cortex. Prechiasmal lesions will produce field loss only in the affected eye. Chiasmal and postchiasmal lesions will produce visual field loss in both eyes. Visual pathway damage at locations A through E will cause visual field loss in the red areas illustrated on the right.

Application of Perimetric Findings

This book primarily addresses the application of perimetry to disease diagnosis and management. The goal of perimetry in such cases is to obtain information important to diagnosis and to the therapeutic 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. Perimetric examinations generally involve careful measurement of light sensitivity at various locations in the field of vision. Because light sensitivity is commonly defined as the stimulus strength that is perceived 50% of the time, the term *threshold sensitivity* often is used when discussing perimetrically measured light sensitivity.

Perimetry may also be used to determine the extent of visual impairment or in order for the patient to qualify for a driver's license. In such instances, subtle defects often are ignored. Most commonly, these examinations are performed by presenting stimuli at intensities that would not be missed unless there were functionally meaningful losses of vision.

Issues in Instrument Design

A perimeter might be characterized as an instrument that can project a stimulus of known size and intensity onto a surface or background having a known brightness, for a known amount of time, and at a known location in the visual field. Effective visual field testing can be achieved only if each of these factors is carefully controlled.

STIMULUS SIZE AND INTENSITY

Threshold sensitivity is determined in Standard Automated Perimetry by varying only the stimulus intensity, not stimulus size. The Humphrey perimeter is capable of testing with the five standard Goldmann stimulus sizes (Figure 2-4), but the 0.43° Goldmann Size III stimulus is used almost exclusively. Size V is sometimes employed in advanced field loss, while Sizes I, II, and IV are almost never used.

The Humphrey perimeter presents white light stimuli that can be varied in intensity over a range between 0.1 and 10,000 apostilbs (asb) (0.03 to 3,183 candelas per square meter). Test results are presented in units of decibels (dB), with zero dB corresponding to the maximum intensity that the perimeter can produce (10,000 asb) and 50 dB corresponding to 0.1 asb (Figure 2-5).

In standardized testing with a Goldmann Size III white stimulus, the lowest stimulus intensity that can be seen by a young, well-trained observer is about

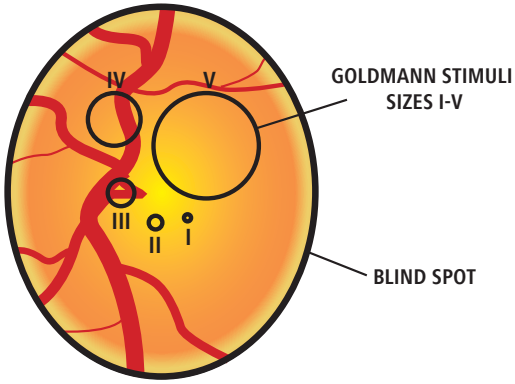


Figure 2-4

Goldmann stimulus sizes. Goldmann stimulus Sizes I through V are available in the Humphrey perimeter. All stimuli are much smaller than the physiological blind spot, which normally subtends 5° horizontally and 7° vertically. Stimulus diameters differ sequentially by factors of two, with Sizes I, II, III, IV, and V subtending 0.1°, 0.21°, 0.43°, 0.86°, and 1.72°, respectively.

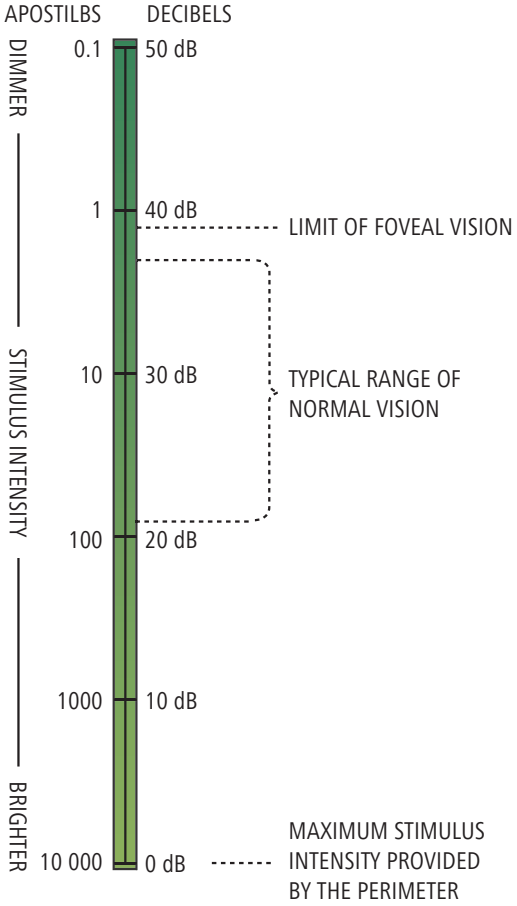


Figure 2-5

Humphrey Field Analyzer stimulus intensity scale. Visual field sensitivity is measured and expressed in decibels (dB), which is a logarithmic unit. Under standard testing conditions, the maximum foveal sensitivity found in healthy, young, normal subjects is near 40 dB (1 apostilb). The maximum stimulus intensity of the perimeter (10,000 apostilbs) corresponds to zero dB.

1 asb, or 40 dB. Thus, the upper (and dimmest) 10 dB of the stimulus range—from 41 to 50 dB—really falls outside the range of human vision when using a Size III stimulus under standard testing conditions. However, the upper 10 dB of stimulus range is useful when using stimuli larger than Size III.

BACKGROUND ILLUMINATION

In standard Humphrey perimetry, stimuli are projected onto a surface that itself is uniformly illuminated at a brightness of 10 candelas per square meter (31.4 apostilbs). This background illumination level was originally used in the Goldmann perimeter and is an internationally recognized standard.[6] This level was chosen because it approximates the minimum level of retinal adaptation for photopic, or daylight, vision—vision that depends upon retinal cone function more than on rod function. The advantage of testing the photopic visual system is that visibility depends more on object contrast than on absolute intensity. Under photopic conditions, changes in pupil size or crystalline lens color and transparency have less effect on test results. At dimmer, scotopic levels of retinal adaptation, absolute object intensity becomes more important than contrast, and pupil size and optic media effects become more difficult to control.

STIMULUS DURATION

The Humphrey perimeter uses a standard stimulus duration of 200 milliseconds (except in the Esterman test), which is long enough for visibility to be little affected by small variations in stimulus duration but is still shorter than the reaction time for voluntary eye movements, so the patient does not have time to see the stimulus in the peripheral visual field and then look toward it.

FIXATION MONITORING

The effect of unsteady patient fixation might be likened to what happens when a camera is jiggled during photography. Some objects in the photograph might appear to be moved and others might appear a bit blurred. Unsteady fixation can blur the perimetric image, changing the size, depth, and location of visual field loss, and thus can be a concern in some patients. Fortunately, most patients fixate adequately, and the fixation monitoring task has primarily become one of identifying those few patients whose gaze is so unsteady that they should be reinstructed on proper fixation technique.

The gaze tracker on the Humphrey perimeter measures gaze direction with a precision of about 2° and automatically records gaze direction each time a stimulus is presented. Gaze tracking results are shown on the perimetrist's video screen during testing and are presented at the bottom of the test

report (Figures 5-8 and 5-9).[7,8] Gaze tracking and its associated analysis techniques continue to evolve, and we expect to see further refinements soon.[9,10]

Some less common models of the Humphrey perimeter rely only upon the Heijl-Krakau blind spot monitoring technique[11] rather than on a gaze tracker. The Heijl-Krakau method provides an index of the quality of patient fixation during an examination by periodically presenting stimuli in the blind spot. Positive responses are presumed to indicate poor fixation, that the patient was not looking at the proper fixation point. The amount of gaze data provided by the Heijl-Krakau method is quite limited, simply because only a few blind spot check stimuli can be presented during a visual field test. Thus, we recommend use of the gaze tracker whenever available.

Static Threshold Perimetry

The objective of static threshold perimetry is to measure the eye's light sensitivity at specific locations in the field of vision (Figure 2-6). Static perimetry was performed manually long before computers were widely available,[12] but was

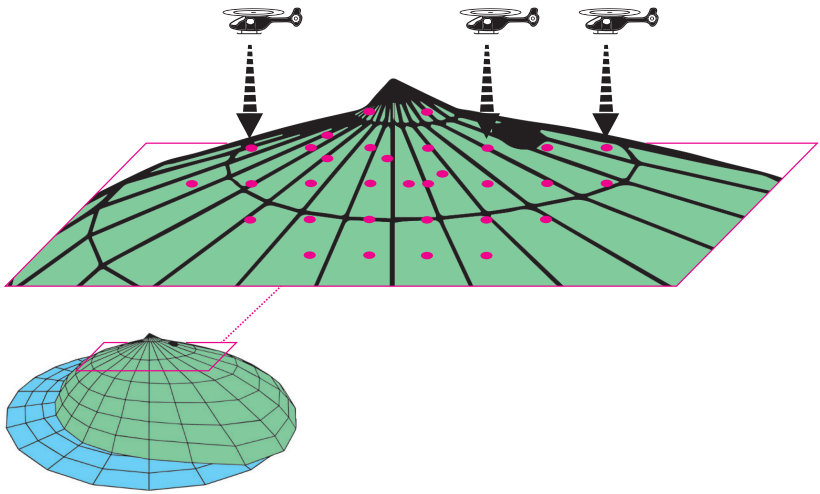


Figure 2-6

Static threshold perimetry. The inventor and physician John Lynn likened static visual field testing to determining the topography of an island by having a helicopter hover at a known altitude over each of a number of preselected locations and then lowering a weighted bucket until it touched the ground. By plotting how far the bucket was lowered at each tested location, a topographic map of the island could be drawn.[19] In static threshold perimetry, stimulus intensity at each test point is increased or decreased in a stepwise manner in order to determine the minimum intensity that can be seen by the patient, which is referred to as the patient's threshold sensitivity.

used only in a few research settings. Computerization facilitated the development of increasingly complex and efficient testing strategies and data analysis methods that previously would have been impractical. Computerization also enabled standardization of testing algorithms, which has greatly improved test comparability between clinics and around the world. Standardization in perimetry now is so highly valued that most clinics and hospitals have standardized on a narrow range of testing procedures—most commonly on a Humphrey 24-2 SITA threshold test. Over the years, a number of researchers have reported computerized static perimetry to be superior to various methods of carefully performed manual perimetry.[13-18]

Clinical Threshold Testing Strategies in Automated Static Perimetry

Threshold testing strategies used in clinical automated static perimetry evolved from methods employed in vision science laboratories. However, those evolutionary changes have been quite profound, due to the fact that doctors and clinics are subject to much more severe time constraints than are vision scientists. Successful clinical testing strategies must balance time efficiency with the need to control measurement accuracy, and maintaining that delicate balance has been a key focus over the many years we have spent inventing and refining the testing and analysis methods used in the Humphrey Field Analyzer (HFA).

One way the first HFA thresholding strategy, which was called Full Threshold, saved time without giving up accuracy was to begin testing at a single location in each quadrant of the visual field. These initially tested locations were called primary points. Time was saved by using threshold sensitivity findings at these primary points to choose initial stimulus intensities at adjacent test points, and those secondary results were then used to determine initial intensities at subsequently tested locations, until the sensitivities at all points had been measured (Figure 12-8b).

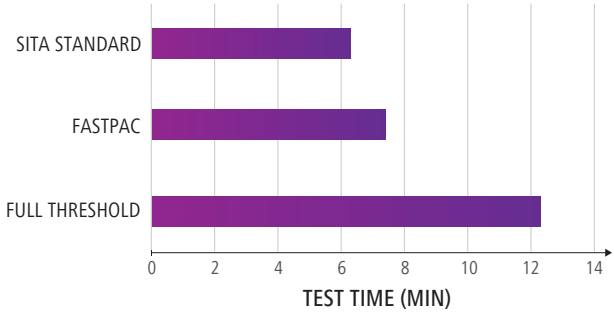
The original HFA testing strategy took about 15 minutes per eye for 30-2 testing of glaucomatous visual fields. Soon after introducing the first HFA, we realized that we might be able to further reduce testing time, and we began development of the SITA (Swedish Interactive Thresholding Algorithm) family of thresholding strategies. We hoped to cut test times in half while maintaining the same or better measurement accuracy and the same or lower variability as the original Full Threshold method.[20,21] We started this project well before computers were fast enough to perform all the computations required by our new method without slowing down the

test. Obviously, we were betting that processors would evolve rapidly, and fortunately they did. In the end, we were able to cut testing time in half with the introduction of SITA testing, without compromise in overall clinical performance.[20, 22-32]

The patented SITA strategies depended upon a host of seemingly small and very technical improvements, and also a few *big* improvements. One of the larger improvements involved invention of comprehensive prior models of both normal and abnormal fields. Essentially, the models allowed us to use all patient responses—all seen stimuli and all unseen—to determine threshold sensitivity, instead of simply relying only on the last seen stimulus at each test point, as we had done earlier. During SITA testing, the models are continuously updated with each patient response, producing real-time maximum likelihood estimations of threshold sensitivity for each test point and also calculations of the precision, or certainty, of those estimates. We used the *certainty* calculations to determine when we could stop testing at each point, instead of always presenting stimuli in inflexible and time-consuming steps, as had been done in earlier testing strategies. A second key improvement involved designing a perimeter that, electromechanically speaking, was so quick that it usually was waiting for the patient, an improvement over the original HFA, in which the patient usually was waiting for the instrument. A third key step was to constantly measure each patient's reaction time and to continuously adjust testing speed to fit each individual patient. We also developed a method to measure False Positive patient responses without having to use catch trials (chapter 5).

Computer simulations were very useful because they allowed us to assess the actual accuracy of candidate strategies, since we had the true threshold values in the simulator. Simulations also allowed us to look at thousands of tests at a time and thus were used to individually optimize each of the many parameters in the new models. For example, we used simulations to optimize the level of certainty required to stop testing at each location. We then confirmed those individual optimizations in small clinical evaluations. Once we had optimized all the individual variables, we performed clinical comparisons of the reproducibility and diagnostic performance of our candidate algorithms with those of legacy strategies (Figures 2-7 and 2-8).

We also stayed away from self-defeating shortcuts, such as trying to reduce testing time simply by averaging results from adjacent test points. Many other details of how SITA was originally developed can be found in the PhD dissertation of one of this book's authors, Boel Bengtsson, and in the dissertation of one of the SITA team's mathematicians.[20-32]



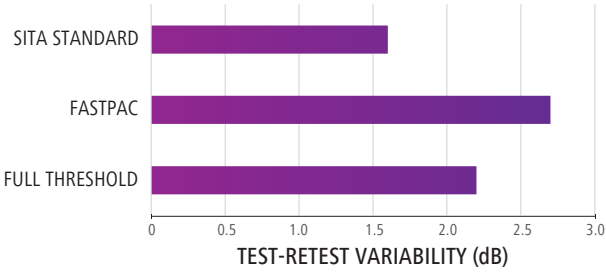


Figure 2-7

SITA Standard 30-2 testing time and variability versus legacy strategies.[20] Our goal was to cut testing time of the ambitious Full Threshold algorithm in half without increasing test variability.

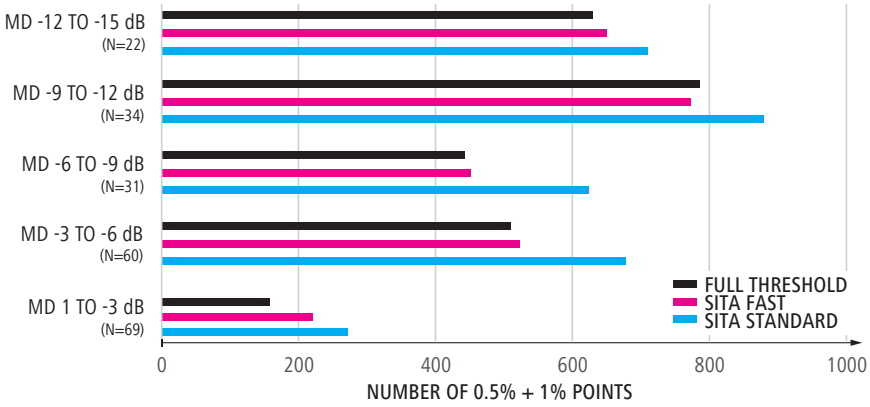


Figure 2-8

Comparison of number of test points showing statistical significance in Pattern Deviation at $p < 0.01$ in 260 glaucoma patients examined using SITA Standard, SITA Fast, and the legacy Full Threshold testing algorithm. SITA Standard and SITA Fast found at least as much glaucomatous field loss as the original Full Threshold using Statpac interpretation tools.[27-29]

In the recent development of SITA Faster, we repeated many of the processes already described. In the SITA Faster project, our goal was to produce a significantly faster version of SITA Fast while preserving SITA Fast's diagnostic performance and reproducibility. To achieve this goal, we identified seven specific modifications: (1) using more efficient stimulus starting intensities; (2) testing primary points once instead of twice; (3) updating the visual field model, incorporating information that was not available when SITA Fast was developed; (4) testing perimetrically blind points once instead of twice; (5) discontinuing routine use of False Negative catch trials; (6) using HFA's gaze tracker instead of the Heijl-Krakau blind spot method; and (7) removing an unnecessary time delay after not-seen stimuli.

As before, individual changes were optimized and tested in computer simulations and then in clinical evaluations. The final SITA Faster strategy then went through a 3-site pilot evaluation, after which we confirmed the design in a 5-site investigator-initiated international clinical trial. This final trial confirmed that SITA Faster saved considerable test time, gave the same results as SITA Fast, and had inter-test variability that was the same as SITA Fast. Mean test time for SITA Faster was 30% shorter than that of SITA Fast and 53% shorter than that of SITA Standard.[33] Independent evaluations later produced similar findings.[34,35] SITA Faster is also discussed in chapter 3.

Static Suprathreshold Perimetry

Suprathreshold testing and threshold testing have different goals. Suprathreshold testing is intended to establish whether the eye's 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 reasonably normal, this method is easy to use with patients who have never had a visual field examination before.

Historically, suprathreshold tests took much less time than the early threshold tests, but this speed advantage has disappeared with the availability of SITA Faster 24-2 threshold testing. Suprathreshold tests also do not provide quantitative data and are not as sensitive to early field loss as threshold tests.[36] As a result, suprathreshold testing is now used much less often in clinical care than in the early days of automated perimetry. Nevertheless, one should remember that suprathreshold tests are easier for inexperienced patients and will produce fewer false positive results than threshold tests in such patients. They therefore still have a role in patients

in whom the suspicion of field loss is small, for example in patients having a positive family history of glaucoma but no other suspicious findings, or in screening (for example) refraction patients for unexpected vision loss. Suprathreshold testing also is used in tests for visual impairment and for driving certification (chapter 3).

Kinetic Perimetry

Prior to the introduction of automated static perimetry, Goldmann manual kinetic perimetry was the clinical standard for visual field testing. The objective of kinetic perimetry is to identify adjacent locations in the peripheral vision that all have a particular threshold sensitivity. A stimulus of known size and intensity is slowly moved from the periphery toward the center of the field until the patient reports seeing it (Figure 2-9). The point where the stimulus is detected is recorded and the same stimulus is brought in from other angles around the hill of vision. Connecting all the points where the stimulus was first detected produces an isopter—a line connecting all tested points having the same visual sensitivity. The test is continued using one or more stimulus intensities and/or stimulus sizes until enough isopters have been produced to characterize the shape of the hill of vision. Often, only two isopters were plotted, one with an intense stimulus that normally could be seen in the periphery of the field and one with a weaker stimulus that was expected to become visible approximately 20° from the point of fixation (Figure 3-8). Analysis of test results was done in a qualitative manner, as normative data and statistical analysis packages were not available.

Today, kinetic perimetry has largely been replaced by automated static perimetry. Nevertheless, the Humphrey perimeter is capable of performing kinetic testing, and instructions may be found in the most current HFA User Manual. The instrument can be run in a fully automated mode or in a semimanual mode. However, kinetic perimetry is rarely recommended. See chapter 3 for further discussion on this topic.

Expected Values and Normal Ranges

Automated static perimeters measure threshold sensitivities at chosen locations in the visual field, and early perimeters simply presented the user with a field of threshold sensitivities in numeric and grayscale form (chapter 5), or numerical deviations from expected values, but with no empirical guidance as to what the normal range at each test point might be. These early data presentations were only useful in detecting quite marked visual field defects, such as well-defined hemianopias or deep localized scotomas.

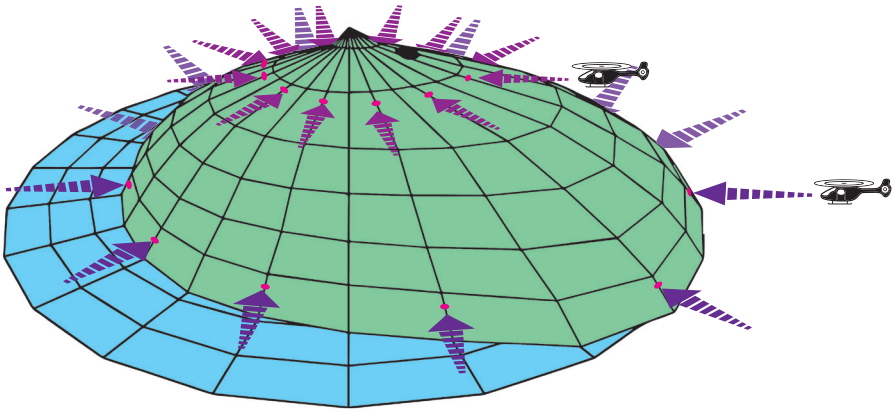


Figure 2-9

Kinetic perimetry may be likened to using a helicopter to map the topographic contours of an island by approaching the island from different directions, always at the same altitude. Whenever the helicopter touches the island, the crew marks the point of contact with a particular color of paint. Connecting all of the painted locations on a photograph taken from high above the island would then produce a line of constant altitude, which in cartography is called a contour line. Other contour lines could be produced simply by repeating the process with the helicopter flying at a different altitude. In kinetic perimetry, a stimulus is brought in toward the island of vision from a number of different directions and the points where the stimulus was first seen are connected on the test record. The line is then a contour of constant visual sensitivity, called an isopter.[19]

It soon became clear that empirically based data interpretation aids were needed and that the place to start was in clinical determinations of the statistical range of visual sensitivities commonly found in people having normal vision. Thus, in 1985 we combined population-based normal visual fields from four clinical trials, one at the University of Iowa, a second at Johns Hopkins University, and our own clinical trials at the University of Lund and at Oak Knoll Naval Hospital in California. All tests were done using the HFA's Full Threshold testing strategy. As far as we know, this may have been ophthalmology's first international multicenter normative database.[37-39,41]

From these data, consisting of 487 tests of 239 normal subjects, we calculated normal ranges for visual sensitivity at each test point location of the 30-2 test pattern, as defined by age-corrected significance limits for normal intersubject threshold sensitivity.[39-42] We incorporated those limits into an analysis application that was programmed into the Humphrey perimeter.[21,43] We called this analysis aid Statpac, and it is described in chapter 5. In the

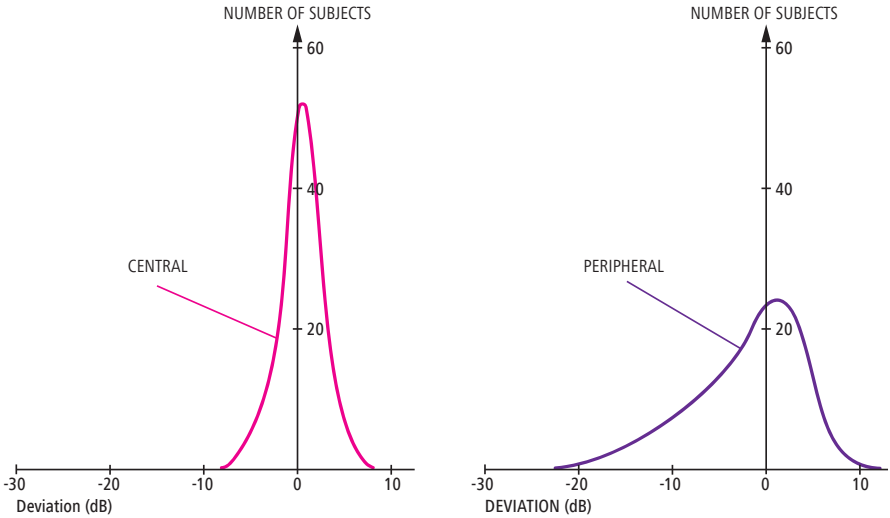


Figure 2-10

Histograms of interindividual deviations from age-corrected normal threshold for a central test point, at 3° nasally and 3° superiorly (left), versus a peripheral test point at 3° nasally and 27° superiorly. Distributions are non-Gaussian and negatively skewed, and skew is more pronounced in the periphery (right), compared to the central point.[43] Statpac includes significance limits at the 5%, 2%, 1%, and 0.5% levels, individually calculated for each test point location and differing among test algorithms.

decades since, we have developed multiple Statpac updates that allowed analysis of test results obtained with new generations of testing strategies.

In analyzing these normative data, we found the distribution of threshold sensitivity to be non-Gaussian and negatively skewed (Figure 2-10) and thus it could not be analyzed using standard parametric statistical methods. We also learned that the range of peripheral sensitivity in normal subjectes is much larger in the periphery than in the center of the field and increases more rapidly in the superior field than elsewhere, and that aging effects are not uniform across the visual field (Figure 2-11).

Detection and Measurement of Perimetric Change

Patients under treatment for glaucoma who continue to lose visual field sensitivity at dangerous rates may require more aggressive therapy. Thus, detection and quantification of visual field progression events and the measurement of the rates of progressive loss are central to successful management of glaucoma patients (chapter 9).

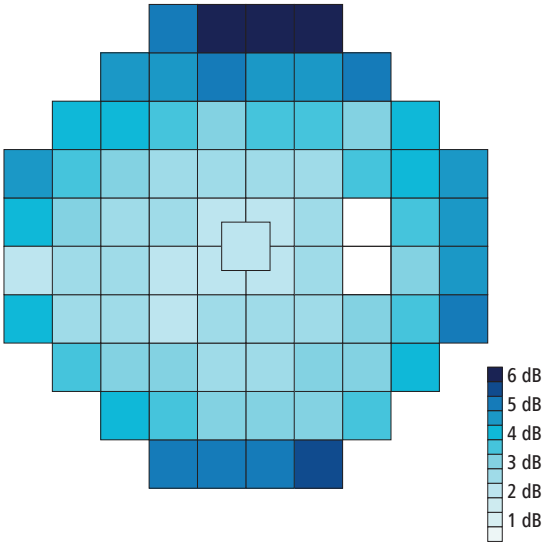


Figure 2-11

Normal intersubject variability of threshold sensitivity expressed as standard deviations of individual deviations from age-corrected normal values in decibels, for the 30-2 test pattern. Normal intersubject variability increases asymmetrically with distance from fixation and is highest in the superior field. In most peripheral test points, distributions are not at all Gaussian but are negatively skewed. Compare to Figure 2-10.[42]

All measurements have some variability, and threshold perimetry is no exception. Visual field deterioration that is repeatably larger than known and expected test-retest measurement variability may be taken as a sign that the patient's peripheral vision has changed. Thus, we realized early on that we needed to empirically quantify the variability of our most important visual field metrics, and we organized a clinical trial in which 51 glaucoma patients were tested 4 times in the space of one month.[44]

Again, we learned that parametric statistical methods could not help us. However, when we did finally master the statistics, we learned that perimetric test-retest variability was quite complex. Pointwise significance limits for statistically significant change from baseline depended upon location in the visual field and also on local and general levels of field loss. In the end, we learned how to identify test points that had changed from baseline by more than the variability seen in 95% of glaucoma patients (Figures 2-12 and 2-13). These findings became part of what we now call the Guided Progression Analysis software for the HFA, which is described in chapter 6.

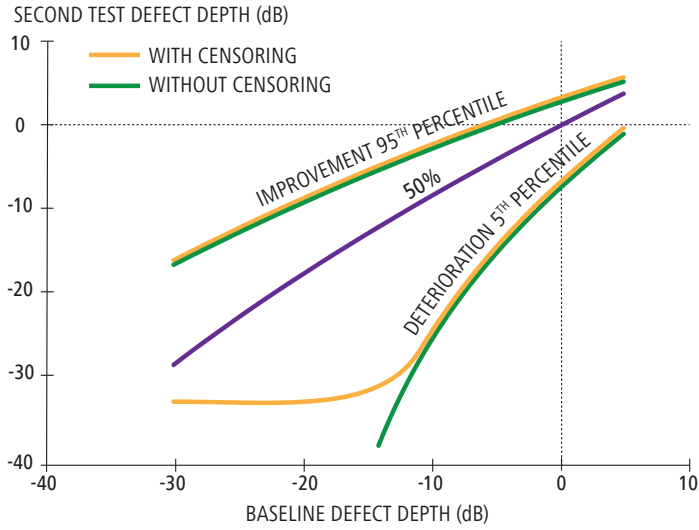


Figure 2-12

Effect of stimulus intensity limitations on test-retest variability; significance limits for pointwise change from baseline, using HFA threshold testing and stimulus Size III. Orange lines show 5th and 95th percentile limits for deterioration and improvement when not correcting for data censoring caused by the instrument's finite dynamic range. The uncorrected orange deterioration curve shows a highly misleading and artifactual decrease in test variability at defect depths worse than approximately -14 dB. Green lines show true significance limits when data censoring is accounted for. The green line demonstrates a continual increase in test-retest variability with increasing visual field loss and suggests that further increases in dynamic range likely would provide only small improvements in ability to judge clinical change. Significance limits for change also vary with baseline Mean Deviation or Visual Field Index values and also with test point location (Figure 2-13).[45,46,48,49]

With development of the SITA strategies, larger multicenter studies were performed in order to quantify SITA inter-test variability in glaucoma patients.[29] The progression analyses used for SITA tests are based upon those clinical trials. Perimetric test variability in diabetic retinopathy also was found to increase with defect depth and with test point eccentricity.[47]

Structural and Functional Measurements

In ophthalmic disease management, we commonly hear about the imperfect ways in which structural and functional measures predict each other. In principle, structural and functional findings would completely corroborate and confirm each other if the measurements were of sufficient accuracy and precision (Figure 2-14). While new methods have been proposed that may

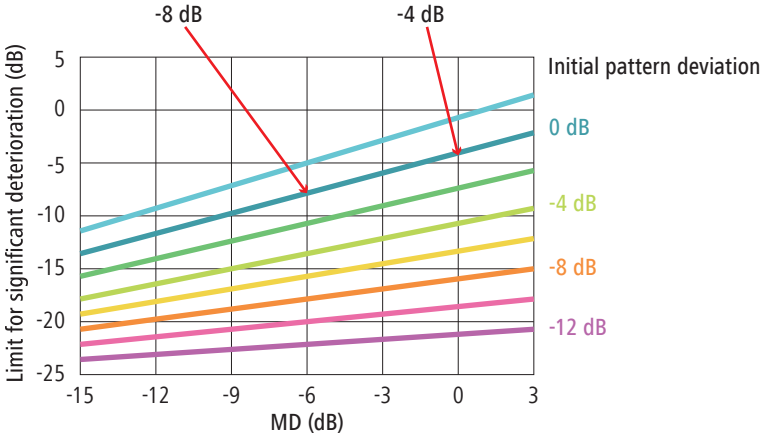


Figure 2-13

Dependence on Mean Deviation and point location of SITA Standard 24-2/30-2 significance limits for deterioration. In addition to the dependency on defect depth illustrated in Figure 2-12, significance limits for pointwise deterioration of Pattern Deviation also depend upon Mean Deviation and test point location. This figure illustrates MD effects in the outer zone of a 24-2/30-2 test pattern. For example, the red arrows show that in a field having an MD of zero, the significance limit for statistically significant progression at a test point having a baseline Pattern Deviation of zero is -4 dB, but it is -8 dB for that same test point in a field having an MD of -6 dB.[45,46,48,49]

significantly improve the ability of structural and functional measurements to predict each other, currently available structural metrics only partially explain contemporary perimetric results and vice versa.[50-60] We also have seen that the level of structure–function correlation can vary, depending upon individual morphological structure, such as in large versus small optic nerves.[61-65]

However, we now know that in glaucoma suspects and in patients with early glaucoma, we sometimes can see statistically significant retinal nerve fiber layer (RNFL) thickness changes from baseline that are not yet apparent in visual field or optical coherence tomography (OCT) comparisons to normal limits.[66] We also know that opportunities for simplification and improvement in the utility of OCT findings may be found in applications that combine multiple OCT metrics into a single index, such as combining RNFL, ganglion cell thickness, and optic nerve topography.[67,68] These and other observations make us hopeful that we will see further improvements in structure–function relationships in the years ahead.

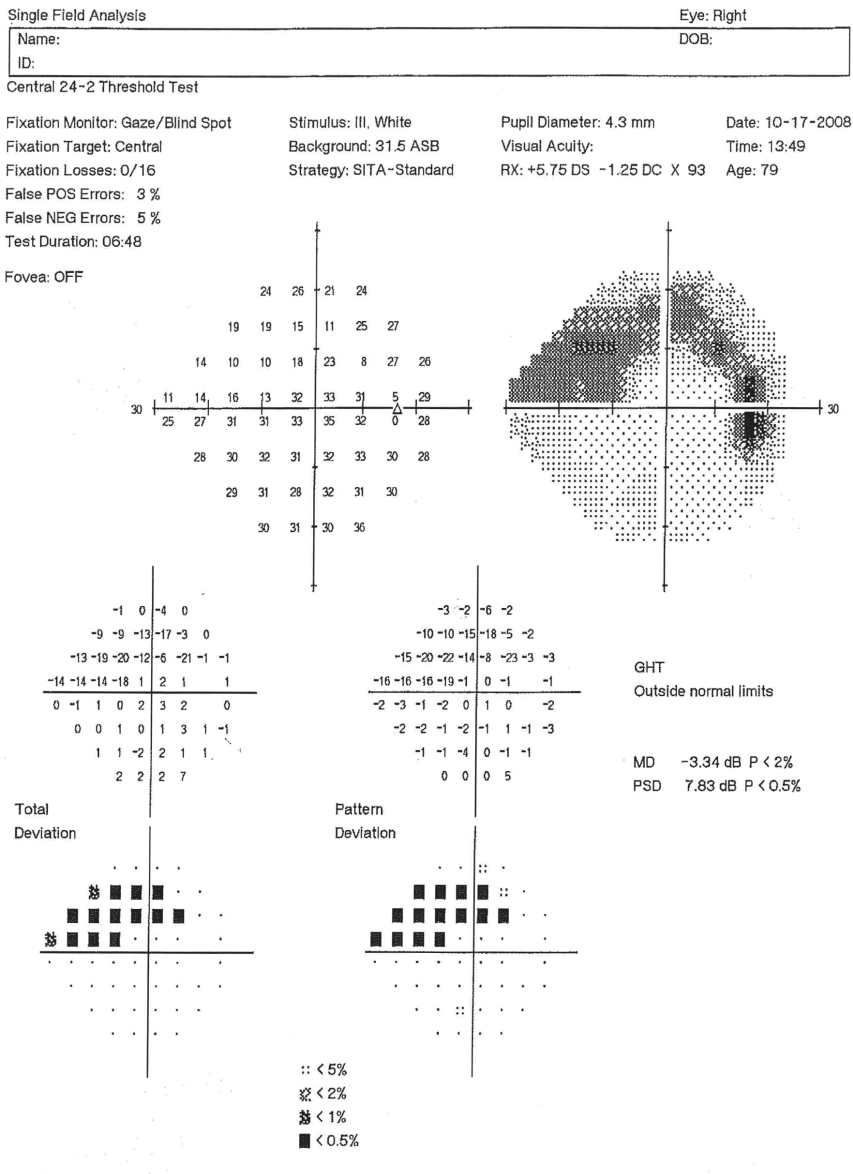
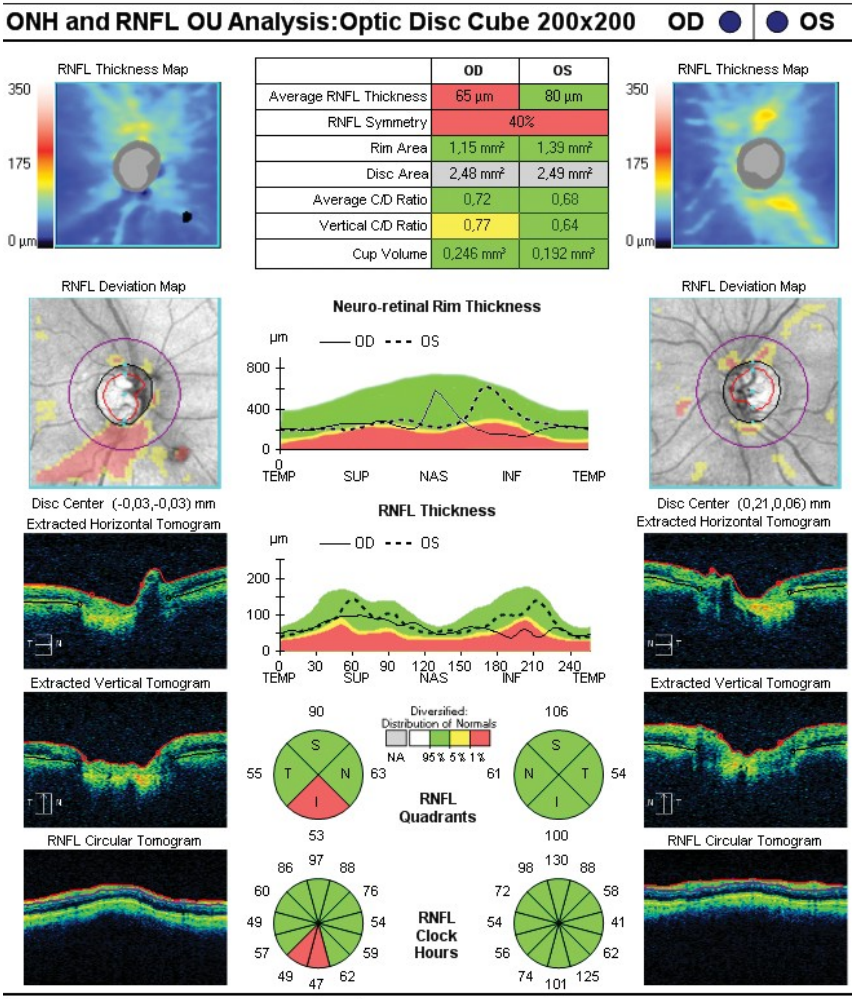


Figure 2-14

Structure–function relationships. Often, visual function data are corroborated by structural findings. The classical arcuate scotoma seen in the upper hemifield of the visual field test result (A) is in good agreement with optical coherence tomography findings (B) in the process showing rather focal thinning of the retinal nerve fiber layer in the area inferotemporal to the optic nerve.



B

Figure 2-14 continued

Much has been said about the fact that patients can lose about 30% of their retinal nerve fibers before corresponding perimetric test point locations fall outside of normal limits.[69] Less has been said about the fact that patients also can lose a third of their retinal nerve fiber layer and still be within normal limits for OCT RNFL thickness (Figure 2-15). We also know that current OCT structural metrics reach their measurement floors at perimetric MDs in the neighborhood of -10 to -15 dB, and thus we should not be surprised to find reduced OCT structural corroboration of perimetric findings in moderate to advanced disease.[70] Artifactual findings frequently affect well-established OCT metrics such as peripapillary RNFL thickness, ganglion cell layer thickness, and optic nerve topography.[71-77]

We make these observations simply to point out that there is ample opportunity for further improvement of all of our diagnostic methods, that automated perimetry continues to occupy an important and central role in the management of ophthalmic disease and plays a more important role than structural tests in the diagnosis and management of glaucoma, and that clinical use of automated imaging findings currently seems to be no less complicated than clinical use of automated perimetry.

Test Specificity and Pretest Probabilities

In discussing the integration of structural and functional findings with other available clinical information, it may be helpful to think a little about the interplay between diagnostic specificity and disease likelihood in various clinical populations. For example, the Humphrey perimeter's Glaucoma

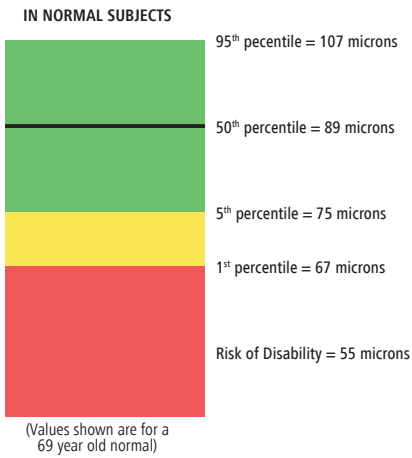


Figure 2-15

Normal ranges of peripapillary retinal nerve fiber layer thickness for Zeiss Cirrus OCT for 69-year-old subjects. The median normal RNFL thickness is about 14 microns above the bottom of the green normal range and about 42 microns above the measurement floor, suggesting that a typical patient can lose a third of her RNFL and still remain in the green normal zone. The Zeiss Cirrus measurement floor for peripapillary RNFL thickness has been reported to be 57 microns.[78] (Source: *Cirrus HD-OCT: How to Read the Cirrus Reports, Carl Zeiss Meditec, 2015.*)

Hemifield Test (GHT) was designed with the goal of having an overall specificity of approximately 94% for an individual test result to be outside normal limits, and thus such an analysis must be expected to produce false positive findings in about 6% of normal subjects (chapter 5). Similarly, most OCT diagnostic metrics are flagged at the $p < 0.05$ level and thus must be expected to fall outside normal limits in approximately 5% of normal subjects, even under ideal circumstances.

Applying GHT analysis to fields from 1,000 subjects taken from a general population having a 1% prevalence of glaucomatous visual field loss would then be expected to misidentify about 60 normal subjects as having abnormal fields, while finding about nine real glaucomas (assuming 90% sensitivity). Thus, used in this population, the GHT would be expected to produce false positive diagnostic findings about six times more often than true positive findings. In contrast, GHT analysis of the visual fields of 1,000 newly referred patients in a large glaucoma clinic, where 50% of such patients typically are found to have glaucomatous visual field loss, would be expected to correctly diagnose about 450 patients with glaucomatous visual field loss (again assuming a sensitivity of 90%) and to misidentify only about 30 normals as having abnormal visual fields. Thus, in this second application, a GHT finding of Outside Normal Limits would be about 15 times more likely to be associated with true glaucomatous field loss than with a false positive diagnostic finding. Structural analyses having similar sensitivities and specificities would perform similarly.

Therefore, in examining patients in whom we have a low level of suspicion, it may be prudent to require two positive and repeatable diagnostic findings, perhaps *both* structural *and* functional change or perhaps *either* structural *or* functional change, paired with some other convincing clinical finding, such as detection of an optic disc hemorrhage or observation of an extraordinarily high intraocular pressure. In the absence of at least two separate and convincing clinical findings, the patient probably will have early disease at most. Thus, it might be preferable to delay making what might be a premature and incorrect diagnosis, whether we elect to treat the patient or not. Such a strategy also recognizes that simply giving a patient a diagnosis—such as, for example, a diagnosis of glaucoma—is associated with a decrease in the patient's quality of life.[79,80] In all cases, it is crucial to adjust clinical interpretation of diagnostic findings on the basis of the level of suspicion we had before the test was done—a factor called the pretest probability of disease.

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3

Choosing a Test

WHEN A PERIMETRIC TEST is needed, a SITA Faster 24-2 Size III white threshold test usually will be your best choice. This chapter explains why this is so, and then discusses the exceptions.

Choosing a Test Strategy

The Humphrey perimeter offers three primary threshold testing strategies: SITA Standard, SITA Fast, and SITA Faster. SITA Standard and SITA Fast were developed in the 1990s and are about twice as fast as the older Full Threshold and Fastpac strategies they replaced, with the same or better reproducibility.[1-12] The more recently developed SITA Faster strategy takes about half the testing time of SITA Standard (Figure 3-1) and its repeatability is the same as that of SITA Fast.[13-16] Recent work has shown that time to detect progression with SITA Fast is very similar to that of SITA Standard, confirming in clinical care settings observations we made in a multicenter clinical trial during the original SITA development project.[16,17]

At least five threshold tests are usually needed to quantify how quickly a patient may be losing visual field sensitivity, and several glaucoma guidelines now recommend more frequent perimetric testing in the first few years after diagnosing a patient having glaucomatous visual field loss, in order to identify rapidly progressing patients and to determine rate of progression more quickly.[18-21] In actual practice, perimetric testing frequency of newly diagnosed glaucoma patients often remains considerably lower than recommended, sometimes due to a lack of resources.[22-25]

We developed SITA Faster to facilitate more frequent testing, and thereby earlier detection of patients who are rapidly progressing toward blindness on their initial or current therapies, and to be able to calculate rate of progression just 2 or 3 years after diagnosis. Given the findings of Saunders, Russell, and Crabb,[16] we now believe that for most patients, the advantages in clinic flow and patient compliance associated with use of SITA Fast or SITA Faster far outweigh their small differences in repeatability compared to SITA Standard. Thus, we now recommend use of SITA Faster in most situations.

Although SITA Faster saves considerable test time, we would like to point out that it is not an "easier" test than SITA Standard or SITA Fast. SITA Faster presents initial test stimuli at each test point at the expected threshold value, which is a lower stimulus intensity than is used in SITA Fast and particularly in SITA Standard. When taking a SITA Faster test, the patient will be presented with a higher percentage of stimuli that are barely visible, making it particularly important to demonstrate to first-time SITA Faster patients just what test stimuli are going to look like. Thus, in patients new to SITA Faster, perimetrists should start the test and then talk the patient through the first few seconds of the examination, until the patient understands what to expect; the perimetrist can then restart the test. As explained in chapter 4, we believe that this approach is helpful for all perimetry novices, and especially for SITA Faster novices, and will make patients and perimetrists happier with and more confident in their test results.

For the great majority of clinical situations (exceptions are discussed later), one should choose either SITA Faster or SITA Standard if one is using a modern HFA3 perimeter. SITA Faster has been constructed to replace SITA Fast, so we see no reason to use SITA Fast on HFA3 perimeters, except perhaps for perimetrically naive patients, since stimuli are easier to see with SITA Fast than with SITA Faster, particularly during the first part of the test. SITA Faster is not available in the older HFA2 perimeters, in which case the choice is between SITA Fast and SITA Standard.

We would also like to point out that the SITA tests are not meant for glaucoma only but are equally useful if we are looking for field loss caused by neurological or retinal disease.

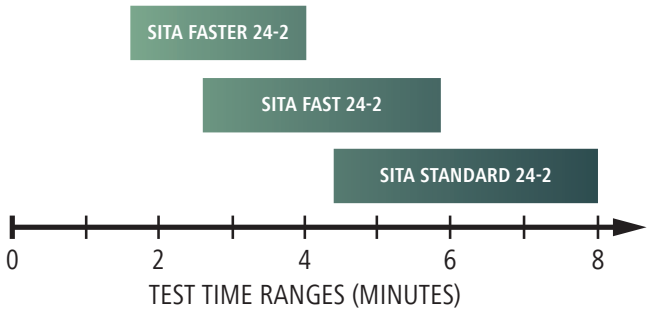


Figure 3-1

Test times. Test times for 24-2 testing in patients with suspect and manifest glaucoma, using the three SITA strategies. Test times increase as visual fields become increasingly damaged. In patients with normal fields, test time ranges would be narrower, since most of the longer test times would disappear.

Choosing a Test Pattern

The 24-2 test pattern consists of 54 test points spaced 6° apart (Figure 3-2). Over the years, the 24-2 test pattern has gradually replaced the legacy 76-test-point 30-2 pattern in most clinics, because little diagnostic information is lost and considerable testing time is saved.[26,27] Fewer trial lens and eyelid artifacts also are seen with the 24-2 test pattern. One argument in favor of the 30-2 test pattern is that progression can sometimes be found earlier, simply because more locations are tested. However, specificity for detecting change is proportionally higher with the 24-2.[28]

Macular Visual Field Testing in Glaucoma

The most central part of the visual field is often retained longest in advanced glaucoma. However, defects close to the center of the visual field are common also in the earliest stages of glaucoma.[29,30] This central field loss may be better

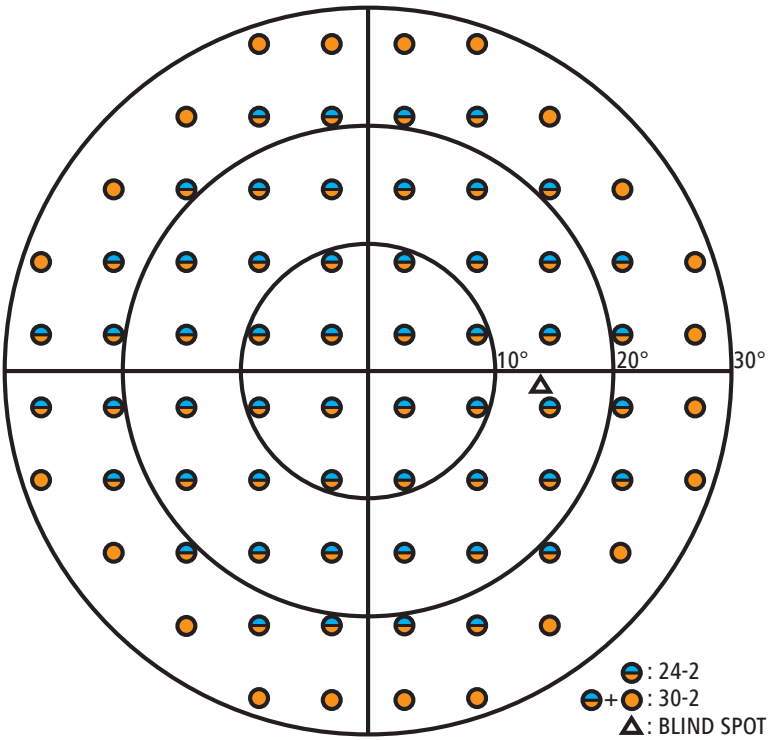


Figure 3-2

Test point locations for the 24-2 and 30-2 tests. Point locations making up the 24-2 test pattern are a subset of those in the 30-2 test pattern. Essentially, the 24-2 test is just a 30-2 with the outer ring of test points removed, except for the nasal-most two. Test points are spaced 6° apart. These are patterns for a right eye.

detected by testing the macular area more carefully, and the rate of detection of such field loss increases when performing 10-2 macular testing in addition to 24-2 testing (Figure 3-3).[31] One study reported that 13% of glaucoma eyes with a repeatable 10-2 visual field defect did not have a repeatable 24-2 defect, but also that 16% of eyes with repeatable central 24-2 visual field defects did not have repeatable 10-2 defects; a separate study found similar results.[32,33] Two more recent investigations concluded that 10-2 testing does not significantly improve the detection of central visual field abnormalities, when added to routine 24-2 testing in glaucoma patients and glaucoma suspects.[71, 73] While 10-2 macular testing can be complementary to standard 24-2 examinations in selected patients,[72] 10-2 testing should not be performed in place of 24-2, such as by alternating the two tests in follow-up visits. Such a practice would delay detection of rapidly progressing patients and also delay determining rate of progression using either test.[18] Early determination of rate of progression is of crucial importance in modern glaucoma management.

In order to take these observations into account, a SITA Faster 24-2C test pattern has been added to the testing options of the Humphrey HFA3 perimeter (Figure 3-4). This new test pattern adds an extra 10 macular test points to the 24-2 test. SITA Faster 24-2C testing takes less time than a SITA Fast

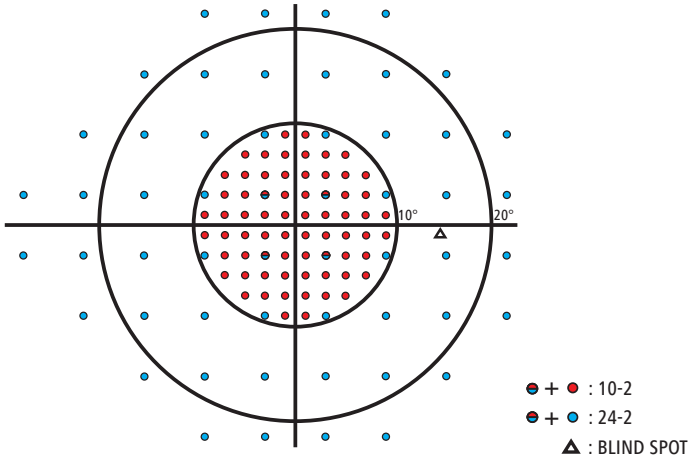


Figure 3-3

Comparison of 10-2 and 24-2 tests. The 10-2 pattern, shown in red, is compared with the more generally used 24-2 test pattern, shown in blue. The 10-2 test pattern is preferred when testing the field in macular disease and is useful in end-stage glaucoma patients having tunnel fields. It is sometimes used as an adjunctive test to the 24-2 in glaucoma or glaucoma suspects, especially if the 24-2 results are normal or questionable. The spacing between 10-2 test points is 2°.

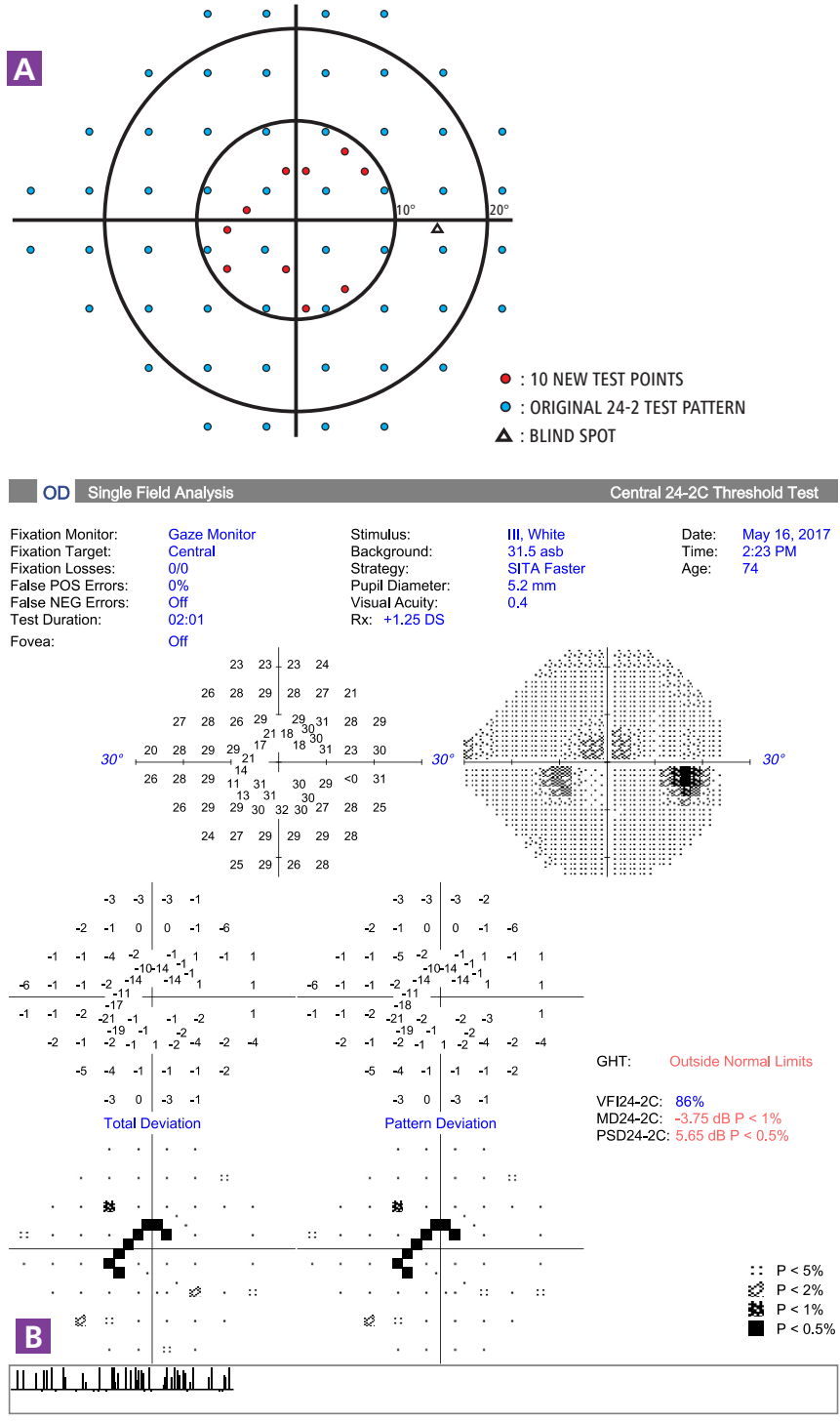


Figure 3-4

The 24-2C test pattern (A) and Statpac analysis (B). The 24-2C test pattern adds an extra 10 macular test points to the 24-2 test. SITA Faster 24-2C testing takes less time than a SITA Fast 24-2 test.

24-2 test. In any case, SITA Faster 24-2C testing may be a practical and useful approach in glaucoma patients and suspects where the 24-2 field is normal but other clinical findings suggest that glaucomatous damage may be present.[34]

Foveal Threshold Testing

The Humphrey perimeter offers the option of measuring threshold sensitivity at the fovea. Foveal threshold measurements have been found to be correlated with visual acuity measurements, though the strength of that correlation may vary from one disease to another.[35] Foveal threshold sensitivity has also been reported to usefully predict visual acuity in eyes with possible nonorganic visual acuity loss.[36] Some colleagues routinely measure foveal sensitivity for the sake of completeness. Most do not measure it.

Exceptions to Testing the Central 30° Field

Most visual field tests are ordered in connection with diagnosis or management of glaucoma, and the perimetric standard of care in glaucoma management concentrates on testing the central 30° field. A few early glaucoma patients will first present with field loss outside the central 30° in the absence of visual field damage centrally.[37,38] However, this occurs infrequently, and since the range of normal sensitivity is quite large outside the central 30° field, testing is rarely done outside the central field in glaucoma management.

Also, in neurological disease, most of the diagnostic information is in the central field,[39,40] and the 24-2 test point pattern is the preferred standard. There are a few exceptions. If a patient has a history that suggests acute optic neuritis but has normal or near-normal visual acuity, a 10-2 test will provide a denser 2° grid spacing with a higher number of test points in the very central visual field (Figure 3-3). The 10-2 test also is the preferred choice when evaluating visual field loss in macular disease, such as age-related macular degeneration (AMD).

Although it is rarely done, peripheral testing can be used to differentiate between retinal detachement and retinoschisis in eyes that cannot be well visualized ophthalmoscopically (chapter 11). Peripheral testing may be useful in early idiopathic intracranial hypertension.[41]

Choosing Stimulus Size

The Goldmann white Size III stimulus has been established as standard in automated threshold visual field testing. Normative data and progression event analysis applications apply only to testing with white Size III stimuli.

See the "Severe Glaucoma" section of this chapter for a discussion of when a nonstandard stimulus size might be advantageous.

Choosing a Patient Fixation Option

During visual field testing, the patient is asked to look steadily at a specific location in the bowl; this location is called the fixation point. The perimeter then presents test stimuli with the chosen fixation point as the center of its coordinate system. All models of the HFA offer four alternative patient fixation target options (Figure 3-5). The most commonly used fixation option is the Central Fixation Target, which consists of a small light-emitting diode (LED) mounted in a hole located at the very center of the bowl. We recommend the Central Fixation Target for all testing, with the following exceptions:

1. Patients who have poor central vision, for instance due to AMD, should be tested using the Large Diamond option. Such patients should be instructed to center their gaze in the middle of the illuminated diamond.
2. If one chooses to add foveal threshold testing to the beginning of a visual field test, the perimeter will automatically illuminate the smaller diamond fixation option and perform a foveal test at the beginning of the test. Patients should be instructed to look at the middle of the Small Diamond for the foveal part of the test. At the completion of foveal testing, the perimeter will switch back to the Central Fixation Target and start the peripheral vision test that was chosen. The perimetrist must then instruct the patient to switch their fixation to the Central Fixation Target.
3. Some seldom-used peripheral testing patterns have points in the superior field that require a lower fixation target instead of the central target. The target used is the Bottom LED of the large fixation diamond. The perimeter is programmed to inform the user whenever this is necessary.

Testing Speed

The SITA testing algorithms automatically adjust testing speed by constantly monitoring each patient's reaction time.[1] It is important, however, to inform new patients that the perimeter will adjust itself to their pace and thus that they should not feel that they must respond in haste. The HFA offers the option of slowing an individual test further, but this option may never be needed.

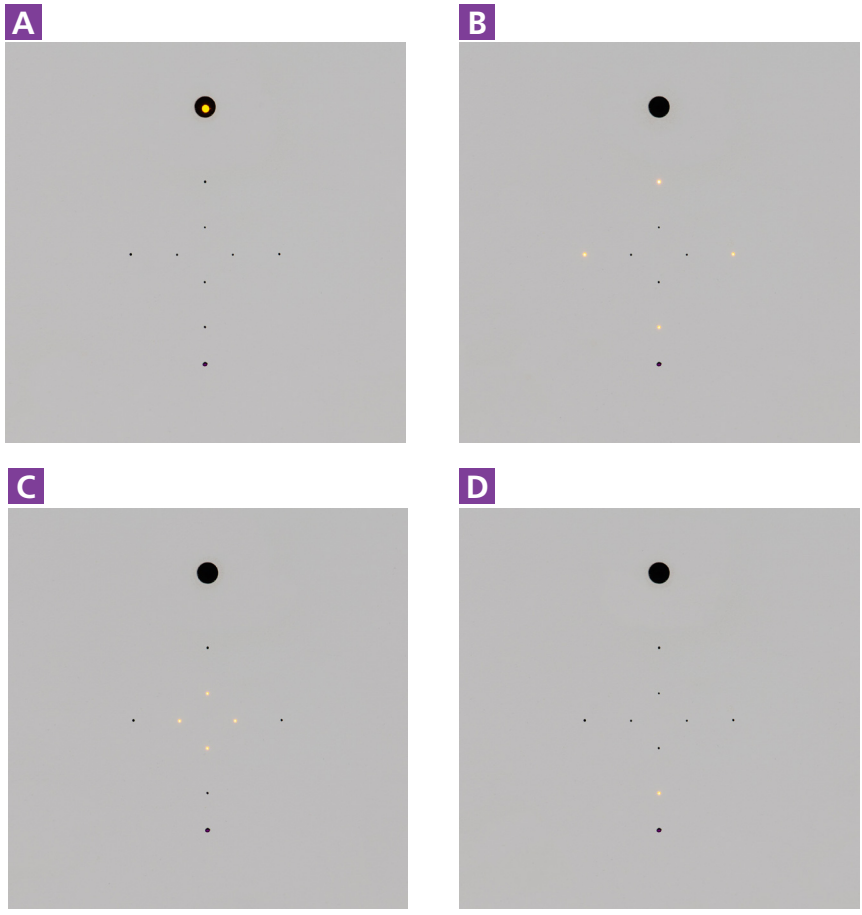


Figure 3-5

Humphrey Field Analyzer fixation targets. The HFA offers four alternative fixation targets. Each target consists of one or more light-emitting diodes that are illuminated during use. (A) The Central Fixation Target is an LED located in a hole at the center of the bowl. It is used in most testing. (B) The Large Diamond is useful for patients with central scotomas, such as those caused by AMD. Patients are instructed to look at the middle of the diamond. (C) The Small Diamond consists of 4 LEDs. Again, the patient is instructed to gaze at the middle of the diamond. The Small Diamond is used when performing a foveal threshold measurement. (D) The Bottom LED is automatically used in a few specialty tests that have test points in the superior field that require a lower fixation light than the Central Fixation Target. Photos: Johnny Ring.

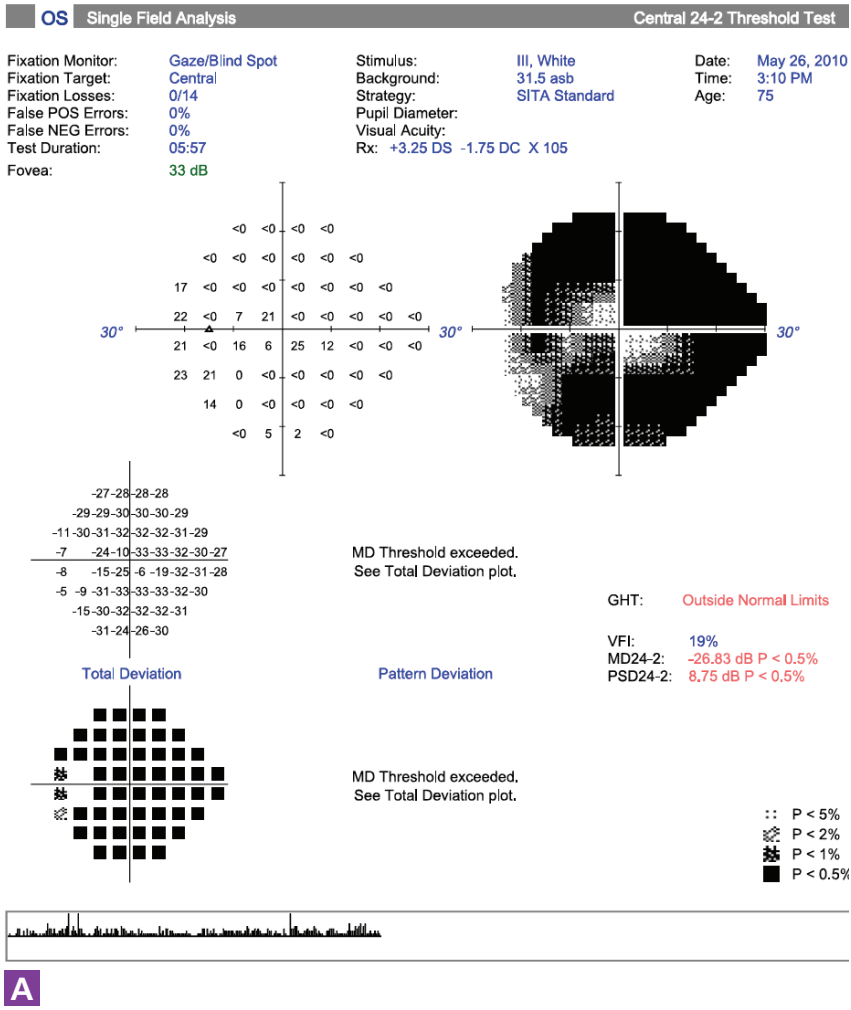
Severe Glaucoma

In very advanced glaucoma, when mainly central islands of vision remain, one can switch from 24-2 testing to the 10-2 test pattern, which covers the area within 10° of fixation with a grid of test points spaced every 2° (Figures 3-3, 3-6A, and 3-6B). Another possibility is to use the larger Size V stimulus, with a 24-2 or a 10-2 test pattern (Figures 3-6C and 3-6D). Using a Size V stimulus will extend the available sensitivity range, often making it possible to continue following patients with very advanced field loss. However, nonstandard stimulus sizes cannot be used with the SITA testing strategies, but only with the more time-consuming older testing algorithms. Also, one will no longer have the benefit of normative data or the Humphrey Guided Progression Analysis. If considering use of a Size V stimulus, it may be worthwhile to use the Fastpac testing strategy, simply because it does take less testing time than the old Full Threshold strategy.

Testing for Drug-Induced Maculopathies

Patients undergoing long-term treatment with hydroxychloroquine or similar medications are frequently sent for ophthalmic consultation in order to monitor for drug-associated maculopathy. Guidelines from the American Academy of Ophthalmology emphasize white SITA 10-2 perimetry for non-Asian patients and 24-2 or 30-2 testing for Asian patients, in whom toxicity is often manifest outside the macula. The guidelines suggest careful examination of the Pattern Deviation probability plots in order to identify statistically abnormal localized loss. Use of red stimuli has been advocated by some, but no clear advantages over standard white stimulus testing have been documented, and normative limits for red testing are not available.[42-44]

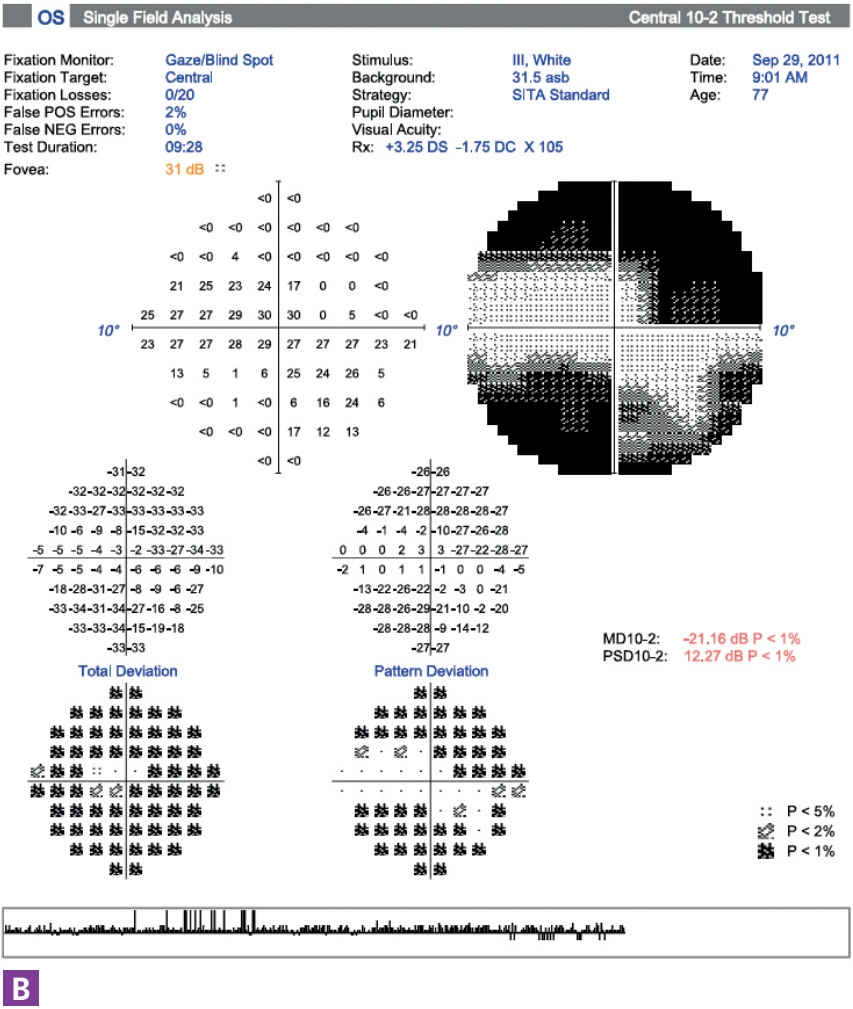
Sivakumar and colleagues have published a web-based calculator for recommended hydroxychloroquine dosing levels.[45] Although ophthalmic caregivers may be unlikely to prescribe hydroxychloroquine, having access to such a calculator may be beneficial in identifying patients who are taking higher than recommended amounts of hydroxychloroquine when they are sent for ophthalmic consultation.



A

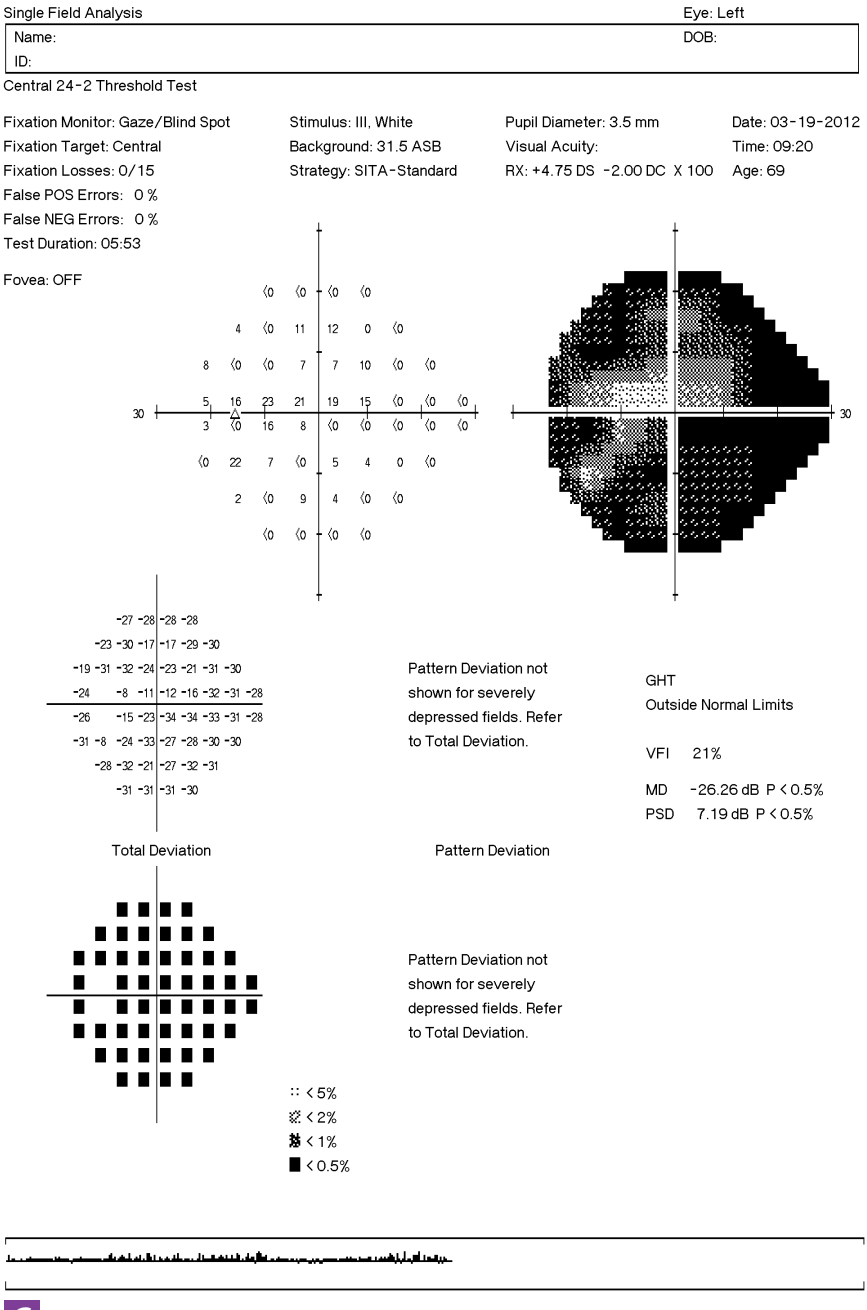
Figure 3-6

Visual field testing in severe glaucoma. In very late stages of glaucoma, where only a few points in the 24-2 or 30-2 patterns have remaining vision, one might switch to a SITA 10-2 test (A and B). In some cases, one might instead switch to a Size V stimulus, but continue to use the 24-2 or 30-2 pattern (C and D). SITA is not available for Size V testing, so this switch will come at the price of increased test time.



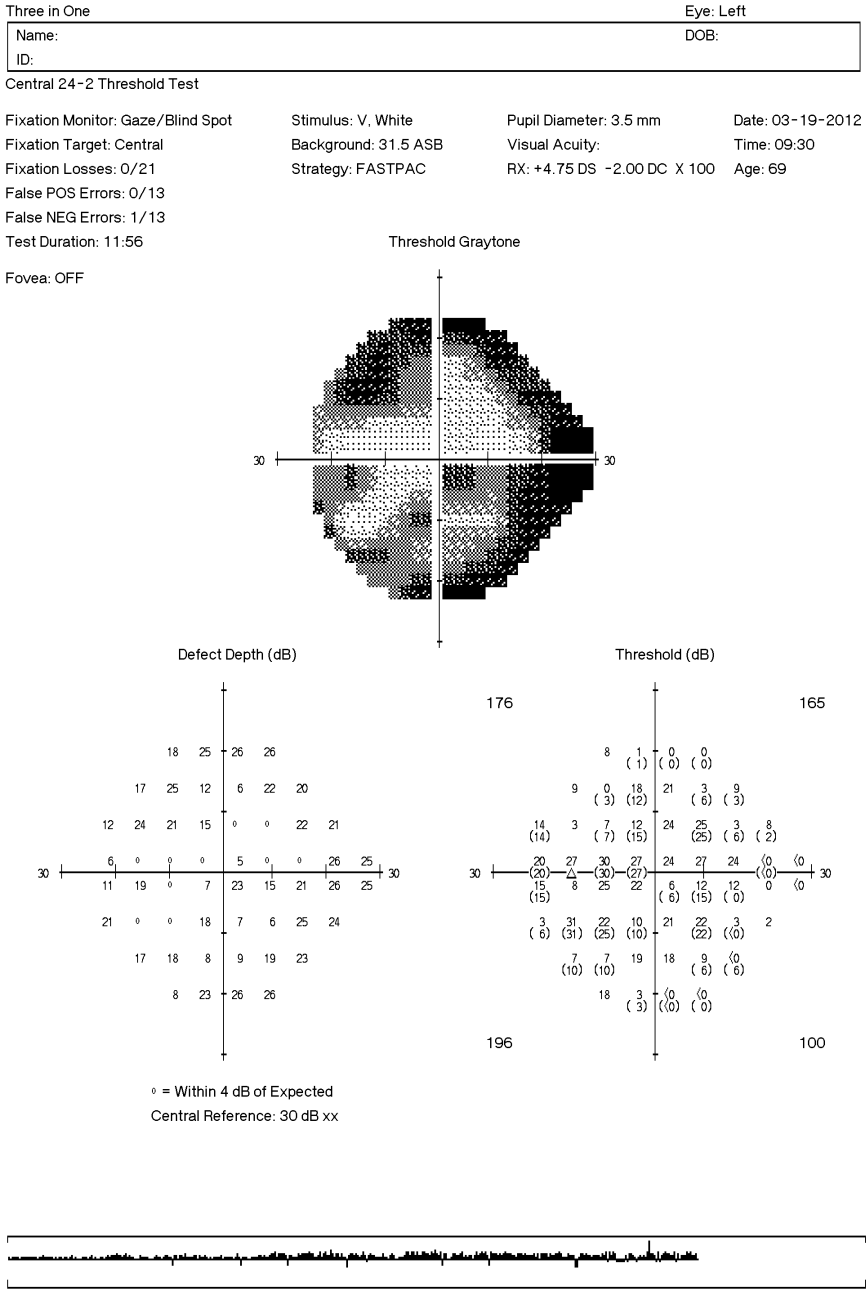
B

Figure 3-6 continued



C

Figure 3-6 continued



D

Figure 3-6 continued

Testing for Visual Impairment

Sometimes visual field testing is performed for reasons other than to establish a diagnosis or to recognize visual field change associated with disease management. Knowing the character and degree of visual function may help guide rehabilitation. Or perimetry may be performed to determine whether enough visual impairment exists to make the patient eligible for insurance compensation, to establish fitness to drive, and sometimes to document need for blepharoplasty. Regardless of the purpose, such testing requires a different approach from that used in disease diagnosis and management.

In testing for visual field impairment, the goal is to identify substantial visual dysfunction. Thus, visual field impairment examinations usually are performed using stimuli that are so intense that they will be missed only if there is substantial visual field loss. The stimulus most commonly used for such tests is the quite intense Goldmann III 4e stimulus, which in Humphrey terms is Size III 10 dB white.

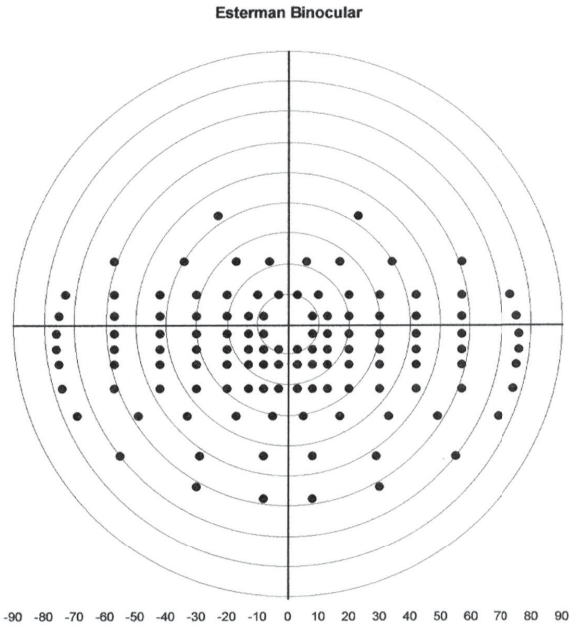
The Esterman test is commonly used in visual field impairment testing.[46] Binocular and monocular versions of this test are offered as standard testing options on current Humphrey perimeters (Figure 3-7). The binocular version presents Size III 10 dB white stimuli at each of 120 points in the central and peripheral visual field and records whether or not each stimulus has been seen. The Esterman test is performed using the patient's customary distance spectacles, without adding any near refractive correction, in order to let the perimetric test result show whatever visual field limitations might be imposed by the spectacles, the refractive assumption being that the stimuli used are so strong as to not be significantly affected by any refractive blur associated with the near testing distance.

Figure 3-7

The Esterman test. The Esterman binocular test (A) is commonly used to assess visual impairment; in this example (B-D), it is being employed for driver's license qualification. The deep field defects of the two eyes' glaucomatous fields (C-D) do not overlap very much, and therefore few stimuli have been missed in the Esterman binocular test (B).

Figure 3-7

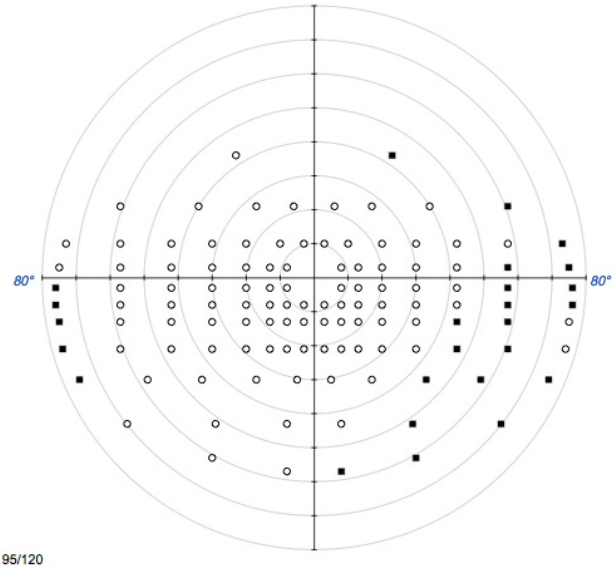
A



OU Suprathreshold — Esterman Binocular Suprathreshold Test

Fixation Monitor:	Off	Stimulus:	III, White	Date:	Mar 19, 2020
Fixation Target:	Central	Background:	31.5 asb	Time:	2:39 PM
Fixation Losses:	0/0	Strategy:	Two Zone	Age:	73
False POS Errors:	0/12	Test Mode:	Single Intensity		
False NEG Errors:	0/12	Pupil Diameter:			
Test Duration:	05:33	Visual Acuity:			
		Rx:			

Stimulus Intensity: 10dB



○ Seen 95/120
■ Not Seen 25/120
△ Blind Spot

Esterman Efficiency Score: 79

B

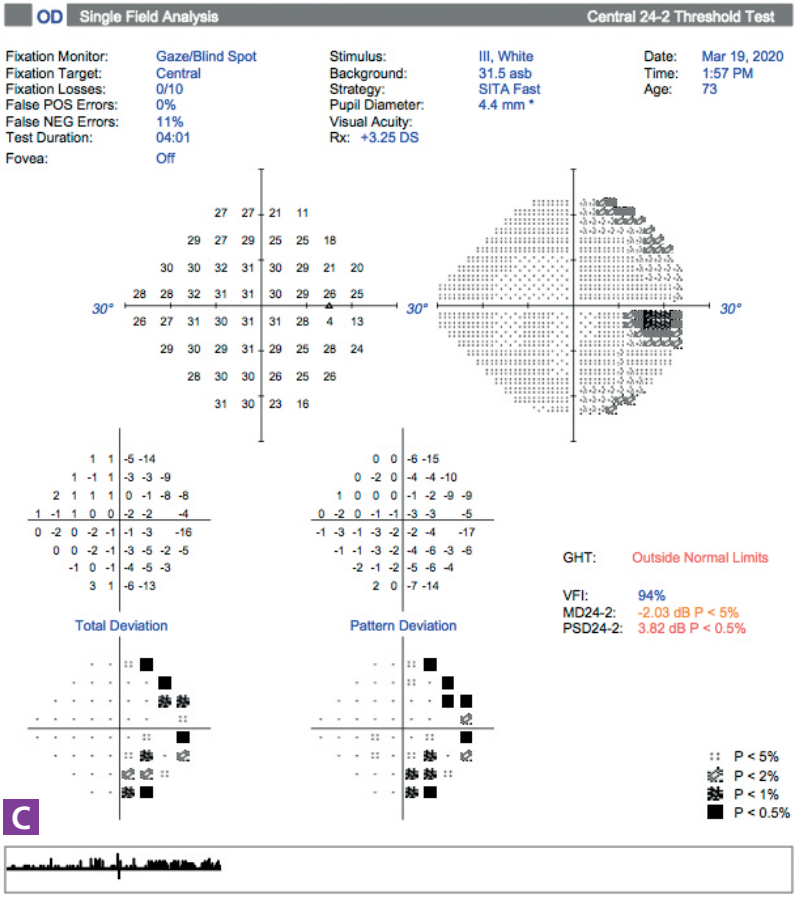


Figure 3-7 continued

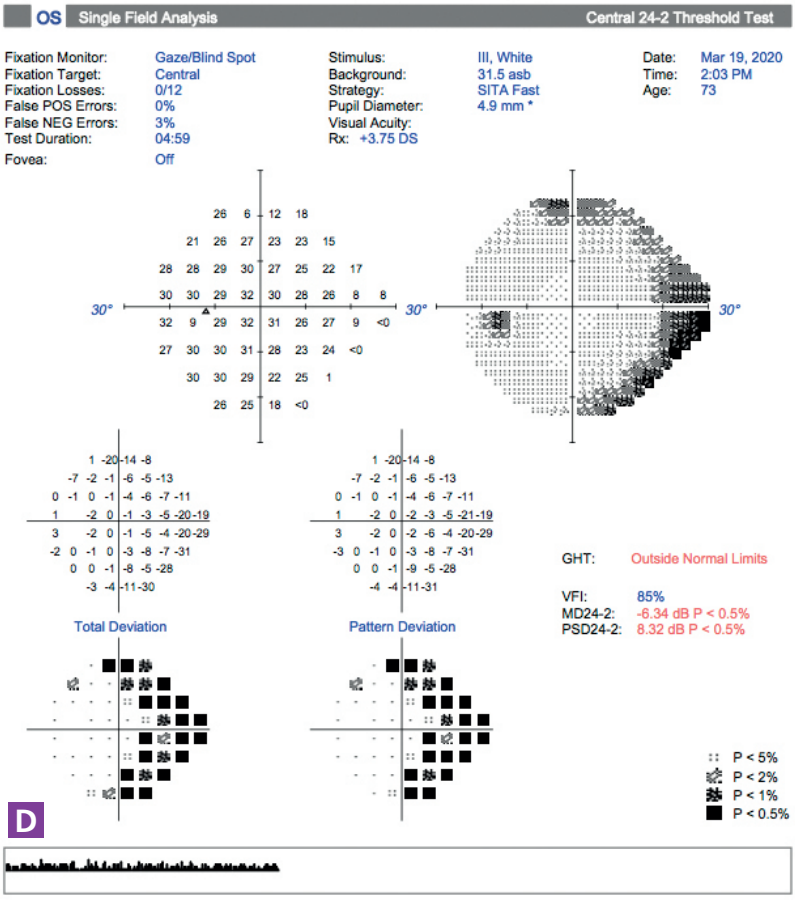


Figure 3-7 continued

LEGAL BLINDNESS

Standards for legal blindness due to visual field impairment vary from country to country—and in some countries, from one government agency to the next. The World Health Organization defines blindness as a visual acuity worse than 0.05 (20/400) or a visual field with a diameter < 10° in the better eye.[47]

US-based practitioners are sometimes asked to certify patient vision relative to the US Social Security Administration's three alternative criteria for legal blindness: (1) visual acuity in both eyes of 0.1 (20/200) or worse; (2) a 30-2 Humphrey Mean Deviation in both eyes equal to or worse than -22 dB; or (3) a constriction of the central visual field in both eyes to less than 20° at its widest diameter. The width of the central field may be calculated from an HFA 24-2 or 30-2 test by drawing pseudoisopters on the numerical sensitivity printouts, midway between test point locations with threshold sensitivity of 10 dB or better and points with sensitivity of less than 10 dB.[47]

DRIVING

In some countries, licensing of automobile drivers is based partially upon visual field assessment.[48] The overall visual field is most important in driving, to the extent that even total loss of one eye may well be compensated for by the remaining eye.[49,50] Eye movement also can compensate somewhat for binocular field loss. Patterns of eye movements seem to be different in patients with bilateral visual field defects, compared to healthy individuals, when viewing a traffic scene.[51]

Anderson and Patella have suggested that, in the absence of more conservative guidelines from local authorities, drivers should have binocular visual fields extending at least 50° both to the right and to the left of fixation.[52] No criteria are given for the superior and inferior fields, except to note that an extensive superior visual field is not needed to notice overhead objects such as traffic signals when approaching an intersection.

BLEPHAROPTOSIS

Perimetry is sometimes used to document the extent of visual impairment secondary to blepharoptosis, although nonperimetric methods also may be used.[53-55] Such testing is best done using single-level suprathreshold testing and a bright stimulus. It is possible to confirm that the impairment is due to ptosis by repeating the test with the eyelids held up with surgical tape. It may be helpful to consider that it is quite common, especially in elderly patients, to find asymptomatic and apparently nondisabling ptotic field restrictions affecting the upper row of test points in the central 30-2 test. Thus, it may not be necessary to test outside the central visual field when investigating meaningful effects of blepharoptosis.

Short-Wavelength Automated Perimetry

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 yellow background of 100 candelas per square meter. The yellow background serves to reduce the responsiveness of the red and green cones by saturating them with yellow light, so as to test mainly the blue cone system.

Contrary to previous belief,[56,57] research has shown that SITA testing with standard white stimuli detects as much or more field loss in glaucoma as SWAP, and also at least as early.[58,59] Moreover, SWAP has a higher test-retest variability and is heavily affected by cataract. Thus, SWAP is no longer recommended for glaucoma management.

Colored Stimuli

While the HFA is capable of testing with colored stimuli, we are not aware of any evidence that colored stimuli on a white background offer any advantages over standard white stimuli, and because no normative data exist for colored stimuli, they are almost never used. See the section on drug-induced maculopathies earlier in this chapter.

Kinetic Perimetry

In the days of Goldmann manual kinetic perimetry, it was common to use just two different stimuli, and to thus produce two isopters, one in the extreme periphery and one at about 20° eccentricity. A common misunderstanding is that such a kinetic field examination tested the whole visual field, but threshold sensitivity actually was known only at the two dozen or so locations in the visual field where the patient first perceived the stimulus (Figure 3-8). If the most central isopter tested was at approximately 20° from fixation, then any localized field loss inside of that isopter would be missed. It is therefore not at all surprising that much early glaucomatous field loss was missed by kinetic perimetry.[60-65] The Armaly-Drance screening technique added suprathreshold static perimetric testing to kinetic perimetry, in response to this limitation.[66,67]

Nowadays, almost all visual field testing is done with automated *static* threshold perimetry. Although the Humphrey perimeter can perform *kinetic* testing (Figure 3-8),[68,69] we do not recommend kinetic perimetry as a routine test. Nevertheless, there are a few clinical situations where one might consider kinetic testing, including:

1. Severe glaucoma in which the ordinary 24-2 field shows only a few test point locations where the patient was able to see even maximally intense test stimuli. Here, kinetic perimetry might still work, because moving stimuli are often easier to see than static ones, a phenomenon known as statokinetic dissociation.[70]
2. When one is interested in testing the peripheral visual field. Outside the central 30° field, the interpatient variability of standard automated static perimetry is very high. The slope of the hill of vision is steep in the periphery, and kinetic testing may give smaller variability than static.
3. Perhaps sometimes to test for or document visual impairment.
4. Perhaps in children.

The HFA can perform kinetic perimetry in manual or automated modes. The automated mode has several advantages over manual Goldmann perimetry, if kinetic perimetry is the choice: the results are not biased by the perimetrist; stimuli can be presented in random order, which reduces the risk of faulty fixation; and stimuli are moved with constant speed and always start from the same positions. The latter ensures the same reproducible test conditions, which is a great advantage in follow-up.

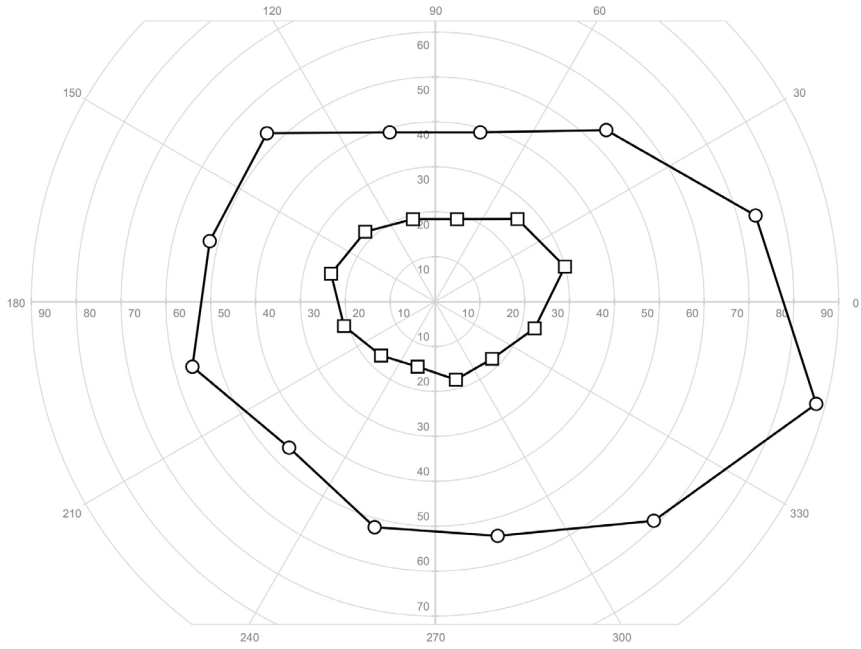


Figure 3-8

Kinetic testing on the Humphrey Field Analyzer. This is a kinetic 2-isopter field obtained on an HFA3.

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4

Patient-Friendly Perimetry

MANY YEARS OF THOUGHT and development have gone into making automated perimetry as simple and effective as possible. In this chapter we will present suggestions that can make visual field testing more patient-friendly and more effective.

Perimetry can be difficult and disliked by patients, but this does not have to be the case. In the Early Manifest Glaucoma Trial (EMGT), we tested hundreds of patients who had no previous perimetric experience.[1] Very few patients, perhaps two or three out of several hundred, could not be enrolled in the EMGT due to inability to perform automated perimetry. The reason was very careful instruction and supervision of patients during their first perimetry examinations. It takes just a few extra minutes to explain and demonstrate the test before each patient's very first testing session. A few patients may need a second explanation, but they are in the minority.

Positive Expectations That Can Promote Success

Almost all patients can and will produce reliable results if they just understand why perimetry is being performed, what to expect, and what they need to do.[2] Instilling positive expectations in staff and patients probably is the most important step you can take to make perimetry effective and patient-friendly in your practice.

Patients will have positive expectations . . .

- if they understand the goals of visual field testing and its importance in their care.
- if they realize that the instrument is programmed to dim the stimulus until they no longer can see it, and that they probably will see the light less than half the time.
- if they understand that when they do see the light it will usually be quite dim, even if they have perfectly normal vision.
- if they understand that even patients with perfect vision feel unsure about pushing the button, but that the results will still be valid and useful.

- if they are comfortably positioned at the perimeter and are reassuringly supervised.
- if they understand how the stimuli will look, how to respond, and how long the test will take.
- if they understand that the instrument will adjust its timing to their individual reaction time and pace, and that there is no need to respond hastily.
- if they know that they can blink normally and that they can pause the test if they need to, by holding down the response button.

Staff members will have positive expectations . . .

- if they understand the role of perimetry in therapeutic decision-making.
- if their doctors have taken a personal interest in their perimetry training and have shown positive expectations about the process.
- if they have personally taken perimetry tests and are able to communicate their experiences to patients.
- if they understand the importance of each patient's emotional and physical comfort.
- if they understand that it really is possible for them to facilitate patient performance and also patient satisfaction.

Patients and staff affect each other.[3] Positive staff behavior creates positive patient expectations and vice versa. Failure to provide new patients with important information and reassurance can exacerbate their fears about disease and blindness and cause frustration with the process in general. Patient frustration also can lead to staff frustration, because staff tire of hearing patient complaints and because frustrated patients tend to produce less useful visual field test results.

The Doctor's Role

Positive staff and patient expectations start with the doctor. The doctor must lead, first by explaining to patients why perimetry is important in treatment decisions (Figure 4-1). For glaucoma patients, the doctor should explain that tonometry alone is not enough and that what really counts is how well they see now and how well they will see in the future. We find that patients immediately understand when we explain that visual field testing is the best and most basic way for us to confirm that their treatment is correct and sufficient to preserve their vision. One may show patients illustrative parts of their visual field test results, explaining again why this is useful information. In our

Figure 4-1
The doctor's role. First, the doctor should explain the importance of visual field testing at least once to each patient who is undergoing routine perimetric testing. Second, the doctor must instruct and support the perimetric staff.

experience, patients who understand the value of perimetry and who have been properly coached during their initial tests usually are more than willing and able to do visual field testing and require less staff and doctor attention in future perimetry tests.

Second, the doctor must instruct, listen to, and support the perimetric staff. Technician training and motivation strongly affect visual field outcomes, such as lowering the frequency of testing artifacts.[4] Doctors should periodically discuss with staff members how and why visual field testing should be performed, why it is important to carefully coach new patients, how careful patient management can improve test result quality and patient satisfaction, and whether office routines should be modified to facilitate high-quality field testing. Doctors should also provide positive feedback and encouragement to staff members whenever possible. There can be no substitute for clear communication of positive expectations by the doctors leading a practice.

The Roles of the Perimetrist

The perimetrist manages the whole process of administering visual field tests, ensuring that the patient understands the purpose and nature of the examination, that the patient is properly instructed on exactly how to take the examination, that the patient's demographic data are properly entered, that the proper refractive correction is used, that the patient is comfortably and correctly seated at the device, and that the patient is adequately supervised and reassured during the examination itself.

EXPLAINING THE EXAMINATION TO THE PATIENT

There are two different aspects to patient instruction. First, the patient must be given to understand the purpose and the nature of the examination, a process that we believe is best addressed as soon as the patient enters the perimetry room. Second, new patients must be given specific instructions

regarding how to actually take the test. The amount of detail addressed in these two steps may vary, depending upon how experienced the patient is at automated perimetry, but rather detailed instructions are important for patients who will take their first test.

Regardless of what the patient previously has been told by their doctor or by other staff members, some patients may not remember why they are being examined. Thus, open-ended questions such as "Do you have any questions about today's examination?" may be helpful. Once the reason for testing is understood, new patients will still be wondering what the test will be like, what they have to do, and how long will it take. The perimetrist must explain and demonstrate to new patients such things as how the stimulus will look and where it might appear, how long testing will take, that blinks are necessary and allowed, how to sit, how to pause the test, and so on (Figure 4-2). Importantly, patients should be reassured that the instrument will adapt to their individual response time, thus providing plenty of time to respond. Such explanations will be more convincing if perimetrists have undergone threshold visual field testing themselves.

New patients must clearly understand that the goal is to measure the sensitivity of their peripheral vision and that the perimeter achieves that goal by gradually dimming stimulus intensity at each tested location until the patient can no longer see it. Or, if the patient does not see a stimulus, the perimeter will come back to that location with stronger lights until one is seen. Perimetry is similar to the determination of visual acuity by presenting

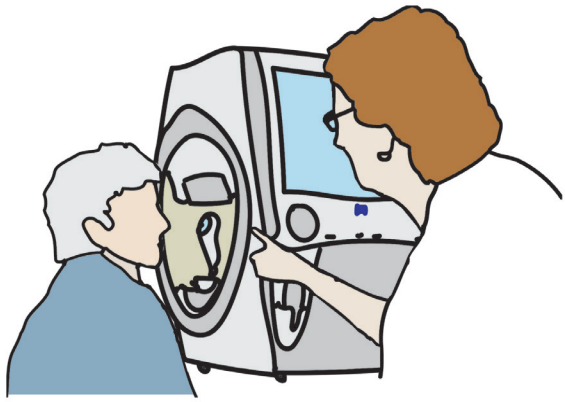

Figure 4-2

The perimetrist's role. The perimetrist plays a central role in the success of visual field testing. Patients who are inexperienced in visual field testing will perform better and feel more comfortable if properly instructed and supported by the perimetrist. Experienced patients will need much less instruction and supervision, especially if they have received careful care on their first test.

smaller or larger letters until the smallest letter that can be seen has been determined. Thus, in threshold perimetry, more than half of the stimuli presented will be too dim to be seen, even for a person with perfect vision, and many of the stimuli that *are* seen are likely to be barely visible. Patients may ask how bright the light must be for them to press the button. Our preferred answer is that they should press the button if they believe that they have seen a stimulus, even if they are not completely sure.

There is value in standardizing the instructions that patients receive. Much may be lost when the elements of what patients need to know are passed down verbally from one perimetrist to the next. We prefer to maintain a written standardized instruction message for perimetrists to refer to, even if they are not expected to follow it verbatim.

The following instructions may be read to new patients or may serve as a guide in defining your own standard instructions. Experienced patients will seldom need such detailed instruction, but new patients will be much more relaxed if they hear and understand each of the points below.

PATIENT INSTRUCTIONS	PERIMETRIST
1. This test will measure the central and side vision of each eye individually. During the test, always look straight ahead at the steady yellow light and blink normally.	Point to yellow fixation light.
2. Other lights will flash one at a time off to the side. Press the button whenever you see one of these lights. There will be plenty of time to respond, because the instrument will automatically adapt to your reaction speed.	Give patient the response button.
3. The test is designed so that it will dim the light flashes until you no longer can see them. Thus, you are not expected to see all the lights, and in fact you probably will see fewer than half of them. This also means that many or most of the lights you do see will be barely visible. Everybody feels unsure of whether she/he has seen a light, but the results still will be valid.	Explain procedure to patient.
4. Blink normally. If you want to pause the test, hold the button down. The test will resume when you release the button.	Demonstrate to patient.
5. Testing time varies, but typically takes about x minutes.* When your test is over, you will hear two beeps. You may then sit back and rest.	Explain procedure to patient.

*24-2 testing duration depends on the strategy chosen. SITA Faster testing typically takes 2 to 4 minutes; SITA Fast, 3 to 6 minutes; and SITA Standard, 5 to 8 minutes (see Figure 3-1).

ENTERING PATIENT IDENTIFICATION DATA

Certain pieces of patient data must be entered consistently for all their tests. Most important is that the patient's name, date of birth, and identification number are always entered in the same way. This is a prerequisite for the perimeter to be able to identify and analyze all of each patient's baseline and follow-up tests. Date of birth also is important, because it is used in age adjustment of the Statpac normative data and to optimize testing efficiency.

An easy way to ensure that identification data are accurate and consistent is to recall the patient's name from previous tests using the perimeter's Patient Search (HFA3) or Recall Patient Data (HFA2 and HFA2i) function. It is possible to further simplify the patient identification process by automatically importing demographics into the HFA from Zeiss Forum or an EMR system (Figure 4-3).

Which Eye to Test First

Conventionally, the right eye usually is tested first. At least one study has found no testing order effect, suggesting that on average it probably does not matter which eye is tested first.[5,6] Still, knowing that some patients may fatigue more than others, we continue to start with the right eye unless there is a reason to do otherwise, so that any fatigue effects will be as constant as possible from visit to visit.

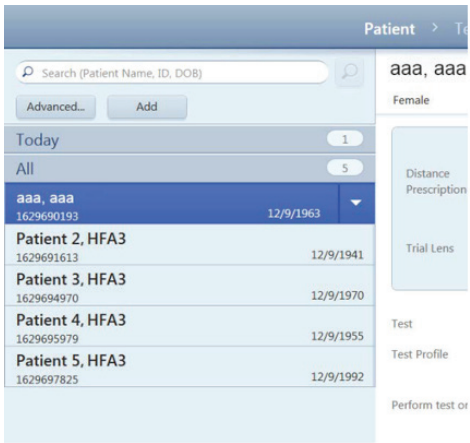

Figure 4-3

Identifying the patient being examined. If the HFA3 is connected to Forum or an EMR system, scheduled patients are listed under "Today." Patient demographics get automatically imported into the HFA upon selection. The same process ensures that existing patient demographics are kept up to date in the HFA database.

REFRACTIVE CORRECTION

Refractive blur reduces visual sensitivity to perimetric stimuli, and it is standard practice to provide refractive correction using trial lenses when testing the central visual field. One diopter of refractive blur in an undilated patient will produce a little more than 1 dB of depression of the hill of vision when testing with a Goldmann Size III stimulus,[7] and for this reason we hesitate to use trial lenses in patients needing less than one diopter of lens correction, a strategy that we find quite helpful if applied in a consistent way. Fully presbyopic patients usually are provided with +3.25 diopter near additions relative to their distance refraction. Patients who are less than fully presbyopic are given lesser additions, either according to standard age-based correction tables programmed into the perimeter's software or based upon clinical judgment. Trial lens correction is only used when necessary for clear vision when testing the central visual field and is never used for testing outside of 30°.

In most testing situations, we prefer to leave astigmatic errors of less than 3 diopters uncorrected and instead to add the spherical equivalent of the astigmatism to the spherical correction. The reason is that small astigmatic errors have little effect upon results and the likelihood of trial lens artifacts increases considerably when a second lens is added. It is probably more important to be consistent from test to test in your choice of a patient's refractive correction than it is to get the correction exactly perfect.

POSITIONING THE PATIENT AT THE PERIMETER

Chair height and instrument height must be adjusted for patient comfort. Proper comfort is important in perimetry because perimetric examination takes somewhat longer than a slit lamp examination or fundus photography, and any discomfort is likely to distract the patient from the task at hand.

Generally, we have found that patients are most comfortable when sitting more or less erect, preferably in an office chair with armrests. Having to lean forward into the instrument can cause the patient to place too much weight on their chin, which often becomes uncomfortable after just a few minutes. Leaning forward also requires an uncomfortable backward flexure of the neck in order to fit into the chinrest and headrest. We find it best to encourage an upright, natural posture and to help the patient slide the chair up to the instrument so that upright posture is maintained. It may be helpful to note that in such an upright position, the patient's legs and feet are under the perimeter, not out in front of the instrument (Figure 4-4).

The patient should be carefully aligned to the correction lenses. The pupil should be at the center of the lens and the lens should be placed as close to the eye as possible without having the lashes touch it when blinking (Figure 4-5).

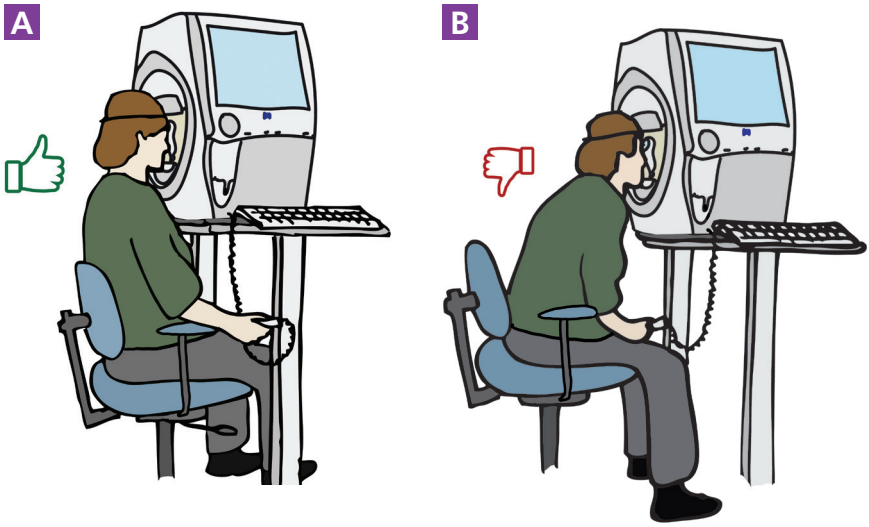

Figure 4-4

Positioning the patient at the perimeter. Patients usually are most comfortable if they are sitting more or less erect with their legs well under the instrument (A). Leaning forward into the chinrest (B) tends to be uncomfortable and to cause neck and back strain. When properly seated, the patient's lower legs are located well under the perimeter.

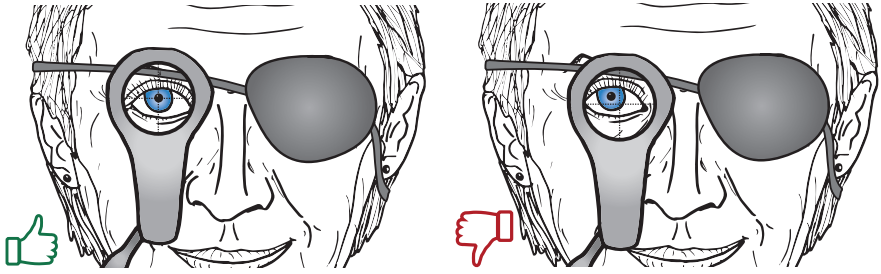

Figure 4-5

Alignment of the patient's eye relative to the trial lens. In order to minimize trial lens artifacts, the perimetrist must periodically check that the patient's eye is still in the center of the trial lens and that the patient has not backed away from the lens holder.

RUNNING THE TEST

In new patients, the perimetrist should be attentive and available during the test to encourage and reassure the patient. The perimetrist also must periodically check that the patient is still in proper position and aligned with the correction lens (Figure 4-5). Experienced patients will require considerably less supervision when they return for follow-up testing, as long as they have been carefully instructed and supervised during their first few tests.

THINGS TO WATCH FOR DURING TESTING

- Does the patient seem comfortable, alert, and calm?
- Is the eye still centered behind the trial lens?
- Is the lens still close to the eye, or has the patient backed away from the headrest?
- Is the patient blinking from time to time?
- Is the patient looking straight ahead at the fixation light?
- Is the upper eyelid high enough so that the pupil is not blocked?
- Is the patient's head reasonably straight, or has it become tilted to the right or left?
- Is the chair still in the right position, or has it slid back from the perimeter?

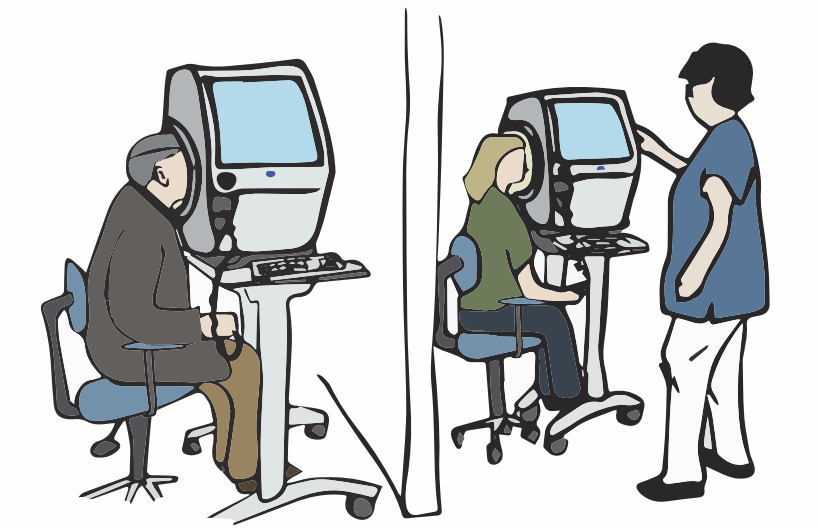

Figure 4-6

Perimetric testing rooms. In clinics having several perimeters, it may make sense to place all instruments in the same room, separated by partitions, or at least curtains. One perimetrist can then supervise more than one patient at a time.

Experienced patients generally need much less supervision, and it may be quite possible for one technician to manage several experienced patients and perimeters at the same time if the testing environment has been suitably organized (Figure 4-6).[8,9] However, when using the new SITA Faster strategy, test times tend to be so short that it may be more efficient to stay with the patient during the whole test.

The HFA has a video output port that allows installation of a duplicate operator screen in another room. The remote screen will show the same information that is being presented on the perimetrist's screen on the HFA. Some HFA models automatically sense the position of the patient's pupil and adjust the chinrest and forehead rest in tiny (0.3 mm) steps, with the goal of keeping the eye centered and aligned with the trial lens. This feature is called Head Tracking and is intended as an adjunct to proper patient instruction and supervision and not as a replacement for the perimetrist.

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5

Statpac Analysis of Single Fields

STATPAC IS A GROUP of computerized analyses included in the operating system of the Humphrey perimeter and in Zeiss Forum Glaucoma Workplace software. Statpac includes the Statpac Single Field Analysis (SFA) and Overview presentations, and the Guided Progression Analysis (GPA).[1-3] Statpac simplifies and standardizes the analysis and presentation of visual field test results in order to help ophthalmologists and optometrists come to more consistent and more useful assessments of test results.[4]

The Statpac Single Field Analysis compares results of a single threshold test with age-corrected normative data and highlights findings that deviate significantly from normal (Figure 5-1). The SFA also presents indices of test reliability, and raw test results. The Overview presentation is a summary report that presents most of the information found in the SFA but for multiple visual field tests (Figure 5-2). This chapter will focus on assessment of results from individual visual field tests as SFA or Overview reports. The Statpac Guided Progression Analysis is described in chapter 6.

Humphrey threshold testing strategies (SITA Standard and SITA Fast/Faster as well as the legacy strategies, Full Threshold and Fastpac) have their own individual normative data. The SITA 10-2 normative data were collected separately and are not based upon the 24-2/30-2 normative data.

Demographics and Testing Conditions

Patient name, identification number, date of birth, age, date and time of testing, visual acuity, pupil size, and eye tested all are presented at the top of the report (Figure 5-1).

Raw Test Results: Grayscale and Numerical Printouts

Simple threshold sensitivities measured at each test point are presented both in numerical and grayscale maps. Sensitivities are indicated in decibels, which are tenths of a log unit; a sensitivity of zero dB indicates that only the maximum available stimulus intensity (10,000 apostilbs) was seen; 10 dB indicates a stimulus one-tenth as intense (1,000 asb) was seen; 20 dB indicates

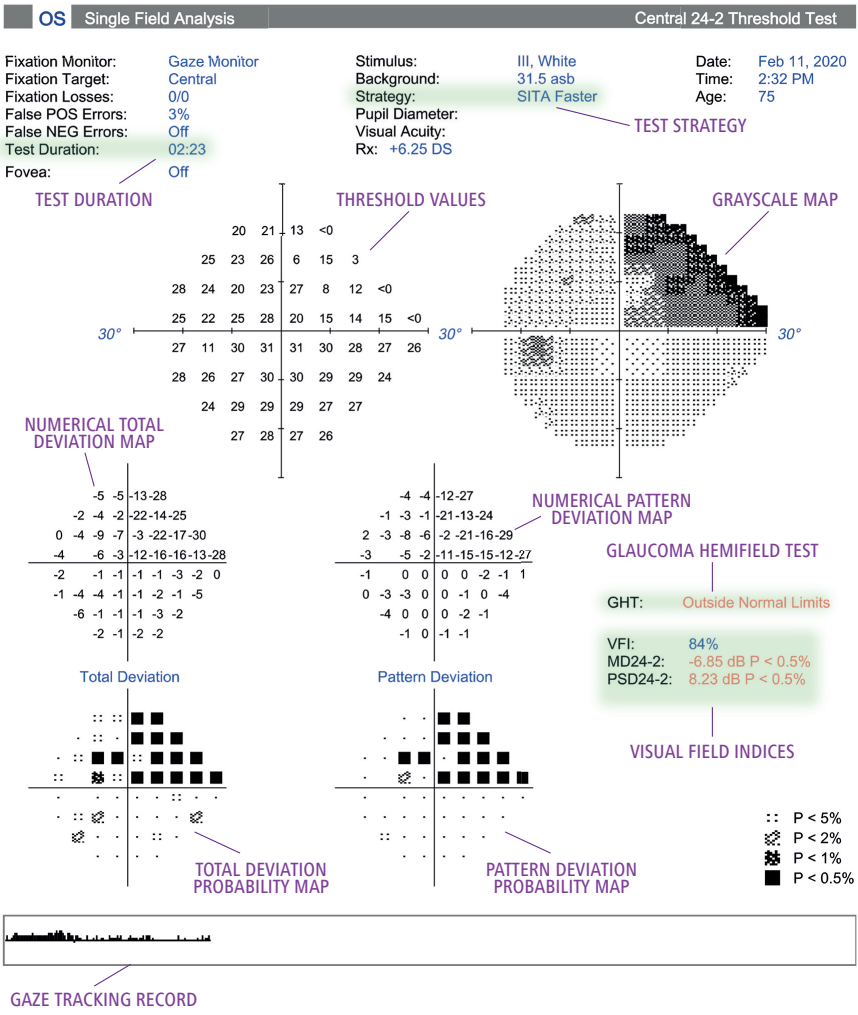


Figure 5-1
The Statpac Single Field Analysis.

1/100th of maximum intensity (100 asb), and so on. A 40 dB (1 asb) stimulus is slightly fainter than the foveal threshold sensitivity found in young perimetrically experienced subjects (Figure 2-5).

Total Deviation

The two Total Deviation maps show the numerical test result differences from age-corrected normal values and identify test points that fall below normal sensitivity by statistically significant amounts. The Total Deviation

numerical map shows the difference from normal in decibels (dB), with positive values denoting points showing better than normal sensitivity and negative values denoting worse than normal. The statistical significances of these deviations from normal depend upon test point location and the test strategy used and are indicated in the associated Total Deviation probability map, in which deviations are highlighted when they are worse than those found in the bottom 5%, 2%, 1%, and 0.5% of sensitivities in normal subjects who are the same age as the patient. A key showing the meaning of the symbols is given near the bottom of the report. A 1% symbol, for instance, indicates that fewer than 1% of normal subjects of the patient's age would be expected to have a sensitivity that is as low as or lower than the value found in the patient's test. The range of sensitivity found among healthy subjects is considerably larger in the periphery than in the center of the field (Figures 2-10 and 2-11). Thus, a finding that is 5 dB worse than age-normal sensitivity is quite unusual at the center of the field—and therefore statistically significant—but is totally within the normal range in the periphery of the areas covered by the 24-2 or 30-2 tests.

Pattern Deviation

The single most useful analysis on a Single Field Analysis printout is the Pattern Deviation probability map. The companion Pattern Deviation numerical map shows deviation levels in decibels for each tested point after an adjustment has been made to remove any generalized depression or elevation of the overall hill of vision. The Pattern Deviation probability map uses the same symbols as the Total Deviation plots to identify points that are depressed by statistically significant amounts, compared to the range of values typically found in normal subjects.

Cataract and corneal opacities cause generalized depression of sensitivity throughout the visual field, which can complicate detection of localized early glaucomatous defects. By removing the generalized component of field change, the Pattern Deviation analysis can highlight subtle localized loss while largely correcting for such effects.

The strength of the probability maps is that they highlight subtle but statistically significant variations that might otherwise escape notice (Figures 5-2, 7-11, 9-4, and 9-5). Probability maps also help deemphasize common artifactual patterns, such as eyelid-induced depressions of sensitivity in the superior part of the field, that often appear on the grayscale (Figure 12-4). Artifactual field loss is discussed in chapter 12.

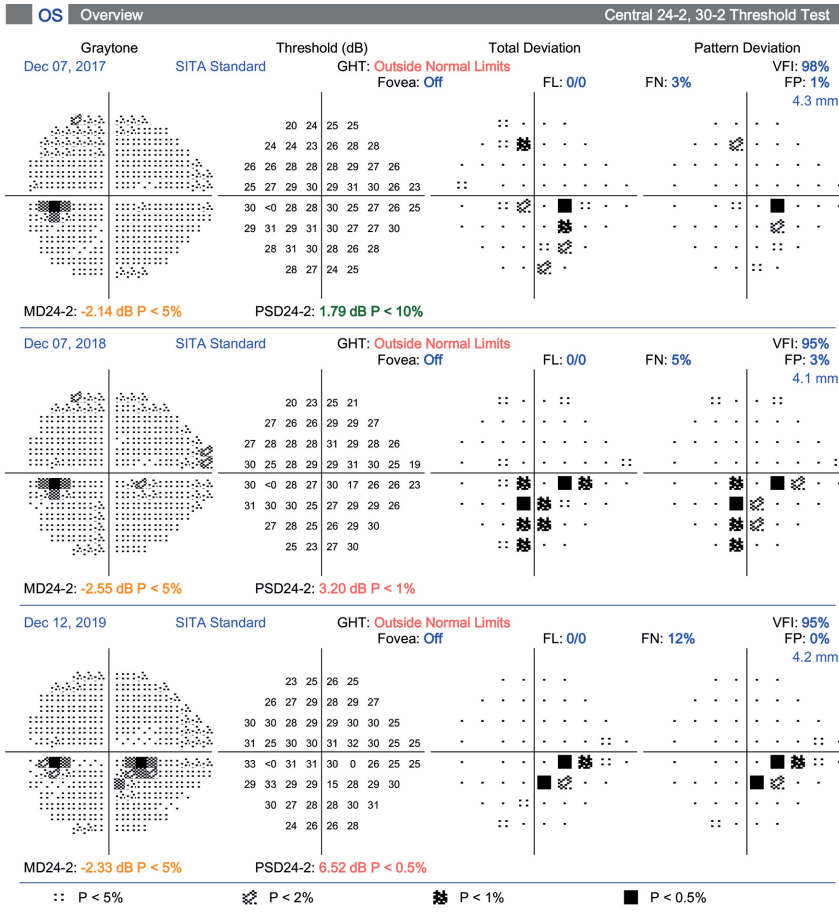


Figure 5-2

Subtle field defects. Subtle abnormalities often are considerably more distinct in probability maps than on grayscale maps, as seen in this Overview report. Thus, it is common to see developing field loss earlier in probability maps.

Comparing Total Deviation and Pattern Deviation

It is useful to compare the Total Deviation and Pattern Deviation maps when evaluating clinical cases. If the two maps look more or less the same, then there is little or no generalized depression. On the other hand, a uniformly depressed Total Deviation map combined with a normal Pattern Deviation map probably indicates cataract (Figure 5-3). The opposite pattern—a Pattern Deviation map that looks more disturbed than its corresponding Total Deviation map—often is associated with a so-called trigger-happy patient who has been repeatedly pressing the response button even when no

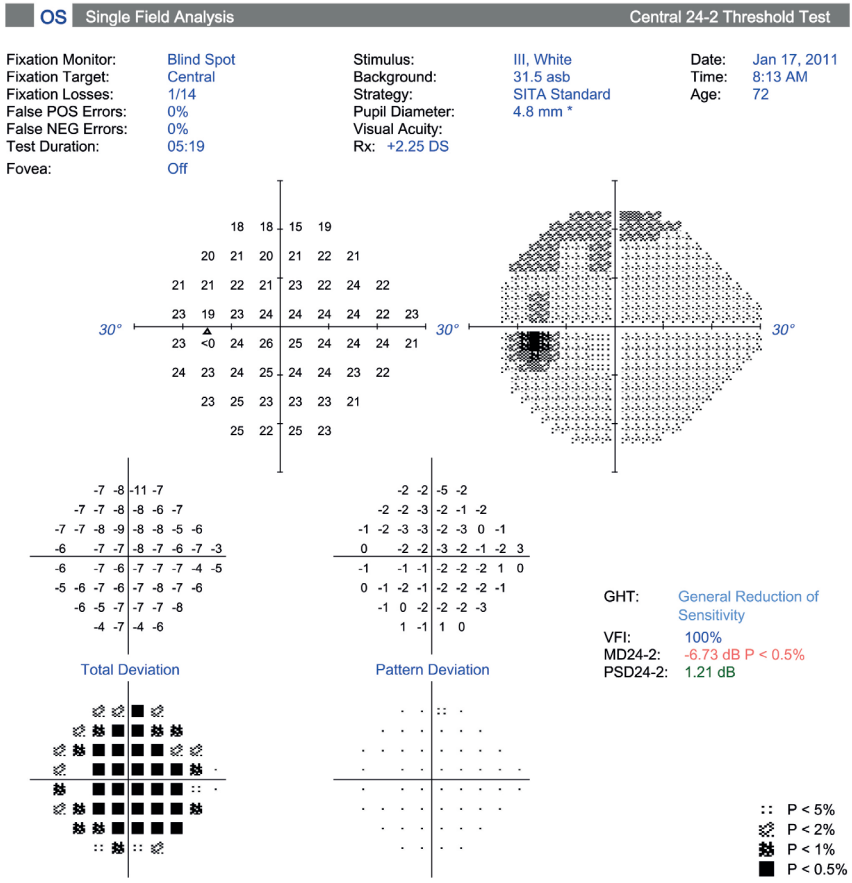


Figure 5-3

A typical cataract pattern in an otherwise normal visual field. There are many significantly depressed test points in the Total Deviation probability map, but almost all the points in the Pattern Deviation probability map are within normal limits. The Mean Deviation is depressed by almost 7 dB and the Glaucoma Hemifield Test (which is introduced as the next topic in this chapter) reports a General Reduction in Sensitivity, a finding that is consistent with a diagnosis of cataract. It is interesting that the depression of sensitivities in the numerical Total Deviation map is around 7 dB in most points, yet centrally located points depressed by that amount are flagged at higher levels of significance than points at the periphery of the test point pattern. This is an illustration of the fact that normal inter-subject variability is smaller centrally, and that therefore a certain level of sensitivity loss may have high statistical significance in the more central parts of the field while being less significant, or even falling within the normal range, in points farther away from the point of fixation.

stimulus was seen (Figures 5-4, 12-9 and 12-10). However, if the differences are small, the patient may simply be better at or more experienced with perimetric testing than most people of the same age.

Glaucoma Hemifield Test

The Glaucoma Hemifield Test (GHT) is an artificial intelligence–based analysis that provides plain-language classifications of 24-2 and 30-2 test results. The GHT is based upon patterns of loss commonly seen in glaucoma.[5-7] Pattern Deviation scores in each of five zones in the upper hemifield are compared to

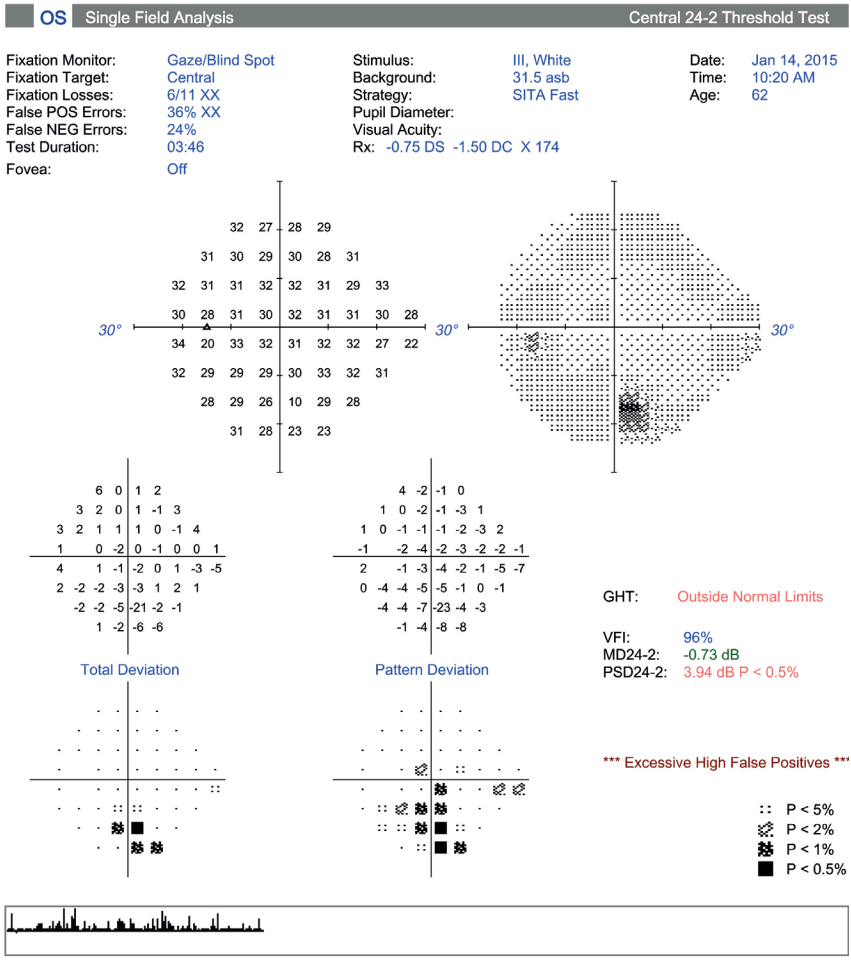


Figure 5-4

An "inverted cataract pattern," with a greater number of depressed test point locations in the Pattern Deviation map. This presentation often is seen in test results having a high percentage of false positive answers from a "trigger-happy" patient.

findings in mirror-image zones in the inferior visual field. Scoring differences between mirror-image zones are compared to normative significance limits specific to each zone pair (Figure 5-5).

GHT findings are divided into the following categories:

- **Outside Normal Limits**. This message is displayed whenever at least one zone pair differs by an amount found in fewer than 1% of normal subjects.
- **Borderline**. Fields not classified as Outside Normal Limits are labeled as Borderline whenever at least one zone pair differs by an amount found in fewer than 3% but more than 1% of normal subjects.
- **General Depression**. This message is presented whenever even the best test point locations have such low sensitivity as to be at levels seen in fewer than half a percent of normal subjects.
- **Abnormally High Sensitivity**. This message is presented whenever the best test point locations are so high as to be at levels seen in fewer than half a percent of normal subjects, and it supersedes and suppresses all other messages.
- **Within Normal Limits**. This message is presented whenever none of the other conditions are met.

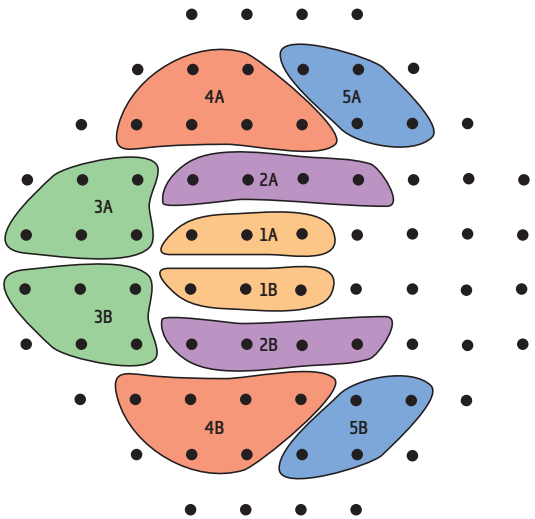


Figure 5-5

The Glaucoma Hemifield Test. The Glaucoma Hemifield Test compares Pattern Deviation probability scores in five zones in the upper field with corresponding mirror-image zone scores in the lower hemifield. Statistically significant findings produce plain-language messages on test reports. All points used in the GHT are common to both the 24-2 and the 30-2 test point patterns.

The GHT has been reported to have high sensitivity and specificity,[8] and the user who is still getting used to visual field interpretation may find identifying glaucomatous visual field loss on the basis of GHT findings to be the best choice. The method was designed to have an overall target specificity of approximately 94% when Borderline findings are treated as being Within Normal Limits, and about 84% when Borderline findings are considered Outside Normal Limits. Actual specificity will depend upon the clinical population being examined. Highly experienced users should expect to find that they sometimes prefer their own interpretations to those offered by this analysis. Note that the GHT's zone pattern is designed to be sensitive to glaucomatous visual field damage. It was not designed to have high sensitivity to field loss caused by diseases other than glaucoma, such as neurological field loss, but it often does detect such loss.

Global Indices

Three summary indices of visual field status—Visual Field Index (VFI), Mean Deviation (MD), and Pattern Standard Deviation (PSD)—appear on the Single Field Analysis printout. It should be emphasized that these indices are not primarily meant for diagnosis. They can be within normal limits in fields with early field loss that is clearly visible in probability maps and sometimes also in grayscale maps.

VISUAL FIELD INDEX

The Visual Field Index is an improved version of the older MD index, that is less affected by cataract than MD except in fields having MDs worse than -20 dB, where cataract effects are similar. VFI also is designed to provide improved correspondence to ganglion cell loss compared to MD.[3] VFI is approximately 100% in normal fields is 0% in perimetrically blind fields. VFI is the preferred index when calculating perimetric rates of progression in the GPA analysis (see chapter 6).

MEAN DEVIATION

Mean Deviation is a center-weighted average of the decibel deviations shown in the Total Deviation plot. MD is primarily used to stage visual field loss and is an older metric for rate of progression. MD is approximately zero dB in normal fields, but the values in perimetrically blind fields vary from approximately -31 dB to -35 dB, depending upon patient age and test strategy (Figure 6-7).

PATTERN STANDARD DEVIATION

Pattern Standard Deviation reflects irregularities in the field, such as those caused by localized field defects. PSD is small, that is, close to zero, both in normality and in blindness, and peaks at moderate levels of localized field loss. Because of this nonlinear behavior, PSD should not be used as a staging or progression index. We find that PSD detects localized visual field loss reasonably well but provides no information about the pattern or shape of the damage. Probability maps and the Glaucoma Hemifield Test are preferable for diagnostic purposes.

Reliability Indices

Three reliability indices were developed in the early days of automated perimetry, with the intention of helping doctors and perimetrists assess the reliability of test results. These indices are the rates of False Positive (FP) response errors, in which a patient may be pressing the response button even when no stimulus has been seen; False Negative (FN) response errors, in which the intention was to identify inattentive patients by periodically presenting test stimuli that were thought to be much brighter than necessary for detection; and Fixation Loss (FL) errors, in which intense stimuli were presented in the presumed location of the patient's physiological blind spot, assuming that if the patient responded to such a stimulus, he or she must not have been looking at the fixation point.

Over time, however, it has become clear that reliability indices do not function as well as was hoped,[9,10] and one would not be entirely incorrect to state that the reliability indices themselves may be the least reliable data in automated visual field testing. We now believe that visual field test results should seldom be discarded solely on the basis of these reliability indices.

FALSE POSITIVE ERRORS

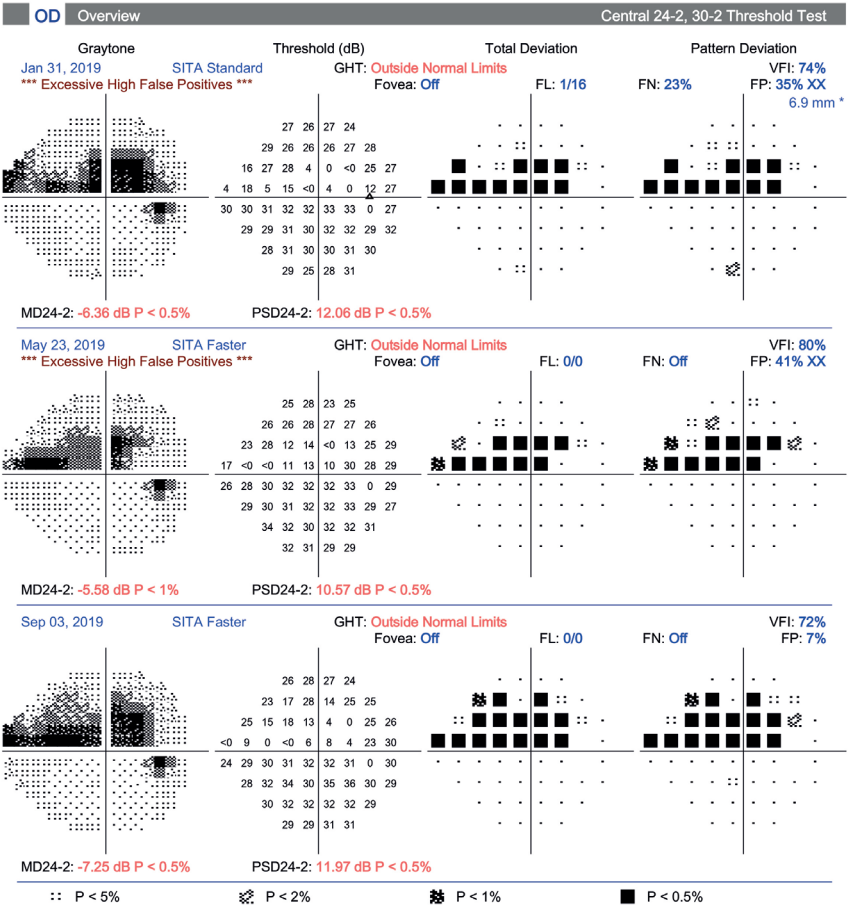
The False Positive response error score measures the tendency of patients to press the response button even when no stimulus has actually been seen—in order to identify so-called trigger-happy patients. With the SITA strategies, patient responses that are made at impossible or unlikely times are used to estimate FP responses.[11] These include responses made too soon or too late after stimulus presentation, considering patient reaction times measured during the same test. Because FP rates depend strongly upon assessment of patient reaction time over the whole course of the test, the FP rate is not calculated until after testing has been completed.

High FP values certainly are associated with compromised test results, but we now know that it is not a strong relationship.[9] It is common to have useful test results with FP rates higher than the current guideline of 15% (Figure 5-6A). While FP rates are useful, we believe that we must now develop better ways of identifying unreliable fields caused by trigger-happy patients.

It is also now clear that the distributions of FP answers are different among different test strategies. Thus, FP rates tend to be lower in SITA Standard tests than in SITA Fast tests, and higher in SITA Faster tests.[12] In the future, the limits for flagging tests based upon FP rates are likely to be higher than the currently suggested limit of 15% and may depend upon the strategy being used. In the meantime, we recommend that one confirms the effect of any finding of Elevated FP Rates by looking for confirmation in the form of any of the other characteristics of a trigger-happy field, as outlined in Figure 12-9 (chapter 12) and in Figures 5-4 and 5-6 in this chapter.

FALSE NEGATIVE ERRORS

The False Negative response score was originally meant to detect patient inattention and to help identify patients who have consistently failed to respond to stimuli that probably should have been seen. FN rates are measured by occasionally presenting intense suprathreshold stimuli at test point locations where threshold sensitivity already has been measured and found to be reasonably normal. A continuing problem is that FN rate estimates are elevated in pathological visual field tests, even in highly attentive patients (Figure 5-7). Thus, the FN index is not specific to patient inattention but is also a characteristic of an abnormal visual field.[13-16] This often is evident in patients with unilateral glaucoma, where FN is higher in the eye with field loss than in the eye with a normal field (Figure 5-7). We have often seen useful visual fields being unnecessarily discarded and patients being retested because of high FN rates, and we usually include pathological fields in our analyses even if FN rates have been high. We believe that all perimetrists should be made aware of the fact that high FN rates are common in pathological fields, even in patients who have performed the test perfectly well. One should certainly not blame the patient for being inattentive, and retesting is not recommended. The new SITA Faster test strategy is programmed to not perform FN testing unless the user insists.



A

Figure 5-6

False positive response rates. High FP rates do not necessarily make test results useless. The first two tests in this Overview report (A) have FP rates that are considerably higher than the often recommended limit of 15% (35% and 41%, respectively). Nevertheless, the two tests present patterns of visual field loss that are similar to each other and to the third test, which shows an FP rate of 7%. Also, low FP rates are no guarantee that a test result is free of "trigger-happy" patient responses. In B, we see classic signs of excessive "trigger-happy" patient behavior in the presence of zero false positive response errors (Figure 12-10). Signs present include white scotomas, impossibly high threshold measurements of 41, 43, and 49 decibels, a message of "Abnormally High Sensitivity" from the GHT analysis, and an "inverted cataract pattern" in the Total Deviation and Pattern Deviation plots. See also Figures 12-9 and 12-10. FP rates must be interpreted in the context of other signs of "trigger-happy" patient behavior, and clinical test results should not be discarded solely on the basis of FP rates.

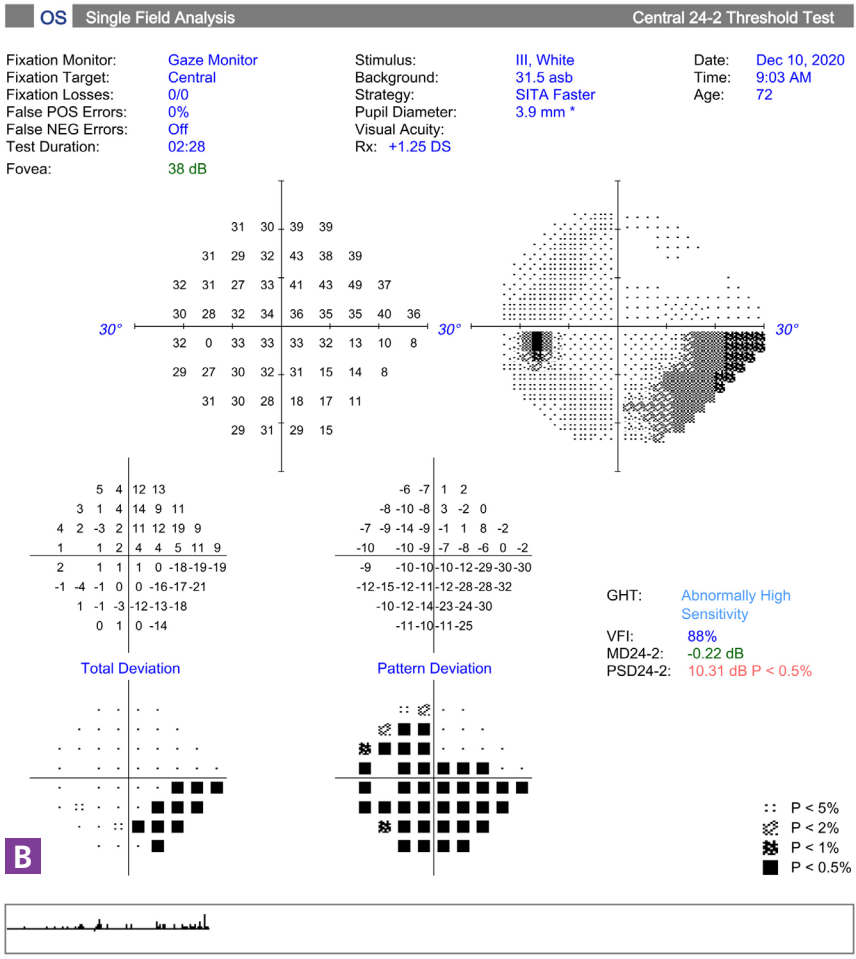


Figure 5-6 continued

FIXATION LOSS RESPONSES

Fixation Loss responses are obtained using a method described in 1974 in which moderately bright test stimuli are presented at the expected location of the physiological blind spot of the tested eye—the so-called Heijl-Krakau method.[17] Positive patient responses to such stimuli are taken to suggest that the patient may not be looking straight ahead. The method has been widely used in many or most automated perimeters, but it has well-known shortcomings.[9] Often, the patient sees the FL stimulus simply because the patient's blind spot is not situated in the location assumed. Another disadvantage of this method is that fixation checks add to the test time and

therefore can be made only occasionally during the test. As a result, we prefer to turn off FL catch trials and to rely instead upon the HFA's full-time gaze tracker. The new SITA Faster strategy relies by default upon gaze tracking and not FL.

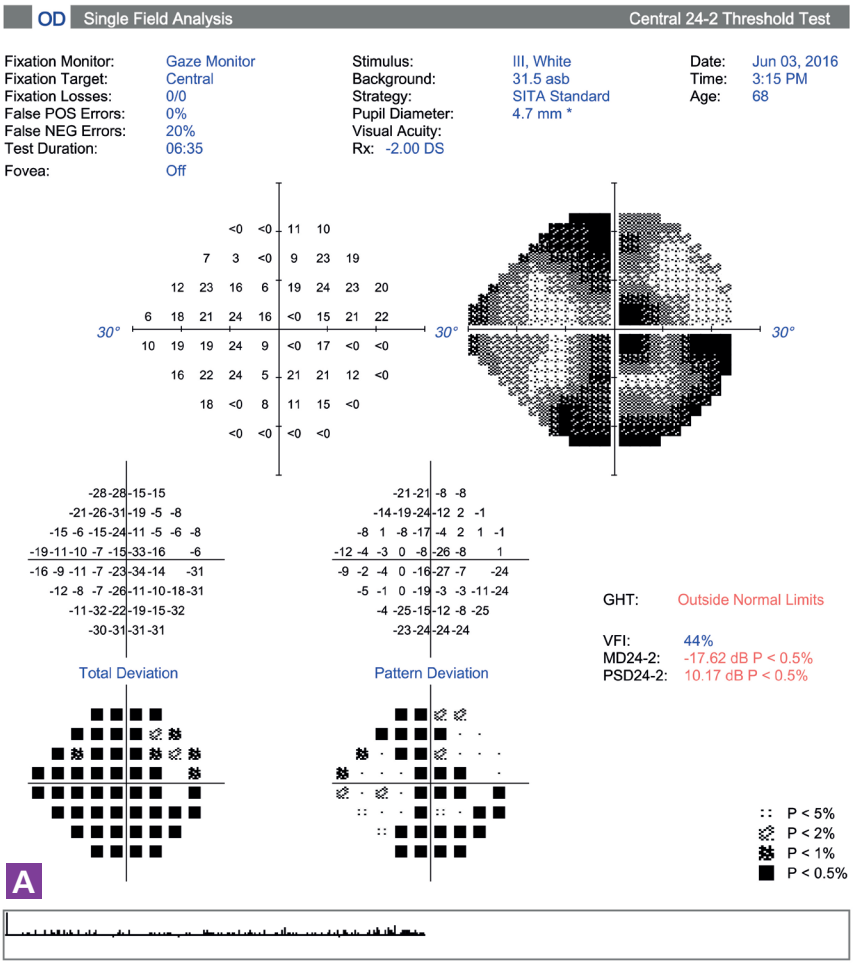


Figure 5-7

Elevated False Negative rates in abnormal visual fields. The measured False Negative rate tends to be higher in abnormal glaucomatous fields than in normal fields. This often is demonstrated in patients with unilateral glaucoma. In this example, the FN error rate was 20% in the glaucomatous right eye (A) and zero in the normal left eye (B). In general, a field test showing considerable glaucomatous field loss should not be discarded simply because the FN rate is elevated.

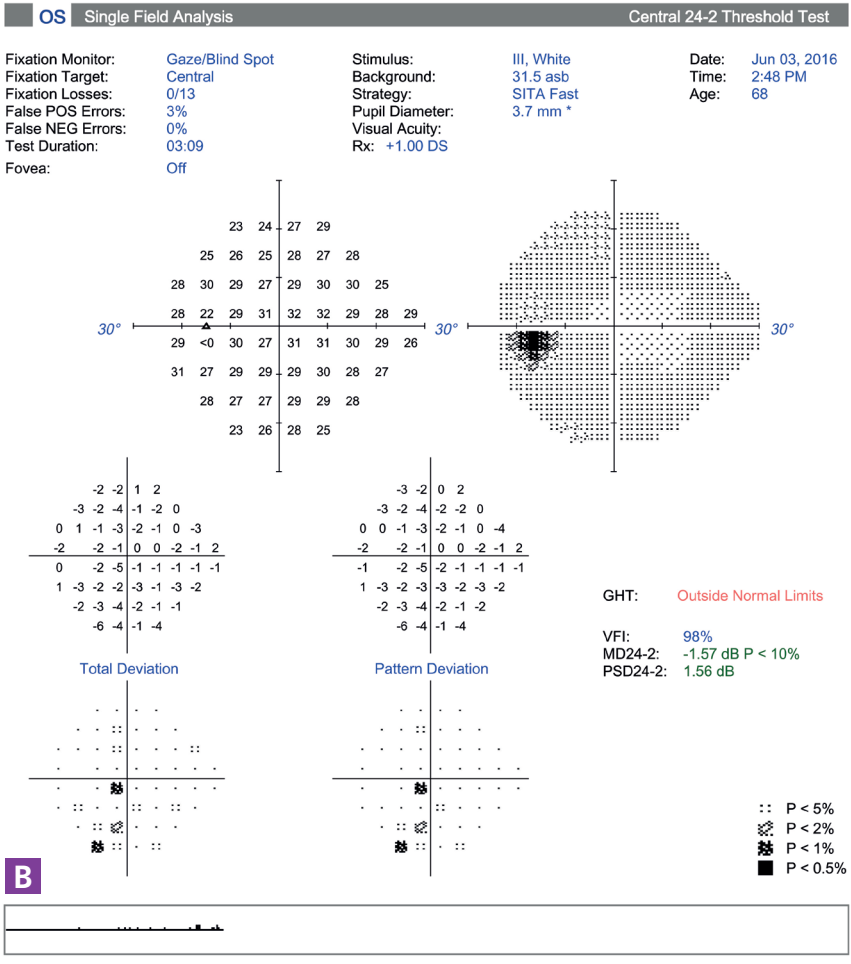


Figure 5-7 continued

Gaze Tracking

In most Humphrey perimeters, an automatic dual-variable gaze tracker measures gaze direction every time a stimulus is presented. A record of gaze stability is presented at the bottom of the SFA printout. In most patients, measurements are precise to approximately ± 2°.

On the gaze tracking record, lines or marks extending upward indicate the amount of gaze error during each stimulus presentation, with full-scale markings indicating gaze errors of 10° or more. Small downward marks indicate that the gaze tracker was unable to measure gaze direction, while larger downward marks indicate eyelid interference with the device's view of the eye, for example because of blinking or squinting (Figure 5-8). Guidelines for interpretation of gaze tracker results are presented in Figure 5-9.

The HFA's gaze tracker uses image analysis to separately locate the center of the pupil and the reflection of a light-emitting diode from the corneal surface. The spacing between these two features strongly depends upon gaze direction while being largely independent of changes in patient head position. Separate calculations provide head position information that is used in one model of the HFA to automatically keep the eye aligned at the center of the trial lens.

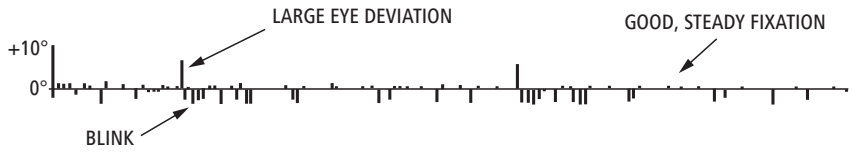
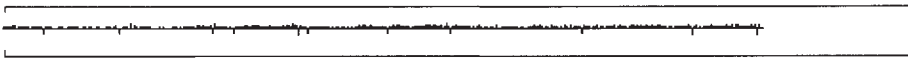


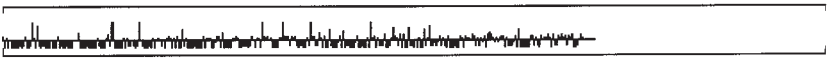
Figure 5-8

Interpretation of gaze tracker report. Upward markings indicate the amount of gaze deviation at the time of stimulus presentation, with full-scale markings indicating gaze deviations of 10° or more. Small downward markings indicate that the system was unable to determine the direction of gaze. Large downward markings indicate that the patient blinked during stimulus presentation.

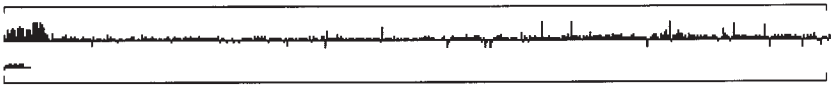


A Exemplary fixation stability with minimal gaze errors.

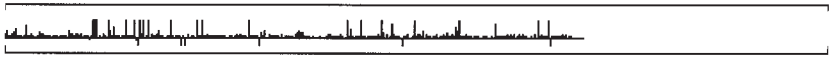
B Mostly consistent fixation, except for a period of instability about a quarter of the way into the test.



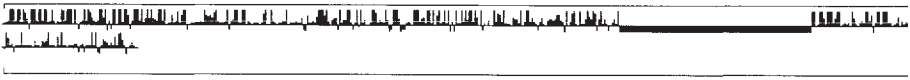
C Frequent loss of tracking signal, indicated by downward deflections of the trace, perhaps caused by blinks or other interference by the lids.



D Initial fixation instability, followed by exemplary steadiness.



E Occasional gaze errors. This represents good fixation stability.



F Unreliable fixation, with numerous maximal gaze errors and loss of tracking signal late in the test.

Figure 5-9

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6

Assessing Perimetric Change

OPHTHALMIC AND NEUROLOGICAL DISEASE can cause significant and progressive visual field changes, and assessment of those changes over time can help doctors determine whether a patient is recovering, stable, or getting worse. Visual field changes that are both statistically and clinically significant may provide a basis for adjustments in prognosis or therapy. However, because increasingly aggressive therapies often have correspondingly increasing side effects and risks, therapeutic escalation decisions may also depend upon whether or not the observed rate of change poses a threat to the patient's quality of life.[1,2]

Measurement of Visual Field Progression in Glaucoma

Standard Automated Perimetry plays a central role in glaucoma management, simply because the primary effect of glaucomatous progression is continued loss of visual function.[2] Standardized methods for detecting and quantifying progressive visual field damage increase the level of agreement between doctors[3] and can provide key information when making therapeutic decisions (chapter 9).

The Humphrey perimeter's Guided Progression Analysis (GPA) offers both event and trend analyses. The goal of event analysis is to assess whether there has been any statistically significant worsening in the visual field. The goal of trend analysis is to quantify the rate of visual field loss and to help the practitioner assess the risk of future visual impairment associated with that rate.

Choosing Baseline Tests

Follow-up tests are compared to baseline tests in order to quantify the amount and rate of change. Choice of baseline tests must be based upon the therapeutic decision at hand, which usually is deciding whether current therapy is adequate. Thus, baseline tests must define the patient's status at a particular time, such as the beginning of therapy, the date when therapy was significantly modified, or the date when the rate of disease progression was observed to have changed abruptly. Tests performed prior to the revised baseline tests are no longer included in the progression analysis.

GPA has been programmed to choose by default the earliest two fields as baseline tests. Sometimes that is a good choice and sometimes it is not. At a minimum, we suggest reviewing the instrument's choices and manually selecting better choices when necessary. GPA also has been programmed to remember the chosen baseline tests in subsequent follow-up examinations.

It is recommended that new baselines tests also be chosen after any major change in therapy, such as after filtering surgery, by selecting two representative fields taken near the time when the therapeutic change occurred. One should try to avoid choosing a baseline consisting of two quite different fields. See chapter 9 for examples of how and when to make such changes.

GPA has been expanded to allow free mixture of SITA testing strategies in any series of tests, in order to facilitate analysis if different SITA test strategies have been used during follow-up. Thus, a patient who has been followed for some years using SITA Standard or SITA Fast can be switched to SITA Faster without having to obtain new baseline tests. This was achieved for the GPA event analysis by calculating significance limits for change for each possible combination of baseline strategy and follow-up strategy. GPA test interchangeability for regression analysis was possible simply because of the strong similarity between the Visual Field Index (VFI) findings of the three SITA thresholding strategies.[4,5] We hope that this capability will encourage conversion to shorter and more patient-friendly test strategies and also encourage clinical use of GPA itself.

Guided Progression Analysis Data Presentation

Our preferred GPA reports for use in glaucoma management are the HFA one-page Summary Report and Glaucoma Workplace's Bilateral GPA Summary (Figures 6-1 and 9-10), which show the baseline fields, trend analysis of all available tests, and a change event analysis of the most recent test. When we want a little more detail, we use the two-page GPA Last Three Follow-Up report, which lets us see change event analyses of the three most recent follow-up tests (Figure 6-2). If one wishes to see event analyses of all available follow-up tests, one may refer to the GPA Full report, which is identical in format to the Last Three Follow-Up but includes all follow-up tests.

GPA Trend Analysis

The goal of trend analysis is to quantify how quickly each patient's visual fields are changing and thereby to help identify patients who are progressing at rates that threaten to cause visual impairment or loss of vision-related quality of life within their expected lifetime. The trend analysis estimates rate

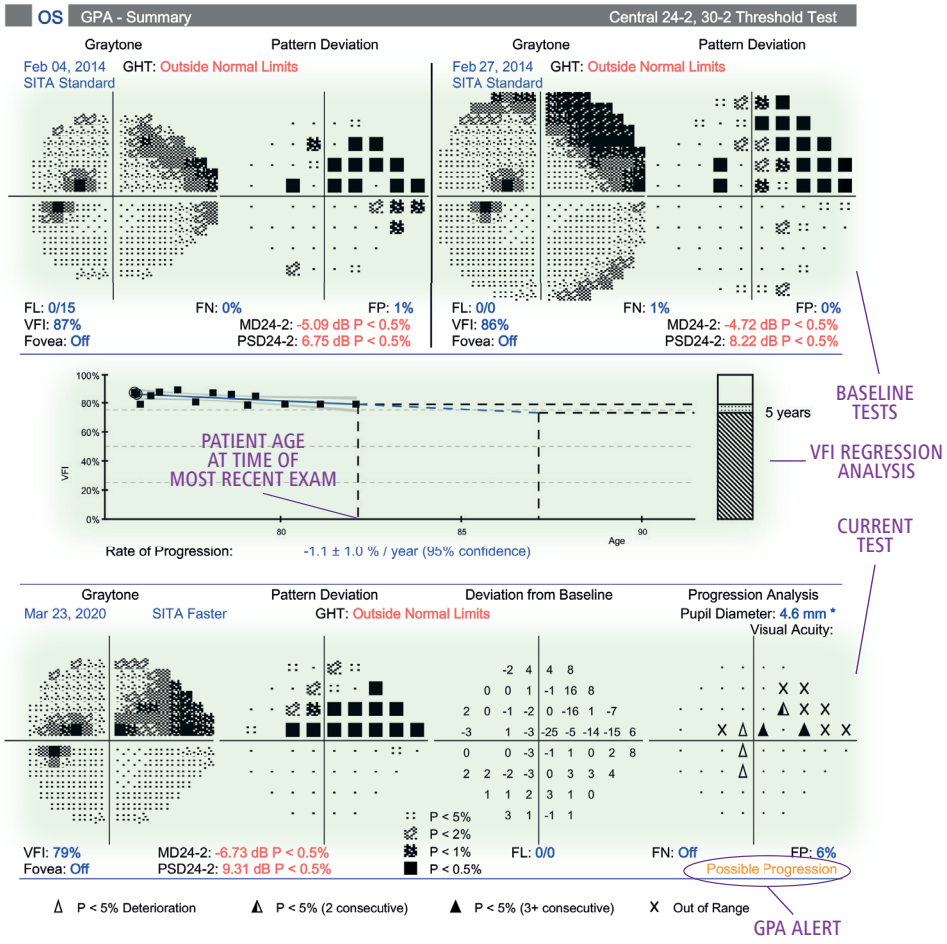
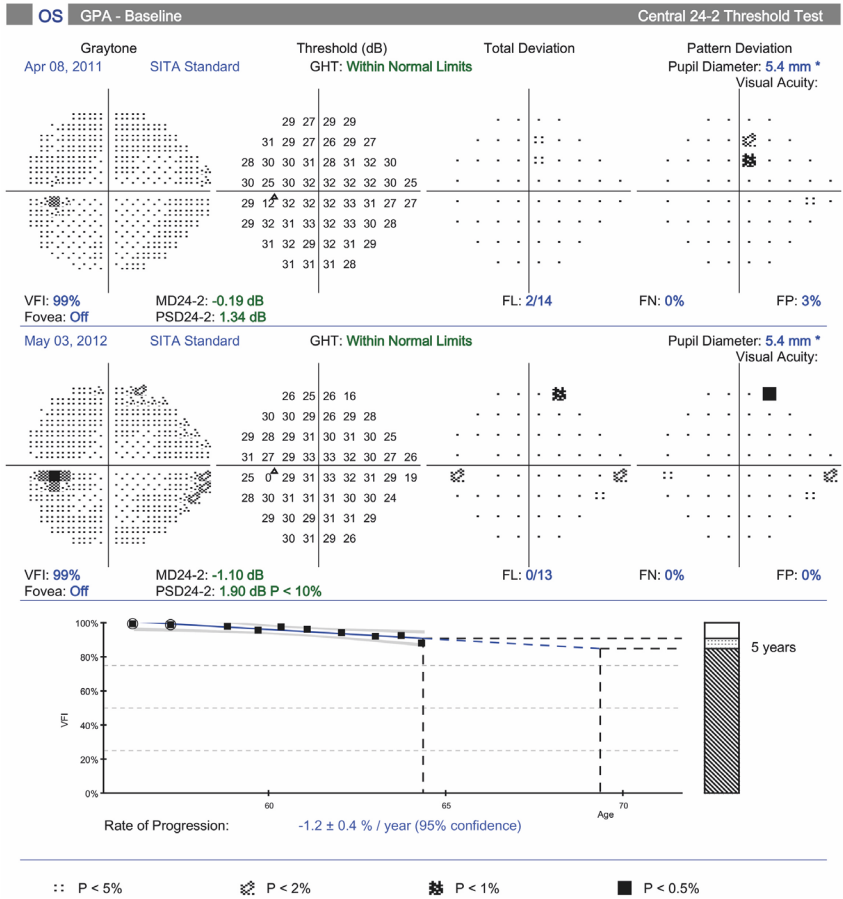


Figure 6-1

The Guided Progression Analysis Summary Report. This report presents the two baseline fields at the top and the most recent field at the bottom. In the middle of the report is a linear regression analysis of the Visual Field Index values of all available visual fields. The linear regression suggests that this eye has shown only slow progression over 6 years of follow-up. However, the GPA Alert's finding of Possible Progression means that a few test points may now have worsened by more than the expected test-retest variability.



A

Figure 6-2

The GPA Last Three Follow-Up is a two-page report showing more complete baseline test information and a regression analysis on page 1 (A). Event analyses of the most recent three follow-up tests are presented on page 2 (B). This patient's regression analysis shows a slow rate of loss. However, this patient is only 64 years old, and all three follow-up tests show progression in the inferonasal field, which has triggered a GPA Alert message suggesting "Likely Progression."

of progression using linear regression analysis of the VFI over time.[6] This regression analysis is automatically calculated whenever five or more eligible visual field tests are available.

VFI is a single number that summarizes each patient's visual field status as a percentage of normal age-corrected sensitivity. Thus, a completely normal visual field would have a VFI of 100% and a perimetrically blind visual

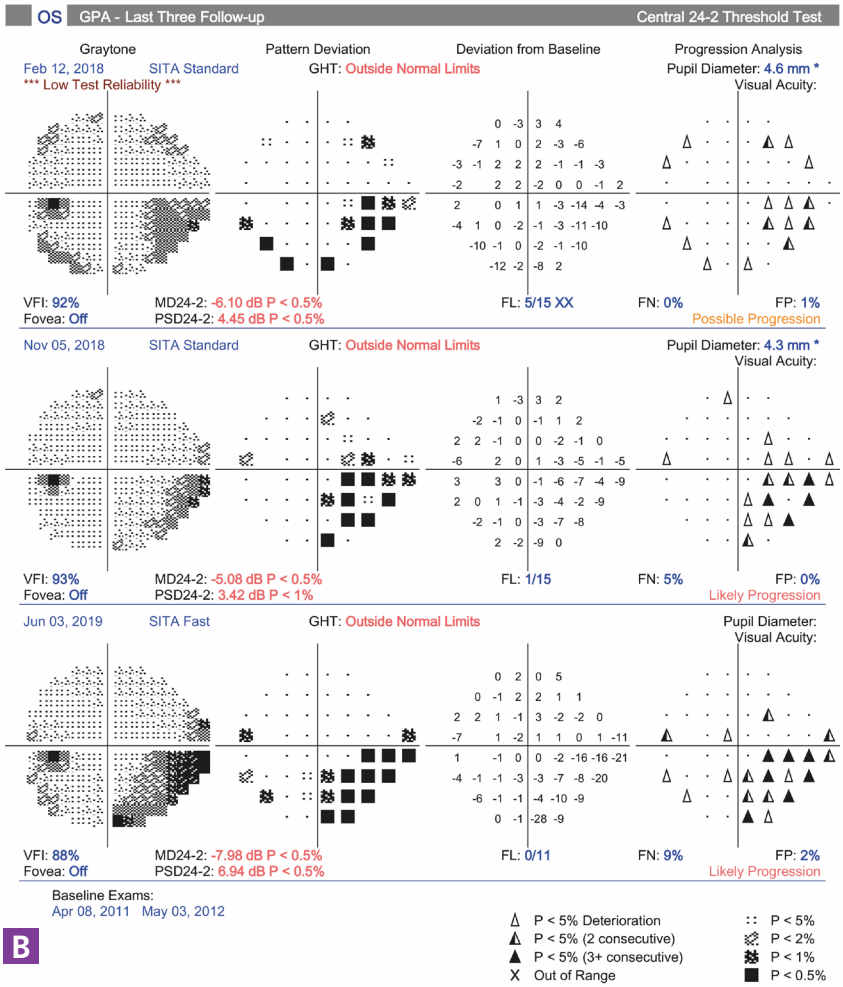


Figure 6-2 continued

field—in which even the perimeter's brightest stimuli could not be seen at any tested point—would have a VFI of 0%. VFI gives central test points considerably more weight than peripheral ones in order to better account for the much higher density of ganglion cells that is normally found in the central retina (Figures 6-3 and 6-4).

In the center panel of the single-page GPA Summary Report is a graph displaying one VFI value for each visual field test the patient has performed,

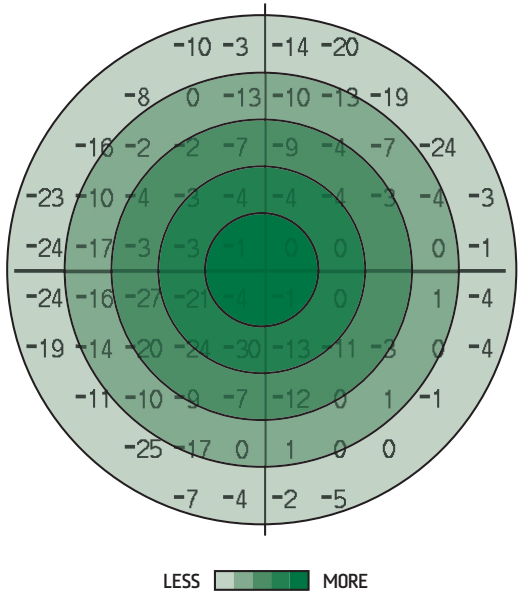


Figure 6-3

Visual Field Index test point weighting. When calculating VFI, central test points are given much higher weight than peripheral ones because of the much higher ganglion cell density closer to the center of the retina.

plotted against patient age (Figure 6-5). When at least five examinations are available, GPA performs a linear regression analysis on the plotted VFI values and calculates the patient's rate of progression as percentage points of VFI loss per year, along with confidence limits on the rate estimate.

GPA provides a projection of the linear regression line into the future, if five or more exams covering a time period of at least 2 years are available and if the width of the calculated 95% confidence interval for VFI slope is found to be no larger than a VFI value of ± 2.5 percentage points. The goal of this projection is to illustrate the patient's possible future course if the present trend continues and is not altered by a change in therapy. Thus, the intent is not to predict what *will happen* but rather to indicate what *may happen* if the present trend is allowed to continue, knowing that such forward projections often are quite accurate.[7] GPA projections never exceed 5 years and are never longer than the perimetric follow-up period thus far. A vertical bar to the right of the regression analysis indicates the patient's current and projected vision status.

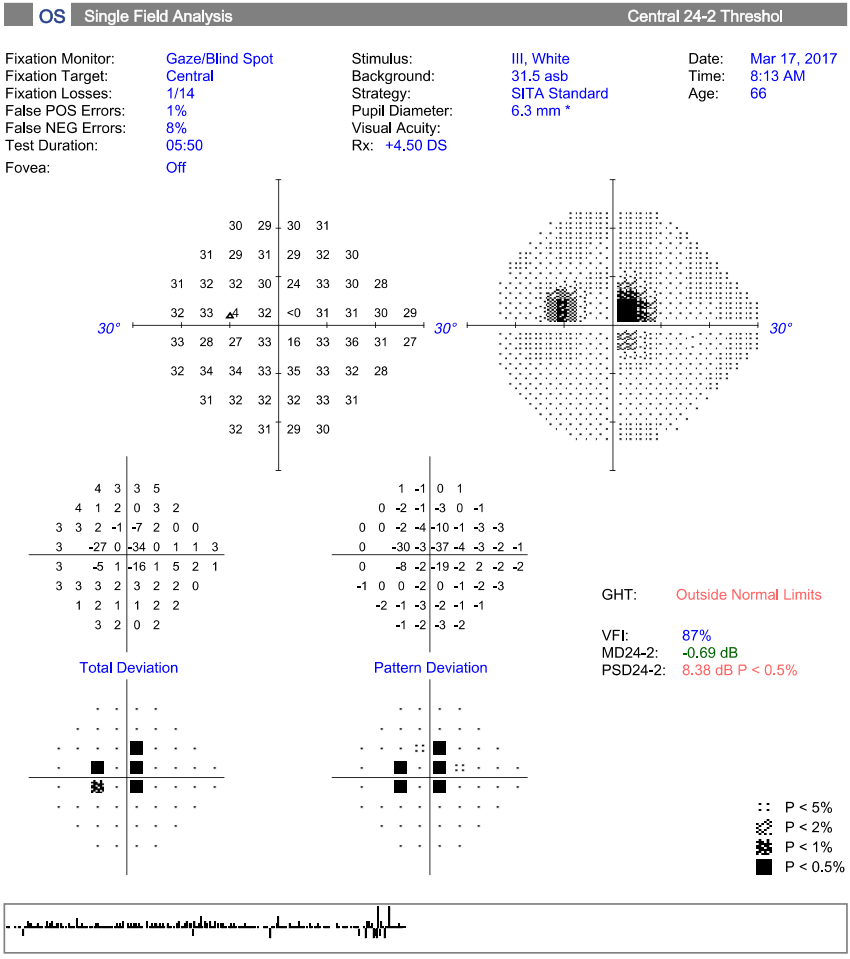


Figure 6-4

Effect of Visual Field Index test point weighting. VFI gives central test points considerably more weight than peripheral ones. In this example, three nasal field test points near fixation show large sensitivity losses. The VFI is reduced by 13% compared to age-corrected normal, while the Mean Deviation value is affected very little, illustrating the higher weight given to central points in the VFI calculation.

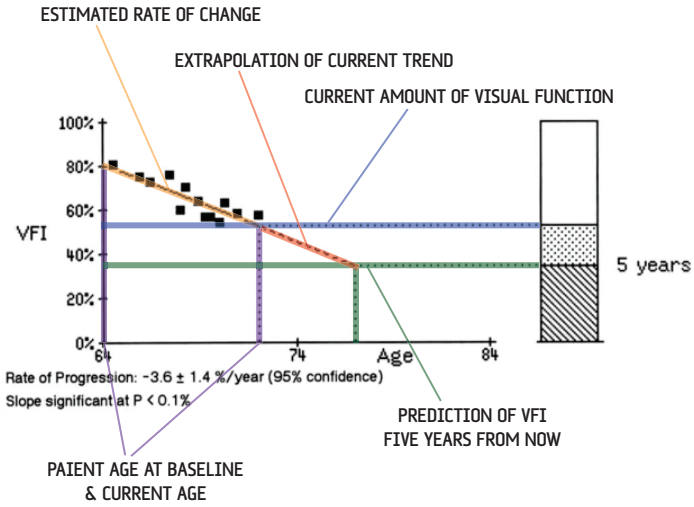
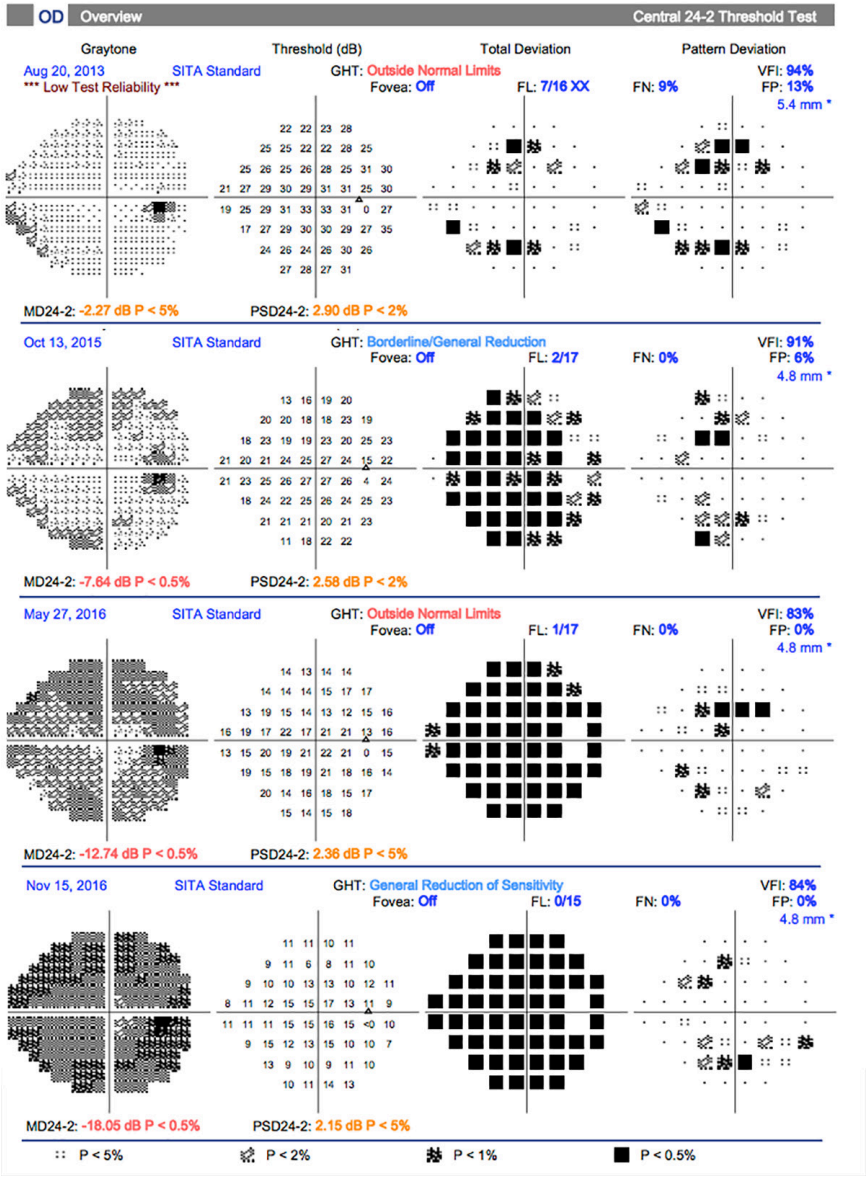


Figure 6-5

Visual Field Index regression analysis. The VFI regression analysis provides critical glaucoma management information: the rate of field progression, remaining visual function, patient age, and an extrapolation of the current VFI trend.

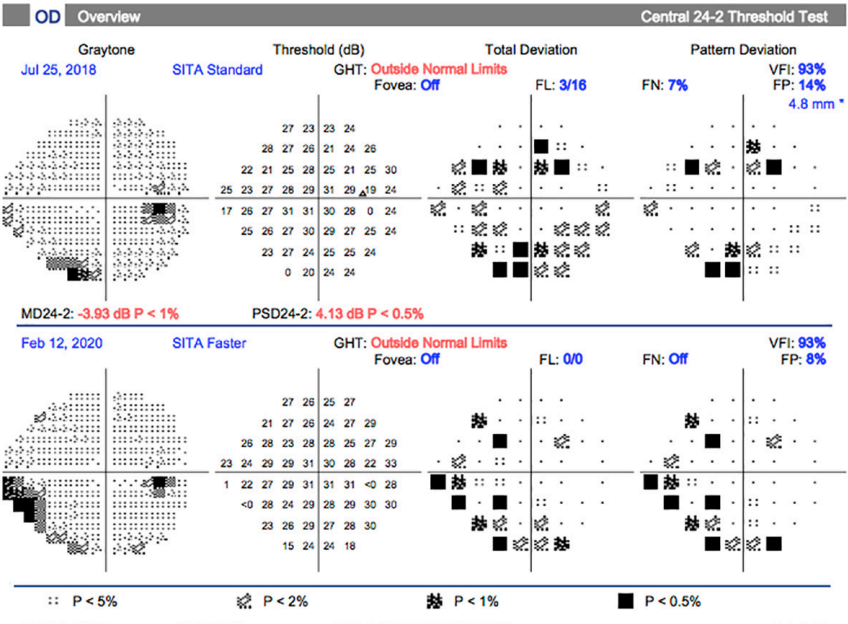
The original HFA estimated rate of progression using linear regression analysis of Mean Deviation (MD). However, the high prevalence of developing cataract and cataract surgery among glaucoma patients often complicates the use of MD.[8] Rate of progression estimates based on VFI have been evaluated in comparison with MD in glaucoma patients suffering from increasing cataract, in glaucoma patients free of cataract, and in glaucoma patients who have had cataract surgery during the course of follow-up. VFI-based progression rates were much less affected by cataract and cataract surgery than rates based on MD, but the two indices produced very similar rates in eyes that were free of cataract (Figure 6-6).[6,9] An additional important difference between VFI and MD is that the MD value associated with blind fields depends upon age and testing strategy, while VFI in a perimetrically blind field always is 0%, regardless of age or strategy (Figure 6-7). Therefore, we see no reason for owners of Humphrey perimeters to continue using the older MD analysis, when the better and newer VFI analysis is available. (See chapter 5, page 86).



A

Figure 6-6

Effects of cataract and its removal on visual fields. Cataract and its removal affect Total Deviation maps and the Mean Deviation index, much more than Pattern Deviation maps and the Visual Field Index. (A) Total Deviation plots show a generalized increase in Total Deviation loss that is typical of developing cataract. (B) After cataract surgery in 2017, the Total Deviation maps again look similar to Pattern Deviation. (C) Because MD is just a weighted average of all Total Deviation values, MD closely tracks changes in Total Deviation maps. (D) VFI is considerably less affected by cataract and by cataract surgery.



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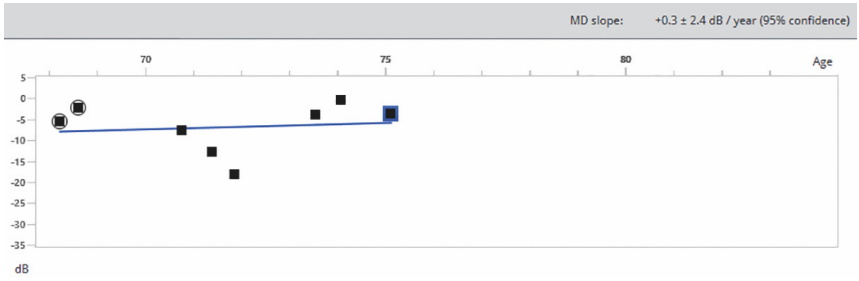

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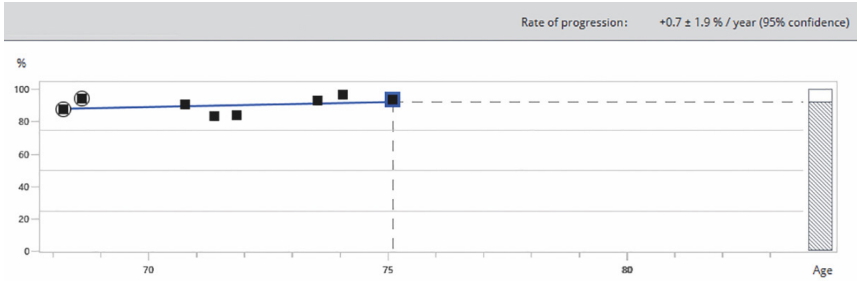

D

Figure 6-6 continued

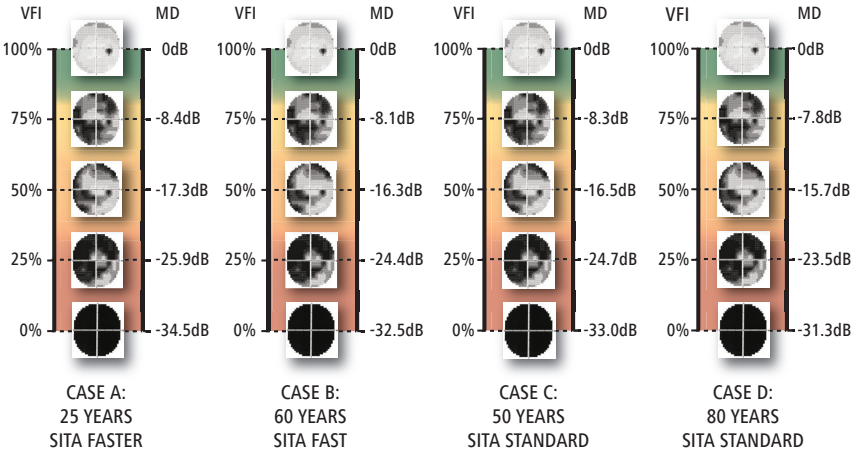

Figure 6-7

Age and test strategy effects on relationship between Mean Deviation and Visual Field Index. MD values associated with perimetrically blind fields depend upon age and testing strategy, while VFI in a perimetrically blind field is always 0%.

GPA Event Analysis

The GPA's Glaucoma Change Probability Map (GCPM) highlights 24-2 and 30-2 test points whose Pattern Deviation values have deteriorated from baseline by more than the 95th percentile of random variability seen in patients having similar levels of glaucomatous visual field loss (Figures 6-1 and 6-2). GPA then determines how many points have been thus highlighted in the follow-up test and whether observed changes have also been seen in earlier follow-up tests. GPA posts a plain-language message called a GPA Alert, based upon the criteria for progression used in the Early Manifest Glaucoma Trial (EMGT).[10]

GPA Alert will display the message "Possible Progression" when the same three or more test points have shown statistically significant deterioration on two consecutive follow-up examinations. A "Likely Progression" message will appear when the same three or more significantly deteriorated test points appear in three or more consecutive follow-up tests (Figures 6-1 and 6-2).

When evaluating Glaucoma Change Probability Maps, the user should expect that each test point will have a 5% risk of being flagged, simply from random test variability. The important concepts here are, first, that test points that are truly worsening will show reproducible change, and second, that statistically significant change must be seen at multiple point locations in the test to be credible.[11] Glaucoma Change Probability Maps are not calculated

for fields having an MD value worse than -20 dB, the reason being that the mathematical model for calculating Pattern Deviation, which forms the basis for the GCPMs, cannot be reliably applied when very severe visual field damage is present.

Analyses based upon the EMGT criteria have been reported to be both sensitive and specific compared to expert consensus. The EMGT criteria have been reported to have a sensitivity of 96% for 30-2 tests and a mean time to detect progression of 33 months, compared to 55 months and 66 months for two other analysis methods that have been used in other large clinical trials. Specificity for 30-2 tests has been reported to be 90% for complete series of 30-2 visual fields consisting of more than 20 tests, which suggests that specificity for analysis of individual follow-up tests must be considerably higher. Analysis of only the points contained in the 24-2 test pattern decreased sensitivity to 91% but increased specificity for whole series of more than 20 examinations to 96%. Median time to detect progression was reported to be 37 months for the 24-2 test.[12] A separate evaluation reported a 24-2 test specificity of 97.4% for any finding of Likely Progression in groups of 10 follow-up tests, again suggesting even higher specificity for individual follow-up tests.[13] In cases of disagreement with expert analysis with GPA, expert consensus classification usually was that progression had occurred,[14] further confirming the high specificity of this analysis and suggesting that progression identified using the EMGT criteria probably has very high credibility as long as the baseline tests have been chosen appropriately.[15] On the other hand, if perimetric examination frequency is low, true progression may occur before the GCPM analysis has had a chance of detecting it. Possible Progression can never be flagged earlier than the fourth test, and Likely Progression not until the fifth, regardless of the magnitude of progression encountered.[16]

The GPA's Change Probability Maps are based upon significance limits for change in Pattern Deviation[17] and thus were designed to minimize the effects of cataract development and extraction on progression analysis. Given the high incidence of cataract in the age group most likely to have glaucoma, we believe that such a strategy should help provide the high level of specificity that is needed in clinical glaucoma care and clinical trials.[12,15] Glaucoma Change Probability Maps were not designed to find the earliest signs of glaucomatous visual field loss but to find the earliest signs of worsening in fields already having some degree of loss. For initial diagnosis, the Glaucoma Hemifield Test and Pattern Deviation maps play more important roles than does GPA.[18]

GPA's Change Probability analysis highlights test points deteriorating by more than the 95th percentile of random test variability seen in perimetrically

experienced glaucoma patients. Significance limits for change are based upon the variability observed in hundreds of glaucoma patients who were tested four times in the space of a month in an international multicenter clinical trial.[19] GCPMs also take advantage of detailed empirical knowledge developed over a 20-year period that quantifies how test-retest variability depends upon general field status, test point defect depth, and test point eccentricity (Figure 6-8).[20] All these factors are included in the mathematical model that provides the basis for GCPMs.[17] See chapter 2 for further details.

GCPMs use triangle symbols to highlight statistically significant deterioration from baseline (Figure 6-9). Each follow-up field is compared to the average of the baseline pair, and open triangles indicate test point locations

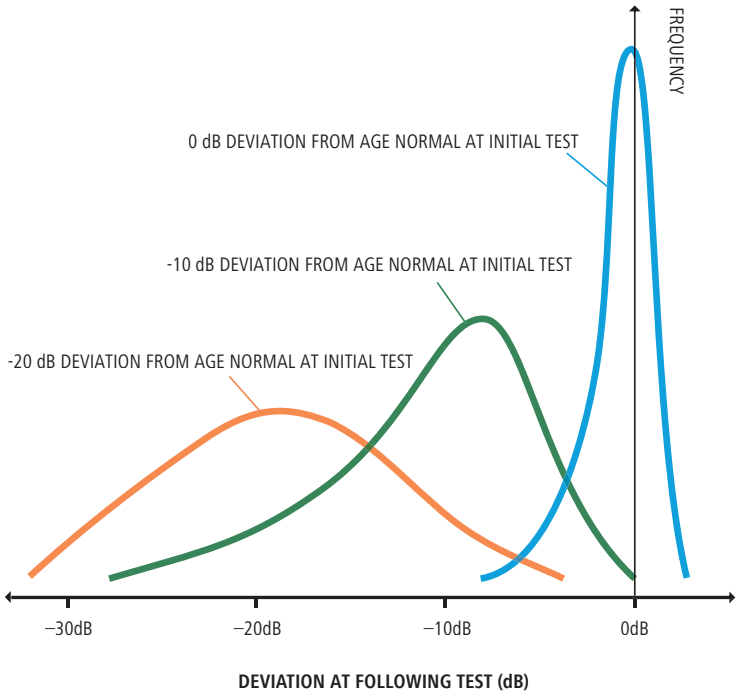

Figure 6-8

Test-retest variability in glaucomatous visual fields. Random test-retest variability in glaucomatous fields is complex but has been characterized empirically in a multicenter clinical trial in order to produce HFA's Guided Progression Analysis. Normal test points may vary little from test to test, just a few decibels up or down (blue curve). Test point locations with damage and reduced sensitivity show larger variability (green and orange curves). Peripheral test points show higher variability than central test points (not shown), and fields having worse MDs show more variability than fields having more normal MDs (Figure 2-13).

showing deterioration that is statistically significant at the $p < 0.05$ level. Half-black triangles identify test points that have shown statistically significant deterioration in two consecutive follow-up examinations, and filled-in black triangles designate locations where such deterioration has been observed in three or more consecutive tests. The intent here is that findings of deterioration should be accepted only when they are consistently repeatable.

Statistical Significance Versus Clinical Significance

GCPMs probably are the most effective method currently available for finding statistically significant perimetric glaucoma progression events, particularly in clinical trials, where many fields may be performed per year. For example, in the recent United Kingdom Glaucoma Treatment Study, very frequent testing and use of GCPMs allowed investigators to demonstrate a significant difference between the study's two treatment arms after just 12 months.[15,21]

In ordinary clinical care, *statistically significant* changes found using GCPM analysis can prompt clinicians to look critically at the patient's trend analyses in order to determine whether *clinically significant* change may be happening. In the end, it is clinically significant change that affects quality of life. Thus, we must focus our attention on careful evaluation of GPA's regression analysis of VFI when finally determining whether a patient's current therapy is adequate.

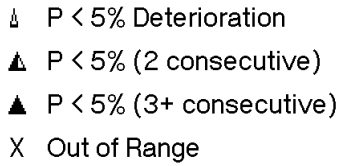

Figure 6-9

Symbols used in Glaucoma Change Probability Maps. The first time that a test point location shows statistically significant deterioration compared to baseline, it is marked with a narrow open triangle. If the same point shows significant worsening at the next examination, a half-black/half-white triangle is used. If this result is confirmed at a third consecutive test, a filled-in black triangle is displayed. Thus, the symbols become more visible as results are shown to be more repeatable. Some narrow open triangles are expected in each test from random variability alone. Test points that fall outside the range that can be analyzed for statistically significant change are marked with an X.

Use of the Overview Report in Visual Field Progression in Diseases Other Than Glaucoma

GPA's Visual Field Index and Mean Deviation trend analyses are not disease-specific. Thus, VFI and MD regression analyses and rate of progression calculations may be used for diseases other than glaucoma. On the other hand, GPA's Pattern Deviation Change Probability significance limits are based upon empirically observed test reproducibility in glaucoma patients and have not been shown to be applicable to other diseases.

Qualitative evaluation of series of visual fields for nonglaucomatous progression can be done by reviewing series of visual fields in Overview format. Diseases of interest may include retinopathies, nonglaucomatous optic neuropathies and other neurological disease. The Overview report puts all of a patient's available visual field tests into a single report (see Figure 6-10 and chapters 10 and 11). While this report does not quantify change, it does provide a broad qualitative overview of a patient's visual field history, the evolving character of any field abnormality, and the level of consistency of findings. The Overview report also may facilitate identification of tests that clearly may not be representative of the patient's medical status, for example because of testing errors.

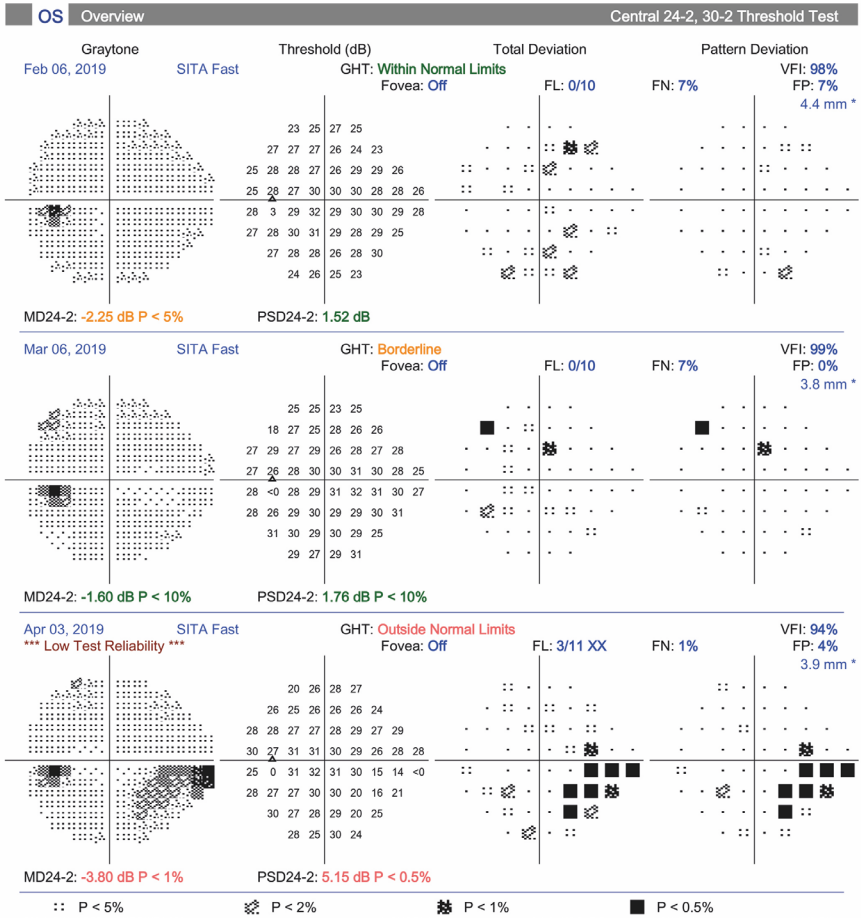

Figure 6-10

Overview report. The Overview report is helpful for displaying the development of field defects over time, particularly in patients with diseases other than glaucoma. The field tests shown in this figure were obtained from a patient being treated for thyroid ophthalmopathy and being followed with monthly perimetry. This 70-year-old woman had a 10-year history of Graves' ophthalmopathy. At the time of these fields her disease activity increased despite high-dose steroid treatment. In this disease, it is common for field defects to develop and regress within just weeks, as we can see in this example. The patient has now undergone surgical decompression.

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7

Glaucomatous Visual Field Loss

GLAUCOMATOUS FIELD LOSS IS the result of axonal damage at the level of the optic disc and is the functional correlate of neural loss or reduced neural function.

Retinal Nerve Fiber Layer and Optic Disc Anatomy

Retinal ganglion cell axons entering the optic disc from the temporal retina curve around the macular area (Figure 7-1). Axons originating from ganglion cells in the temporal superior and temporal inferior retinal areas do not mix but diverge from a dividing line called the temporal raphe, which typically is not quite horizontal. Axons also generally maintain a retinotopic organization within the optic disc in the sense that longer axons tend to be situated in the optic disc periphery while shorter axons from ganglion cells

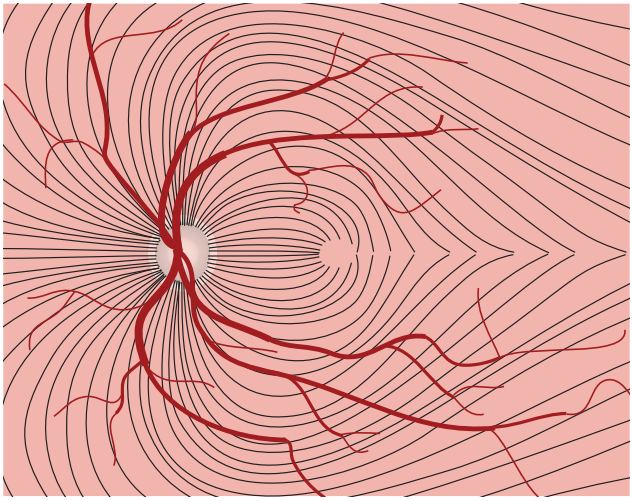


Figure 7-1

Retinal nerve fiber pattern of the central retina. The temporal fibers originate above or below the temporal raphe and arch around the macula to reach the optic disc.

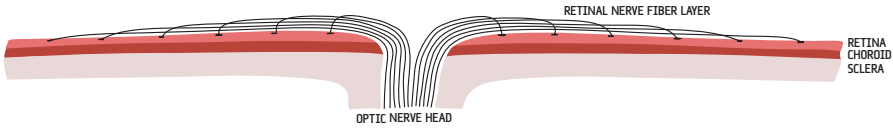


Figure 7-2

Retinotopic organization of optic nerve axons. All axons of the optic nerve converge on and exit the eye through the optic disc. Axons are systematically layered so that longer ones originating far from the disc are situated deeper in the retina and more peripherally in the optic disc.

nearer to the optic disc follow a more central course through the optic nerve (Figure 7-2).

Common Glaucomatous Field Defects and Their Anatomical Correlates

Common glaucomatous visual field defects include paracentral scotomas, arcuate defects, and nasal steps. Mixtures of defect types often occur in the same field.

PARACENTRAL SCOTOMA

A shallow or incomplete notch in the optic disc's neuroretinal rim is likely to damage only a portion of the axon bundles entering the nerve at that location, and the damaged fibers are likely to be of approximately equal length, originating 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 visual field, but they are particularly common in the nasal field (Figures 7-3 and 7-4).

ARCUATE DEFECTS: THE BJERRUM SCOTOMA

A deep focal notch in the optic disc's neuroretinal rim will lead to loss of retinal nerve fibers in the area corresponding to the notch and therefore to an arcuate field defect, often connecting to the blind spot (Figure 9-2). Classically, the corresponding visual field loss courses around the point of fixation and ends abruptly at the nasal horizontal meridian, which corresponds anatomically to the temporal raphe, to produce what is called a Bjerrum scotoma (Figure 7-5).

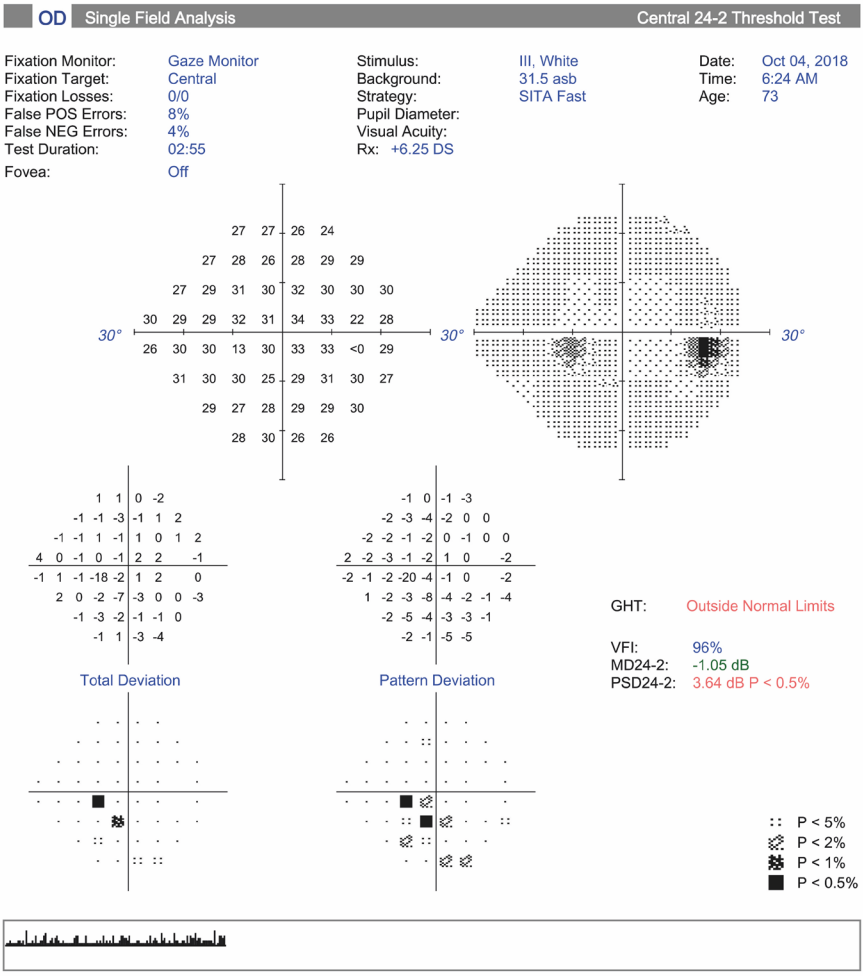


Figure 7-3

Glaucomatous paracentral scotoma. The expected corresponding nerve fiber layer damage is illustrated in Figure 7-4.

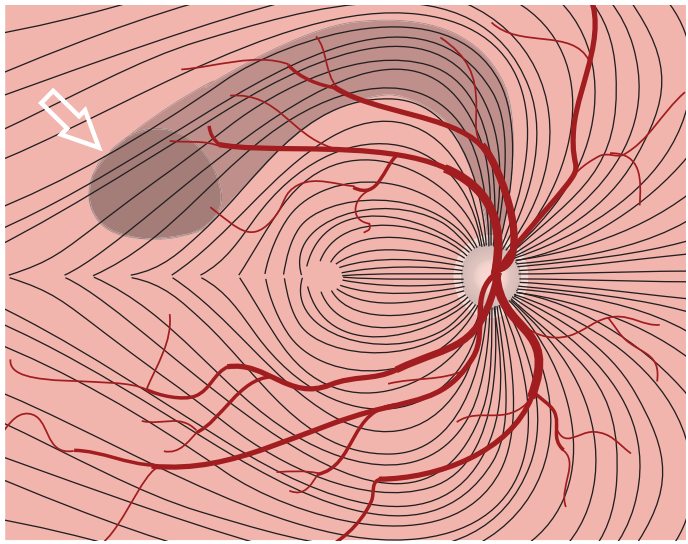


Figure 7-4

Retinal nerve fiber layer appearance in focal optic disc damage. Damaged fibers project in an arcuate pattern and are of similar length. The corresponding ganglion cells are located in the dark oval area above the temporal raphe (white arrow). This illustration is intended to approximate the pattern of nerve fiber loss that would be expected to be associated with the field in Figure 7-3.

NASAL STEPS

A nasal step is a defect in the nasal visual field that sits on the horizontal meridian but does not cross it. Damage to optic disc fibers will seldom be entirely symmetrical when comparing the upper and lower parts of the optic nerve, but instead is likely to involve a larger percentage of lost fibers in either the inferior or the superior half of the optic disc. Such damage frequently manifests as a difference in threshold sensitivity across the nasal horizontal meridian in the visual field. (Figure 7-6).

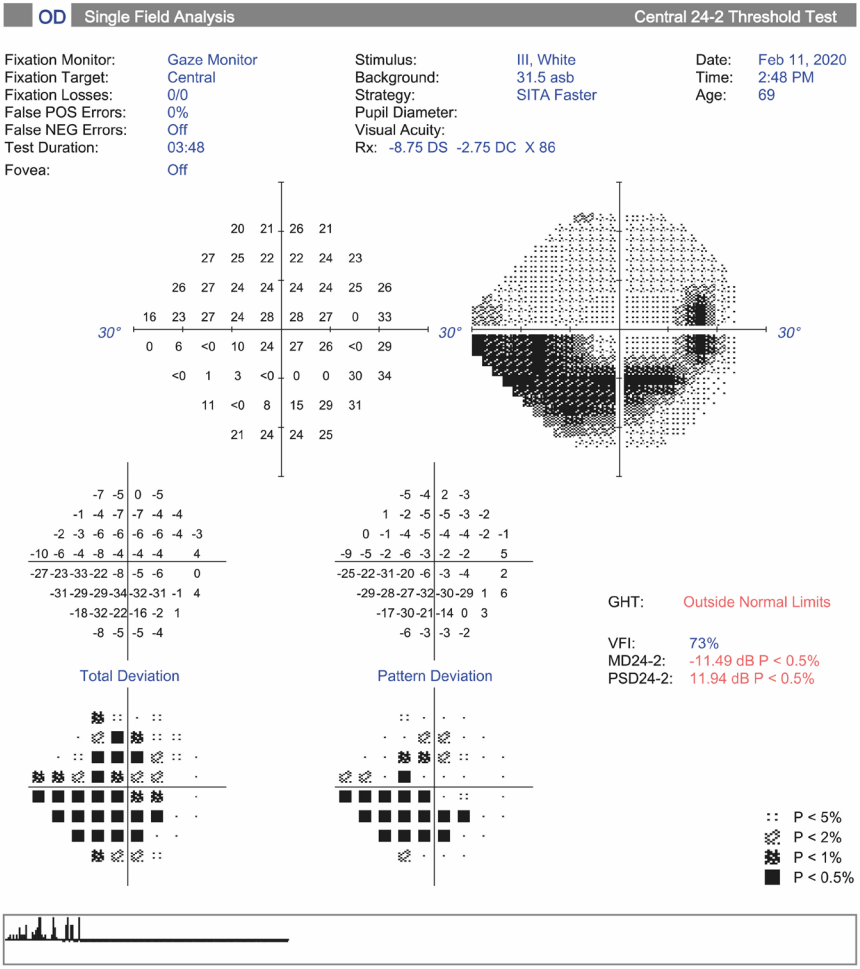


Figure 7-5

Arcuate visual field defects. An inferior arcuate defect is clearly shown in the gray-scale. Looking at the Total Deviation and Pattern Deviation probability plots, we also see arcuate loss in the superior hemifield, that is, the beginning of a double arcuate defect.

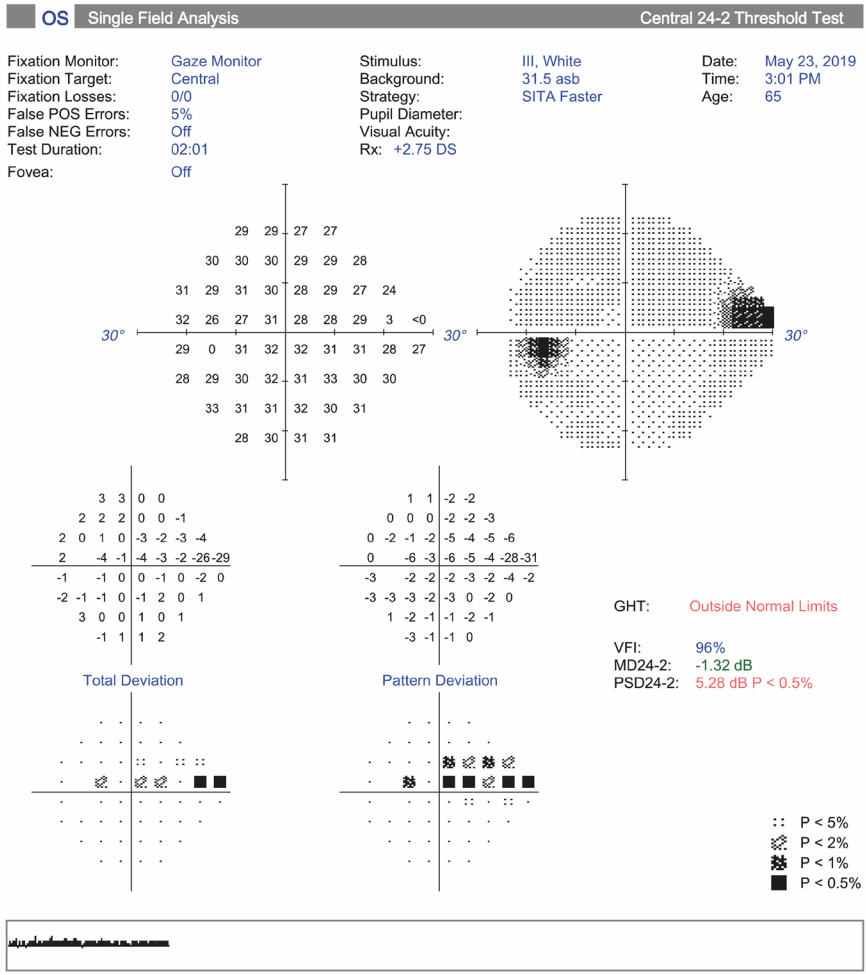


Figure 7-6

Nasal step. In this test result, the grayscale map suggests a nasal step with large sensitivity differences across the nasal horizontal meridian. However, the Pattern Deviation probability map reveals not only a nasal step but also a more extensive arcuate defect.

Localized Versus Generalized Visual Field Loss

Paracentral and arcuate scotomas and nasal defects are examples of localized field loss, that is, defects that are confined and have boundaries that form a shape. Localized glaucomatous loss is often vertically asymmetrical. In early, moderate, and advanced stages of glaucoma, eyes have been reported to more frequently have greater loss in the superior visual field than in the inferior field.[1-3]

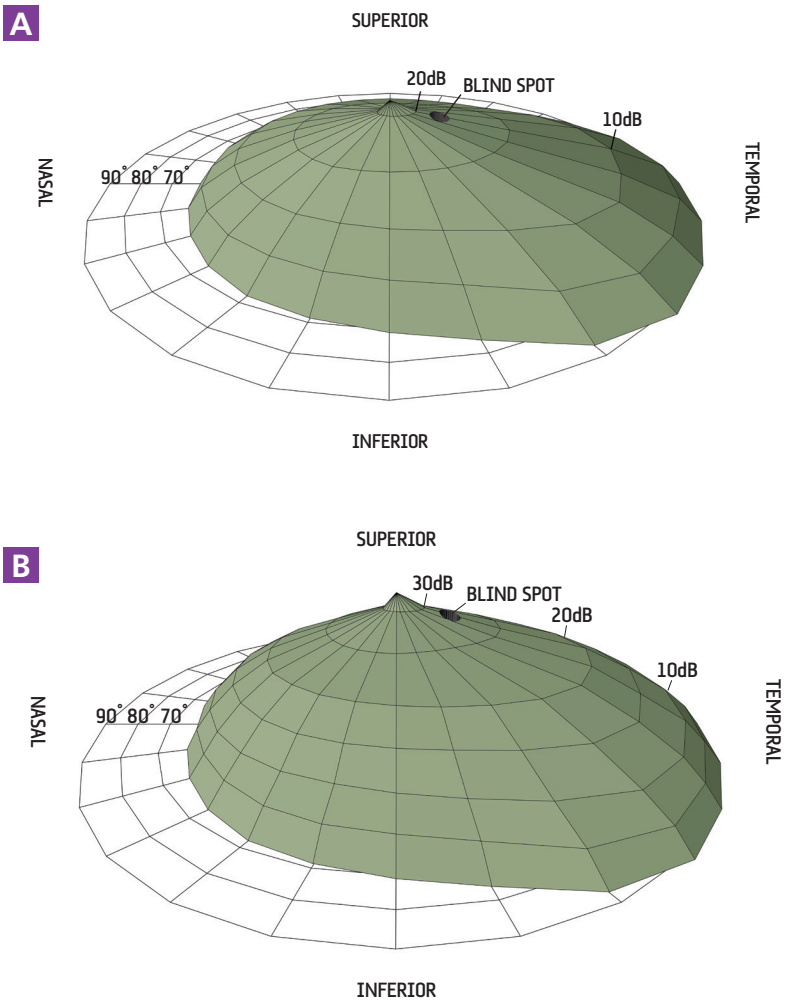


Figure 7-7

Generalized depression of the hill of vision (A) as compared to the normal hill of vision (B).

In contrast, generalized visual field loss is a homogeneous loss of sensitivity across the whole visual field, resulting in a depression of the entire hill of vision without any significant change of its shape (Figure 7-7). Homogenous visual field loss frequently is associated with cataract (Figure 7-8), especially in the age groups most at risk for glaucoma, and also can be the result of corneal opacities (Figure 7-9).

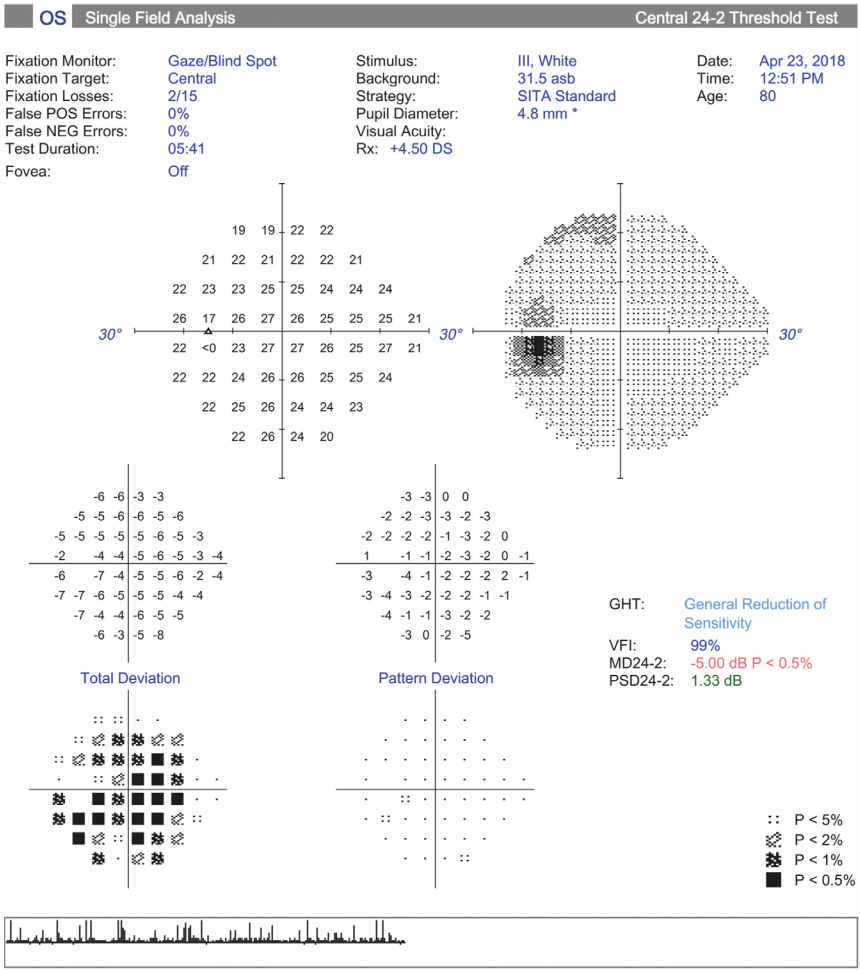


Figure 7-8

A typical cataract pattern in an 80-year-old patient being monitored as a glaucoma suspect. Total Deviation values are significantly and generally depressed, while the Pattern Deviation Probability map suggests normality. The Glaucoma Hemifield Test classification General Reduction of Sensitivity also is typical of cataract. Mean Deviation is depressed by 5 dB, while VFI is normal at 99%.

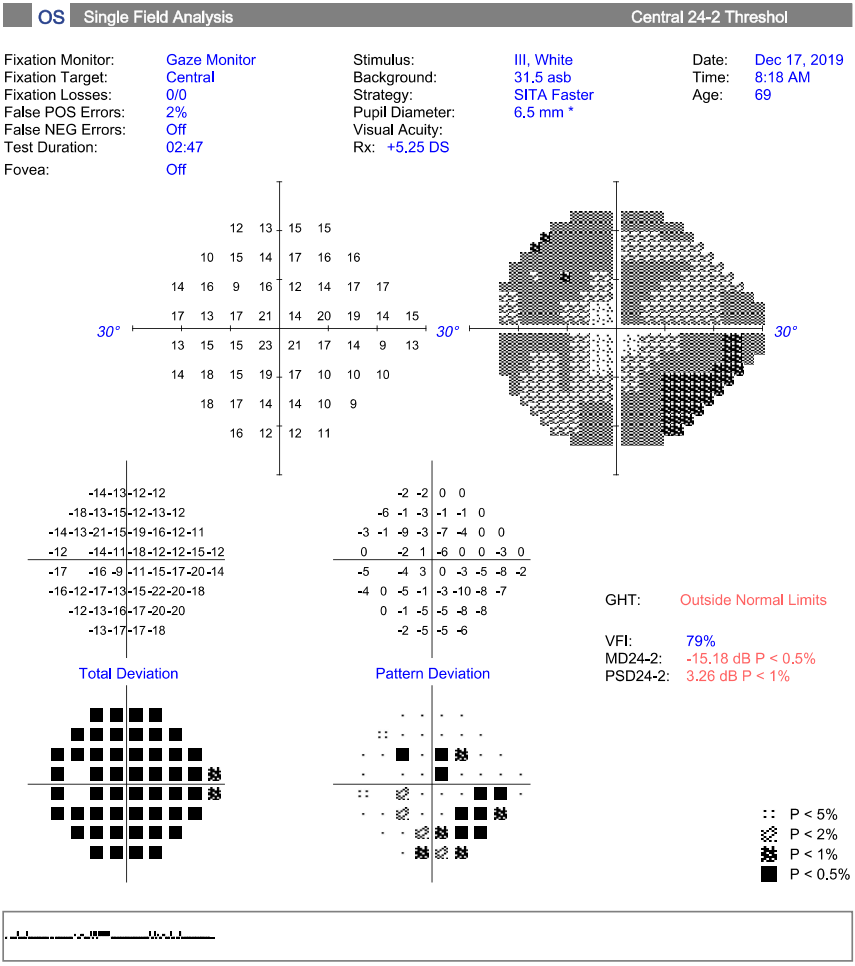


Figure 7-9

Localized plus diffuse visual field loss associated with corneal opacities and glaucoma. The localized loss, caused by glaucoma, is visible in the Pattern Deviation probability map. In most cases like this, the diffuse loss is caused by cataract, but in this patient, who received a corneal transplant because of keratoconus, it is a result of corneal opacities.

Separating localized loss from generalized loss and concentrating on the former will facilitate recognition of the localized and asymmetric damage that is characteristic of glaucoma. The Pattern Deviation maps available on the HFA Statpac printouts are designed to help identify localized and asymmetric losses (see chapter 5) (Figure 7-10).

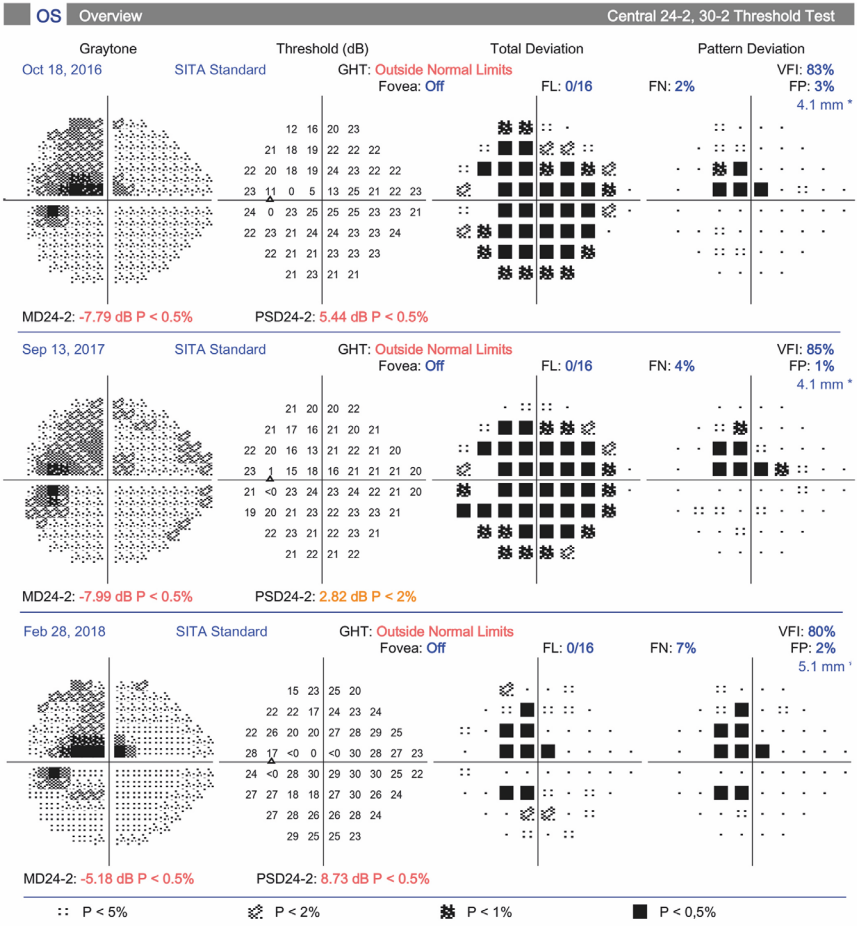
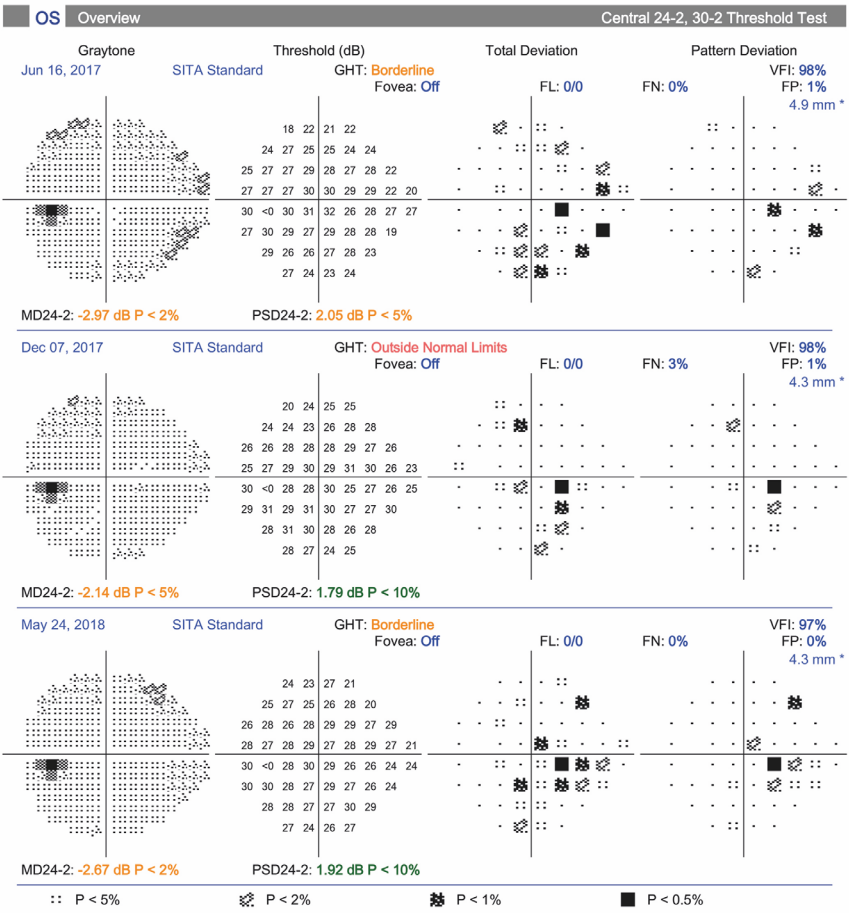


Figure 7-10

Follow-up testing in an eye with glaucomatous field loss and initially increasing cataract. In the first two fields, the Pattern Deviation plots show glaucomatous field loss in the superior hemifield, with Total Deviation findings that are consistent with progressing cataract. In the February 2018 field, the cataract has been removed, and the Total Deviation and Pattern Deviation plots are now similar and may also reveal new damage in the inferior field.

Early Glaucomatous Field Loss

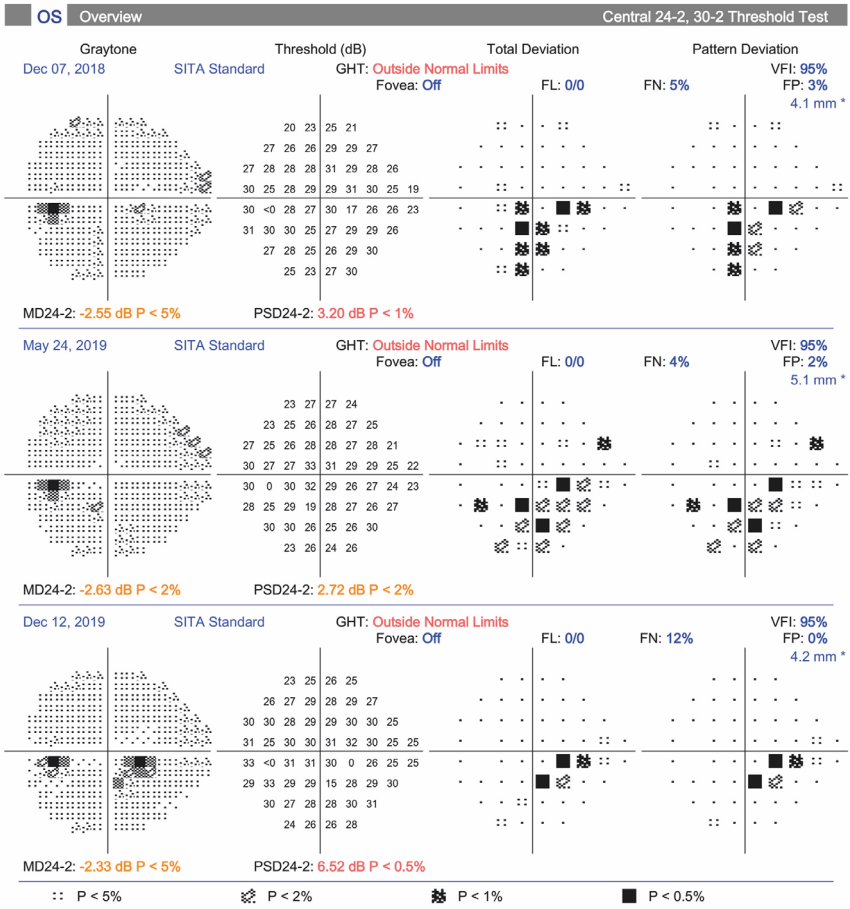
Early glaucomatous field loss usually develops very gradually over a period of years. Subtle local depressions of sensitivity often will come and go for quite some time before finally developing into clear and repeatable defects.[4,5] Pattern Deviation probability maps often will expose early functional loss before it is visible in grayscale representations. The Glaucoma Hemifield Test often also falls outside normal limits as localized abnormalities develop (Figure 7-11).[6,7]



A

Figure 7-11

Early glaucomatous visual field defects. Early glaucomatous defects often come and go, perhaps for years, before finally becoming clear and repeatable. Probability maps often will expose early functional loss before it can be seen in the grayscale.



B

Figure 7-11 continued

Stages of Glaucomatous Field Loss

Glaucoma staging systems differ, but Mean Deviation is usually a the most important metric.[8-10] For most purposes, we prefer a staging system based solely on Mean Deviation (Table 7-1). Note that severe glaucoma begins at a Mean Deviation of -22 dB, which, if present in the patient's better eye, is also the threshold for legal blindness in the US Social Security Administration.

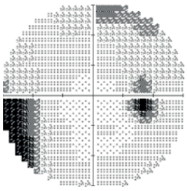
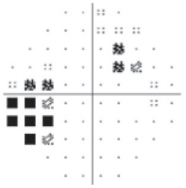
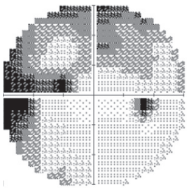
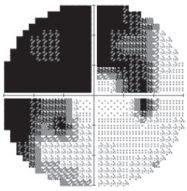
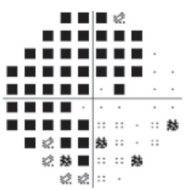
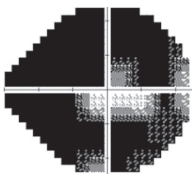
Stage	Category	24-2 or 30-2 MD Score	Grayscale Map	Total Deviation Probability Map
1	Early Glaucoma	Better than -6.00 dB		
2	Moderate Glaucoma	-6.01 to -12.00 dB		
3	Advanced Glaucoma	-12.01 to -22.00 dB		
4	Severe Glaucoma	-22.01 dB or worse		

Table 7-1

The authors' modification of the staging system proposed by Mills et al.[8] These fields were all taken from the same patient over a 15-year follow-up period.

It is important to note that staging systems are mostly used as an aid in classifying disease stages in clinical studies and not as a classification system to be applied in everyday clinical care or to assess disease progression. Such systems are not intended as a method for diagnosis.

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8

Data Integration and Presentation

THE DIAGNOSIS AND MANAGEMENT of ophthalmic disease generally involves consideration of information from multiple sources. Automated perimeters and ophthalmic imaging devices produce an abundance of quantitative data. Clinical observations and histories can include both quantitative and qualitative information. Doctors need reliable, convenient, and timely access to all such information, and this chapter discusses how this can be accomplished.

Basic Management of Perimetric Data

Proper use of perimetric progression analysis applications requires that all relevant visual fields be properly identified and available for use, even tests that may have been performed many years ago. Patient name, birth date, and identification number must be consistent across all test results if analysis programs are to recognize the tests as all belonging to a single patient. During perimetric testing, an effective way to ensure that identification data are accurate and consistent with prior tests is to recall the patient's name from the test archive, using the perimeter's Patient Search command (HFA3) or Recall Patient Data (HFA2 and HFA2i), or by connecting your HFAs to your electronic health record (EHR) system (see chapter 4).

Aggregation of Data from Multiple Perimeters

Clinics having multiple perimeters may have performed some of a patient's tests on one perimeter and other tests on other instruments and must make sure that all tests are available to the progression analysis program being used. In the past, this has been achieved by manually transferring test results among perimeters using diskettes or USB-compatible thumb drives. Today, such manual procedures are not necessary, as the Zeiss Glaucoma Workplace software makes it possible to network HFAs to a centrally maintained database containing all patient tests.

It also is worth noting that patient test results obtained or stored on older HFA1 and HFA2 instruments can be electronically transferred to newer instruments and/or to a Zeiss central archive. Test results from these legacy instruments also can be used in current progression analyses.

Aggregation of Perimetric Tests with Other Clinical Data

Electronic management of patient medical data has rapidly improved and expanded in recent years. With this new level of information access has come a clear opportunity to integrate clinical data from multiple sources into simpler, more comprehensive, and more useful analyses and presentations. To some extent, this already is being accomplished via EHR systems. For example, most EHRs can store and later present images of reports, such as PDF images of an HFA Single Field Analysis or a Guided Progression Analysis report. However, EHR systems have little or no capability to store and later reanalyze raw data, such as automated perimetry tests and imaging data, in order to add today's visual field and optical coherence tomography (OCT) images into a patient's record and then perform progression analyses that include those new results.

The Big Step Forward

Thus, there was an obvious need for computer applications that could aggregate and store raw clinical data from multiple HFAs and also data from multiple ophthalmic imaging systems and cameras. Such an application would have to run on servers accessible to doctors and staff via their desktop computers. And the application would have to perform the same analyses as the clinical instruments, including use of the same normative data and progression criteria.

Once server-based applications could perform all the same analyses as the individual automated testing instruments, the next opportunity would be to start providing reports that could not be produced by the individual devices. At the most basic level, the applications might simply collect relevant clinical data and present it all on the same screen—field test results, OCT images and analyses, and fundus photographs all presented on a timeline into which users also would be able to enter notes, such as prescribed medications, surgical events, and histories. As you will read here, all of this has now been accomplished in at least one commercially available computer application.

But that would only be the beginning. Having all relevant ophthalmic data available in a single application also would mean that new analyses could be developed that combine structural, functional, and clinical data into a single integrated finding, perhaps using what we presently call artificial intelligence. We believe that it is now fair to say that much if not all clinically relevant information can be brought together, allowing the production of such combination analyses to begin, as we will discuss later in this chapter. First, let's briefly discuss an example of what already exists and can be used clinically today—the Zeiss Glaucoma Workplace.

Zeiss Forum and Glaucoma Workplace

The Zeiss Forum product is a server-based software application for managing, archiving, and viewing patient examination results that have been supplied by networked clinical diagnostic devices such as the HFA, ophthalmic cameras, and optical coherence tomography instruments such as the Zeiss Cirrus OCT.

Glaucoma Workplace (GWP) is an analysis application that is integrated into Forum. GWP calculates and presents HFA and Zeiss Cirrus OCT analyses and reports and also archives and presents ophthalmic photographs that have been provided to it in Digital Imaging and Communications in Medicine (DICOM)–compatible formats. GWP software contains HFA and Cirrus statistical analysis software and normative data and can produce combination reports that copresent structure and function data (Figures 8-1).

GWP also can produce combined longitudinal analyses of HFA and Cirrus clinical findings (Figures 8-2, 8-3 and 8-4). GWP allows users to add clinical and surgical event markers to the clinical timeline and to append clinical notes. The markers can highlight medication changes, injections, surgery, and other relevant milestones (Figure 8-5). Users also can add intraocular pressure measurements and target ranges, as well as central corneal thickness data, to GWP timelines. GWP progression analysis thus functions as a summing point where clinical data from multiple sources can be collected, stored, presented, and analyzed in a single window.

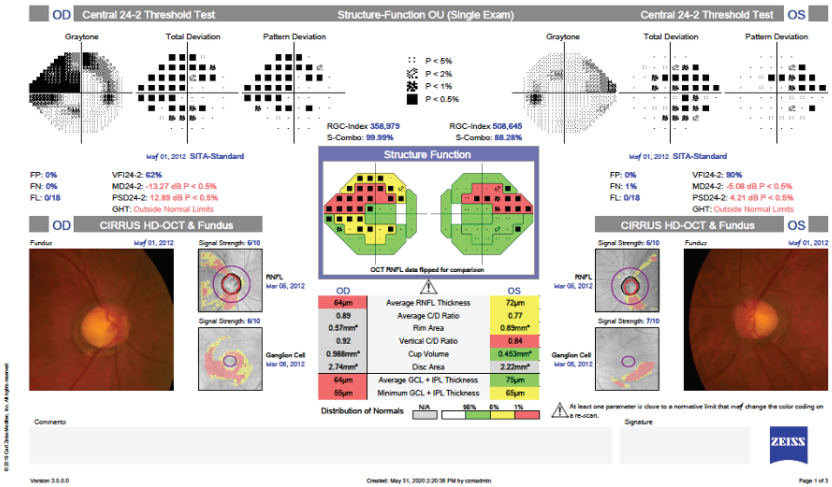

Figure 8-1

Visual field tests and analyses, spectral-domain OCT findings, and retinal photographs presented by Glaucoma Workplace software in a single report. As of the publication date of this book, the analysis box in the center of this report, labeled "Structure Function," was not available in the United States.

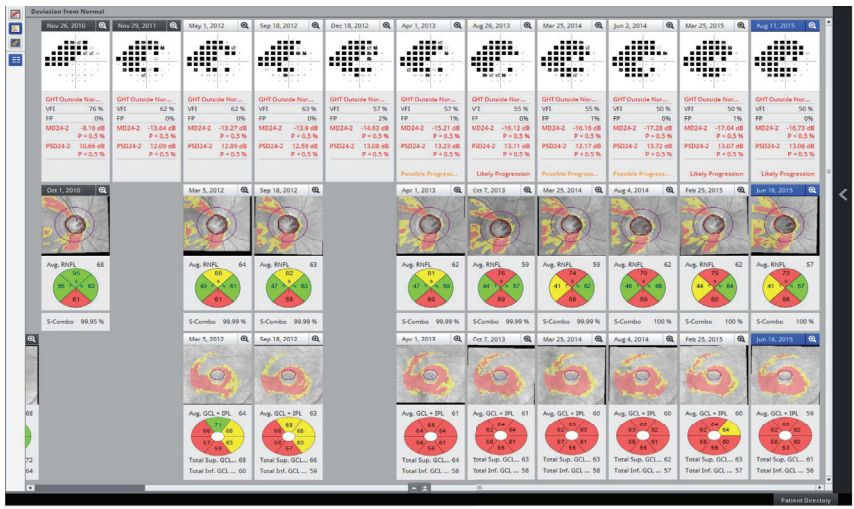

Figure 8-2

Screen view of Glaucoma Workplace structure–function analysis relative to normal limits. Top two rows show HFA probability plots and summary metrics over time, below which are Cirrus OCT Retinal Nerve Fiber Layer, and Ganglion Cell/Inner Plexiform Layer analyses.

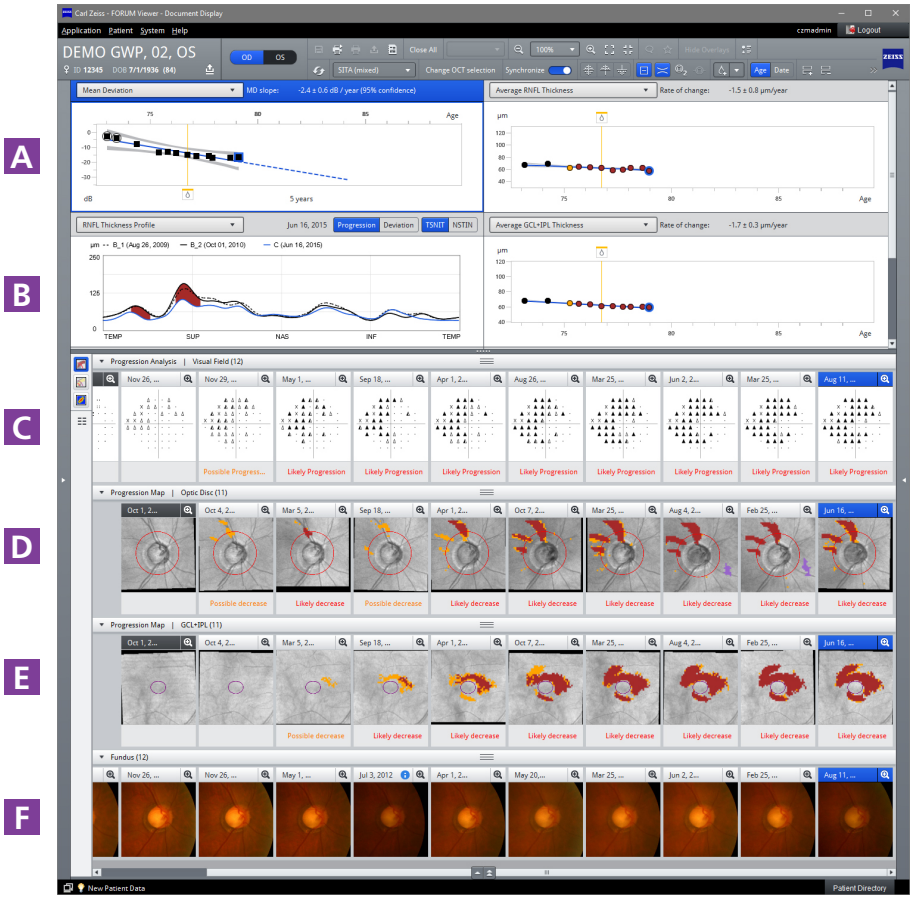

Figure 8-3

Screen View of Glaucoma Workplace Structure–Function Guided Progression analysis. A and C show statistically significant and repeatable perimetric change. B, D, and E show areas of retinal nerve fiber layer and ganglion cell/inner plexiform layer change, respectively. Orange areas in the OCT progression analyses have changed by amounts that exceed significance limits for expected variability, and red areas have shown statistically significant change in two consecutive images. (F) Bottom row shows optic nerve photos.

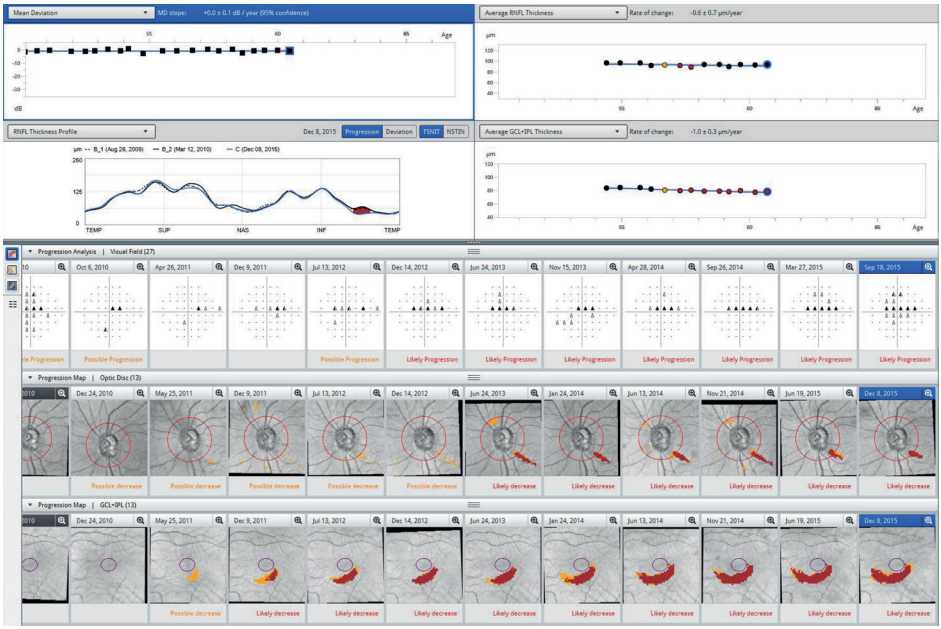

Figure 8-4

Structure–function progression analysis. Structural changes from baseline are in agreement with observed perimetric progression events.

Looking to the Future

Clear opportunities exist to construct analyses that go well beyond the colocation of structural and functional findings, seen today in summing point applications such as Glaucoma Workplace.

By means of artificial intelligence methods, experimental "combo" programs have computationally incorporated both OCT and visual field findings into diagnostic metrics that consider both.[1-3] The same has been done experimentally with combination analyses for progression,[4-6] which may suggest that there are opportunities to reduce the time required to identify rapidly progressing glaucoma patients. Combo analyses might also add a higher level of standardization to clinical decision-making.

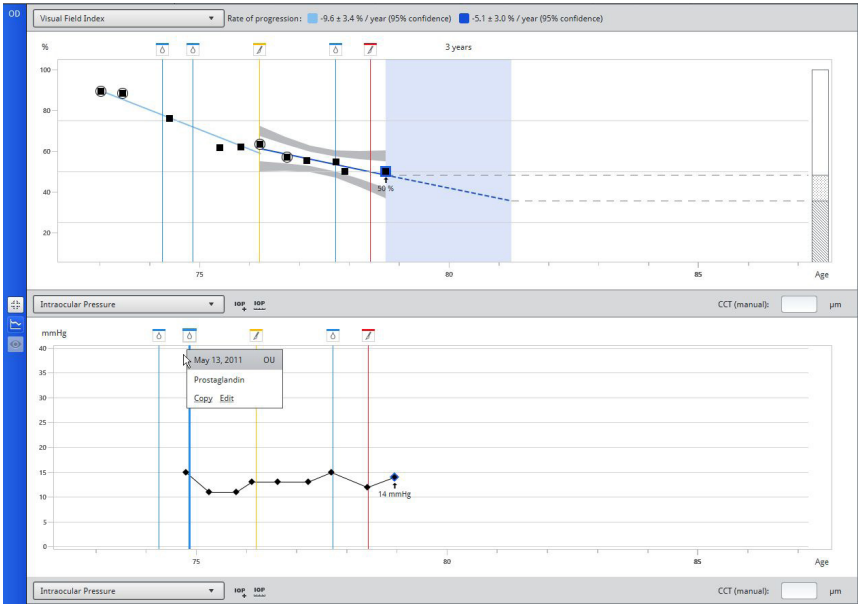

Figure 8-5

Glaucoma Workplace allows users to add event markers to the clinical timeline and to append clinical notes. The markers can highlight medication changes, injections, surgery, intraocular pressures, and other relevant clinical milestones, with the goal of presenting a condensed diagnostic and therapeutic history of the tested eye.

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9

Perimetry in Glaucoma Management

IN THIS CHAPTER, WE will discuss effective use of perimetry in glaucoma management, which includes both glaucoma diagnosis and management of patients already diagnosed with glaucoma. The principles are simple and straightforward, the interpretation tools provided with the Humphrey perimeter are of great help, and we can improve the effectiveness of glaucoma management by understanding how to best use these methods.

Perimetry remains central to glaucoma management, not only because visual field loss is a firm diagnostic sign of glaucomatous damage but also because treatment goals and proper titration of each patient's therapy must primarily be based upon visual function status and prognosis, as defined by the level of existing visual field damage and the observed rate of perimetric progression.

The goal of glaucoma management is to prevent loss of visual function, especially as it relates to quality of life.[1,2] Severe glaucomatous visual field damage is associated with profound loss of quality of life, and even moderate visual field loss can have significant implications (Figure 9-1).[3-13] Clinical trial findings suggest that each additional millimeter of reduction of intraocular pressure (IOP) serves to further reduce progression risk, so maximum pressure reduction will be associated with minimum risk of glaucomatous progression.[14,15] On the other hand, such therapy can have significant side effects. Maximal medical therapy is also associated with more inconvenience and higher cost than monotherapy, and surgical therapy brings its own well-known risks. Thus, effective diagnostic information is needed to choose the correct therapy for each patient and to know when therapeutic adjustments are necessary.

In the past decade, we have seen the welcome arrival of increasingly effective automated ophthalmic imaging devices, and these new devices are now providing important information that is also relevant to glaucoma management. However, imagers do not give us measurements of how well a patient is seeing, and imaging, therefore, should be seen as complementary to automated perimetry and not as a replacement for it. The diagnosis or follow-up

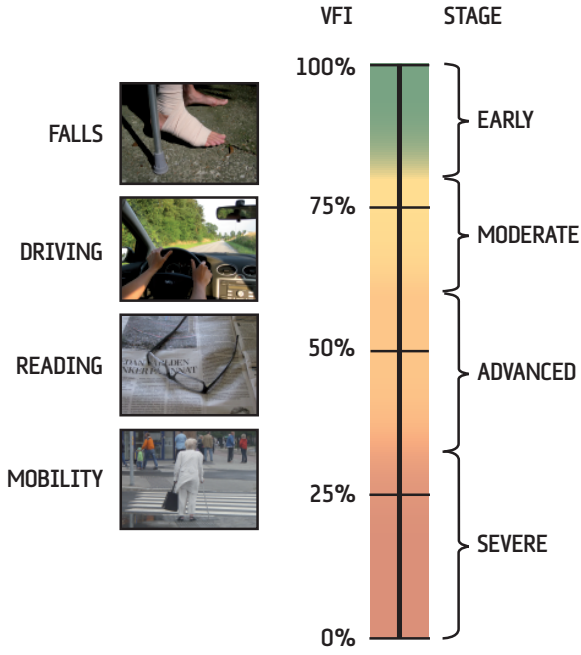


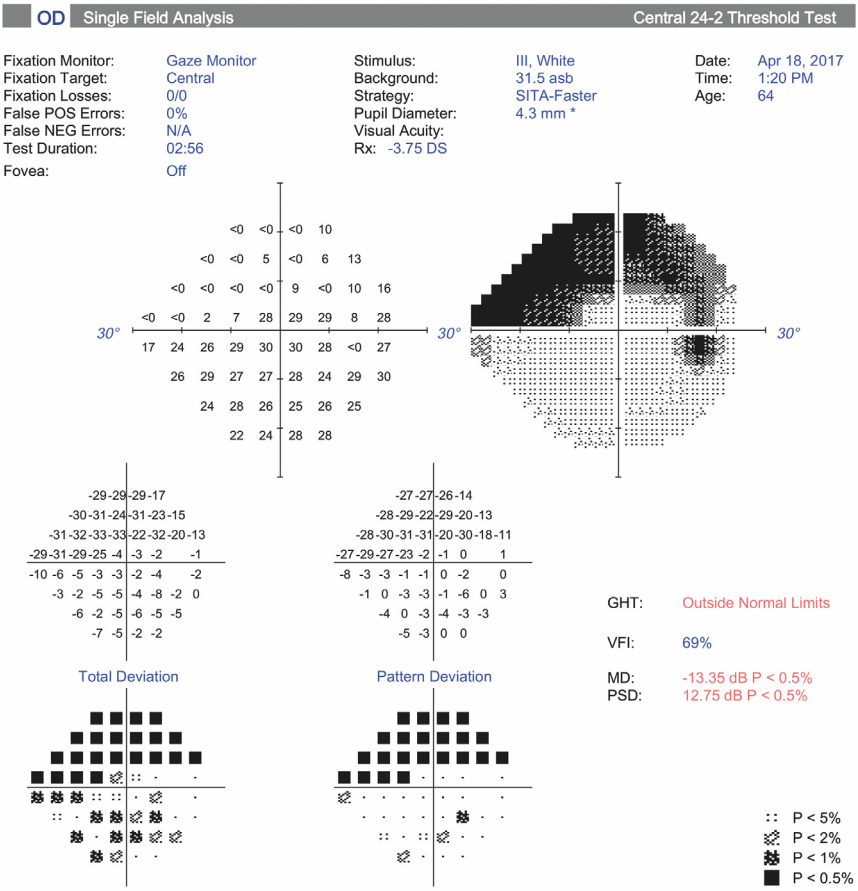
Figure 9-1

Relationship between degree of glaucomatous field loss, particularly in the better eye, and quality of life. Different daily activities may become more obviously affected at different levels of loss and location of loss.

of glaucoma cannot be made on the basis of optical coherence tomography (OCT) alone, as was pointed out in the recently published 5th edition of the guidelines of the European Glaucoma Society.[16-18, 32]

Perimetry in the Diagnosis of Clearly Manifest Glaucoma

Glaucoma is often detected at a sufficiently advanced stage, with field defects that are so typical of glaucoma, that the diagnosis is absolutely clear at the first clinical visit, particularly if the optic disc also is typically glaucomatous, and thus confirmatory visual field testing may not be necessary to make a diagnosis (Figure 9-2).[19-21] However, qualitative optic nerve evaluation can be unreliable, particularly in eyes that have large or small optic discs (Figure 9-3),[22] and experts may disagree when trying to quantify optic disc parameters.[23,24] If the encountered field loss is neither typical and clear-cut nor strongly confirmed by other findings, a confirmatory field is usually recommended.



A

Figure 9-2

Initial visual field tests from two perimetrically naive patients who had clearly manifest glaucoma on their first visits. The first patient's field (A) shows a classical arcuate (Bjerrum) scotoma accompanied by corresponding optic disc damage (B). The second patient's field (C) also would be diagnostic, if supported with corresponding optic disc or other clinical findings. Here we can see saucerization at the lower pole of the disc (D).

B

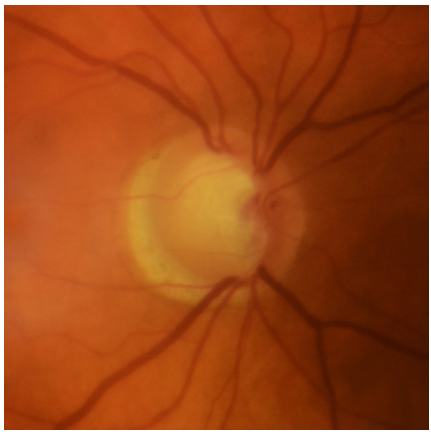
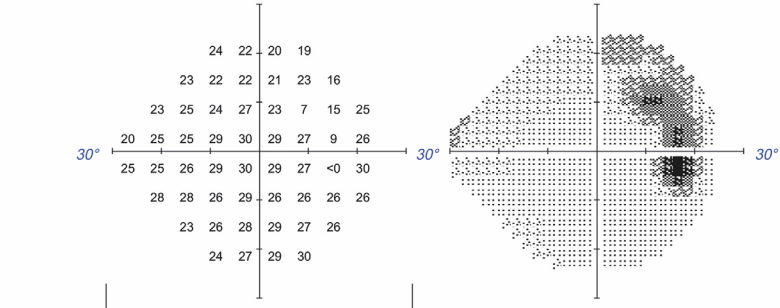
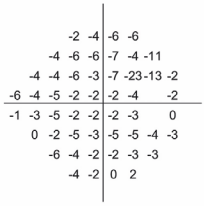


Figure 9-2 continued

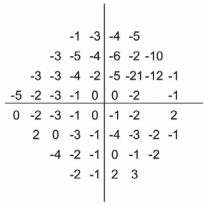
OD Single Field Analysis — Central 24-2 Threshold Test

Fixation Monitor:	Gaze Monitor	Stimulus:	III, White	Date:	Apr 24, 2017
Fixation Target:	Central	Background:	31.5 asb	Time:	10:45 AM
Fixation Losses:	0/0	Strategy:	SITA-Faster	Age:	78
False POS Errors:	3%	Pupil Diameter:	3.4 mm *		
False NEG Errors:	1%	Visual Acuity:			
Test Duration:	02:53	Rx:	+3.00 DS		
Fovea:	Off				





Total Deviation



Pattern Deviation

GHT:	Outside Normal Limits
VFI:	94%
MD:	-4.06 dB P < 1%
PSD:	3.73 dB P < 0.5%

:: P < 5%
P < 2%
P < 1%
P < 0.5%

C

D

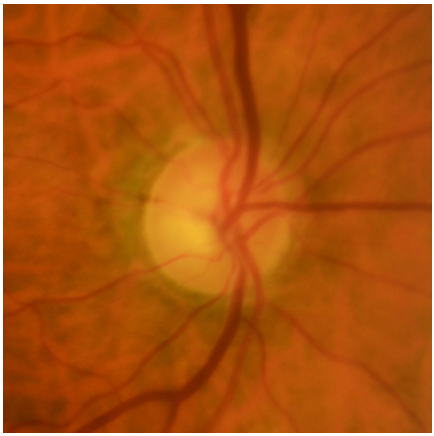


Figure 9-2 continued

Results from the Early Manifest Glaucoma Trial have demonstrated that two consecutive, well-supervised visual field tests that show Glaucoma Hemifield Test classifications of either Outside Normal Limits in the same sector of the field or Borderline in the same sector plus corresponding optic disc signs can lead to a glaucoma diagnosis that is almost always correct even in perimetrically naive patients.[25] The Pattern Deviation probability plot can confirm the nature of the visual field abnormality and may serve to verify that the field damage is characteristic of glaucoma rather than indicating some other disease.

Perimetry in the Diagnosis of Glaucoma Suspects

Compared to cases of clearly manifest glaucoma, the situation is entirely different when following glaucoma suspects who initially have normal fields in both eyes, such as patients with ocular hypertension. In such patients, it is very possible that a field test result consistent with early loss will not be confirmed by later testing, and that several years may elapse between the earliest appearance of subtle field loss and the arrival of convincing and repeatable field defects. In the Ocular Hypertension Treatment Study, 1% to 2% of patients developed repeatable signs of glaucoma each year[26]—considerably fewer than the approximately 5% diagnostic false positive rates associated both with single visual field tests and with analyses of single automated images. For this reason, in such a situation, we would expect to see significantly more false positive test results than true positive results when relying on isolated diagnostic findings.

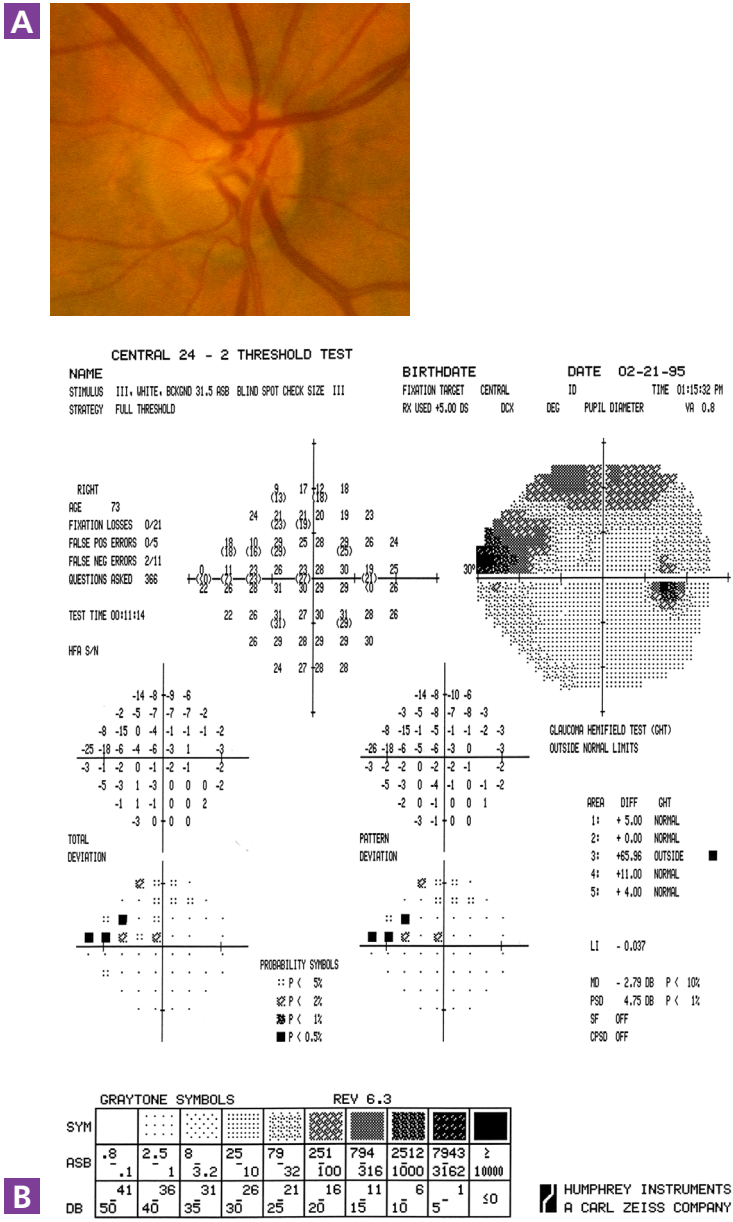
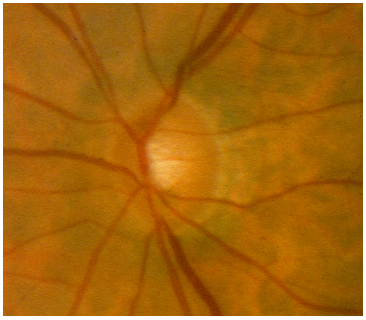
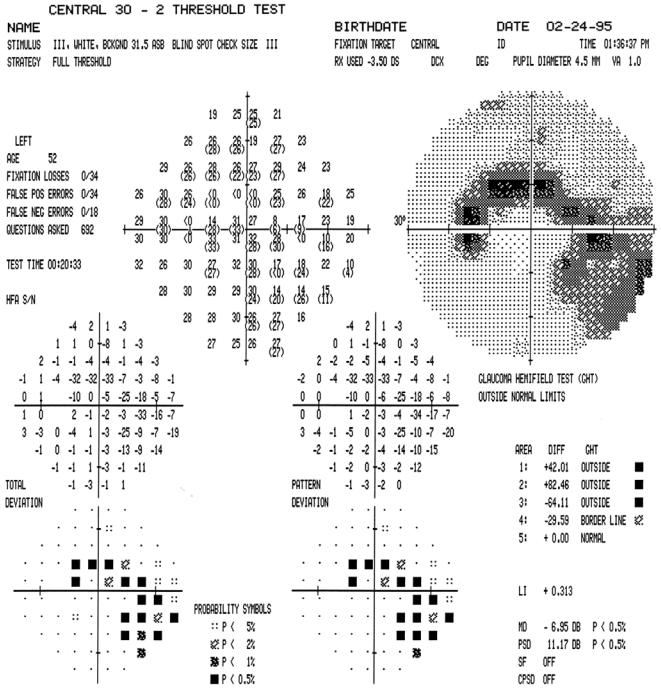


Figure 9-3

Relationship of early disc abnormality to early visual field loss. Glaucoma can often be diagnosed simply by inspecting the optic disc alone, but not always. Here are two examples from eyes with manifest glaucoma with field loss. These discs were shown to a large number of ophthalmologists in a research project undertaken in conjunction with a glaucoma conference and were misclassified by a majority of ophthalmologists. The disc in (A) was misclassified by 66% of participating doctors and the one in (C) by 53%. The field from the eye depicted in (A) is shown in (B), and the field corresponding to the disc in (C) is shown in (D).[24]

C





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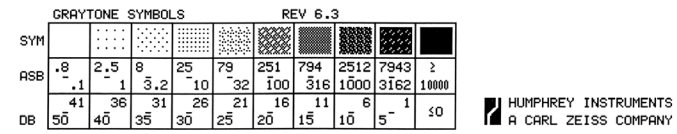


Figure 9-3 continued

Therefore, glaucoma suspects producing an isolated visual field test with a Glaucoma Hemifield Test classification of Outside Normal Limits, or a single test showing a small cluster of gray symbols in the probability maps, should not be regarded as definitely having glaucomatous visual field damage.[27,28] Instead, such findings must be confirmed. However, if a defect appears in the probability maps of several tests, or at least of two consecutive tests, one can confirm glaucomatous field loss long before the patient has developed defects that would be so compelling that a single field test would be sufficient (Figures 9-4 and 7-11).

In glaucoma suspects, it usually is not necessary to repeat questionable visual field tests during the same visit, and perhaps might even be unwise if the patient is fatigued. Typically, there is little urgency, and a second test can be deferred until the next planned clinic visit.[28] On the other hand, there may be situations in which it may be preferable to schedule a new test sooner. Patient age is often an important factor. Finding initial glaucomatous visual field loss in an otherwise healthy 60-year-old clearly suggests a much greater risk of visual impairment during the patient's expected lifetime than would be the case if the patient were 85 years old and in poor health.

The foregoing discussion specifically addresses management of glaucoma suspects who historically have normal visual fields in both eyes. The situation is different in an eye showing only a suspicion of field loss while the other eye is already under treatment for glaucoma. In these patients, the appearance of early and subtle visual field defects may well justify more immediate action, even if that action is only to schedule the patient to return soon for confirmation testing.

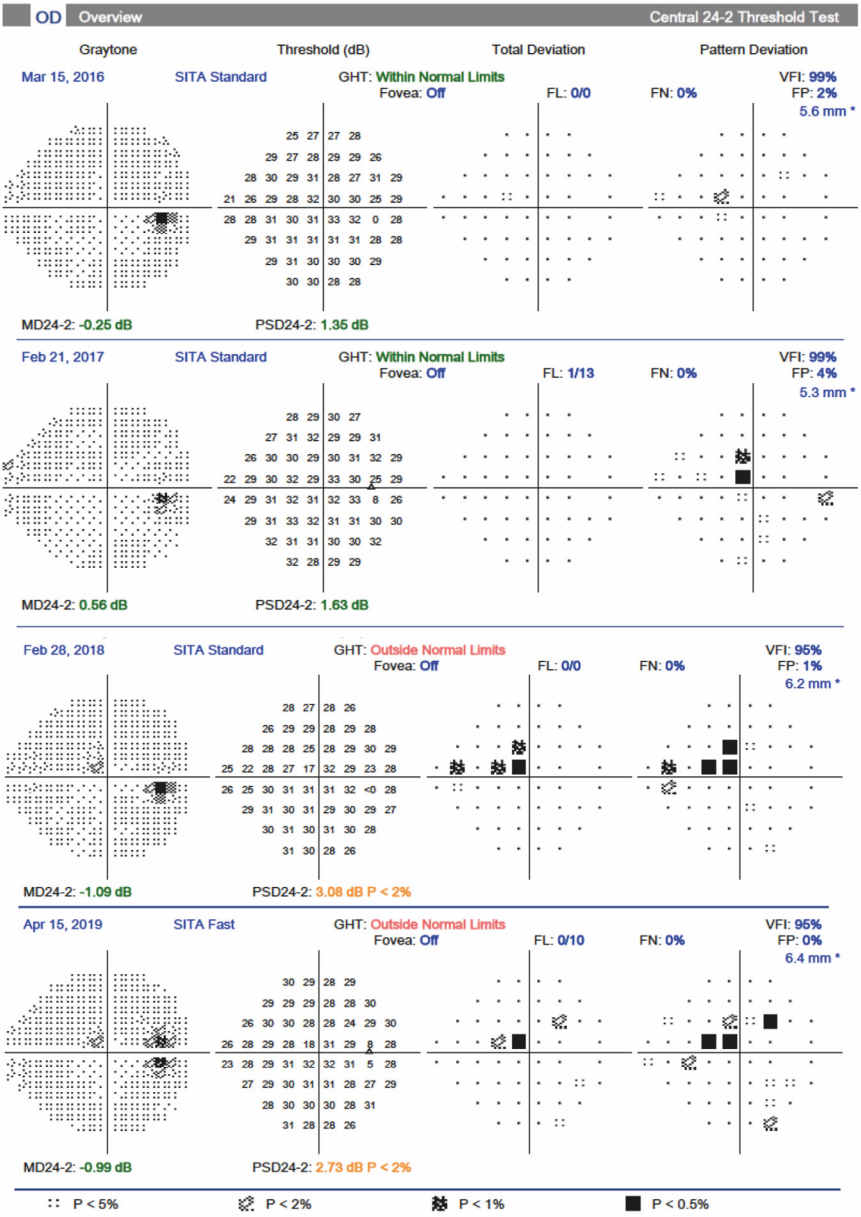
Finally, we wish to emphasize the value of probability maps for early diagnosis. If we look only at the grayscale map, we may miss early field loss that is evident in probability maps. In glaucoma suspects, a repeatable pattern in probability maps can be convincing evidence for a diagnosis of manifest glaucoma (Figures 9-4 and 9-5).

The Role of Perimetry in Glaucoma Follow-Up

The most important role of perimetry is in management of patients who already have a diagnosis of glaucoma. When following glaucoma patients, the primary goal at each patient encounter must be to determine whether current therapy is adequate or needs to be changed. Unacceptably rapid visual field progression often provides compelling evidence of inadequate therapy, just as stable visual field status over time strongly suggests that current therapy is adequate. The Guided Progression Analysis (GPA) program of the Humphrey

Figure 9-4

Development of field abnormalities in a patient originally being followed for ocular hypertension. Initial defects often are subtle and may come and go. Similar abnormal findings in several consecutive visual field tests usually are necessary before a diagnosis can be established with certainty. Very early field loss is commonly evident only in probability maps, and it may take years before such losses become recognizable in the grayscale maps.



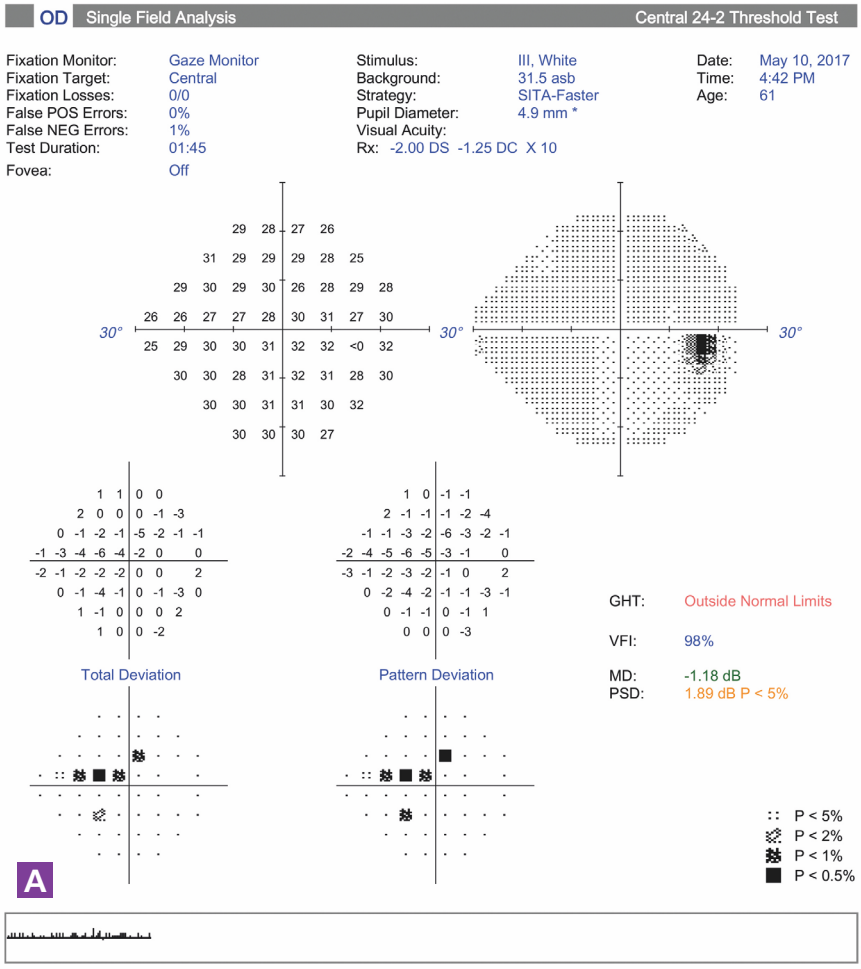


Figure 9-5 SITA Faster

Early diagnosis of glaucomatous field loss. It is important not to focus on the gray-scale maps but instead on the probability maps. It is common to see diagnostic and repeatable field loss in probability maps while grayscale maps still look entirely normal. While participating in a clinical trial, this patient was tested three times in the same day, using each of the three SITA strategies. All three test results show the same convincing findings (A, B, C). Optic disc findings were too subtle to be diagnostic in this patient, but an arcuate retinal nerve fiber layer defect can be seen in the fundus photograph (D), and optical coherence tomography findings are also in line with the perimetric results (E).

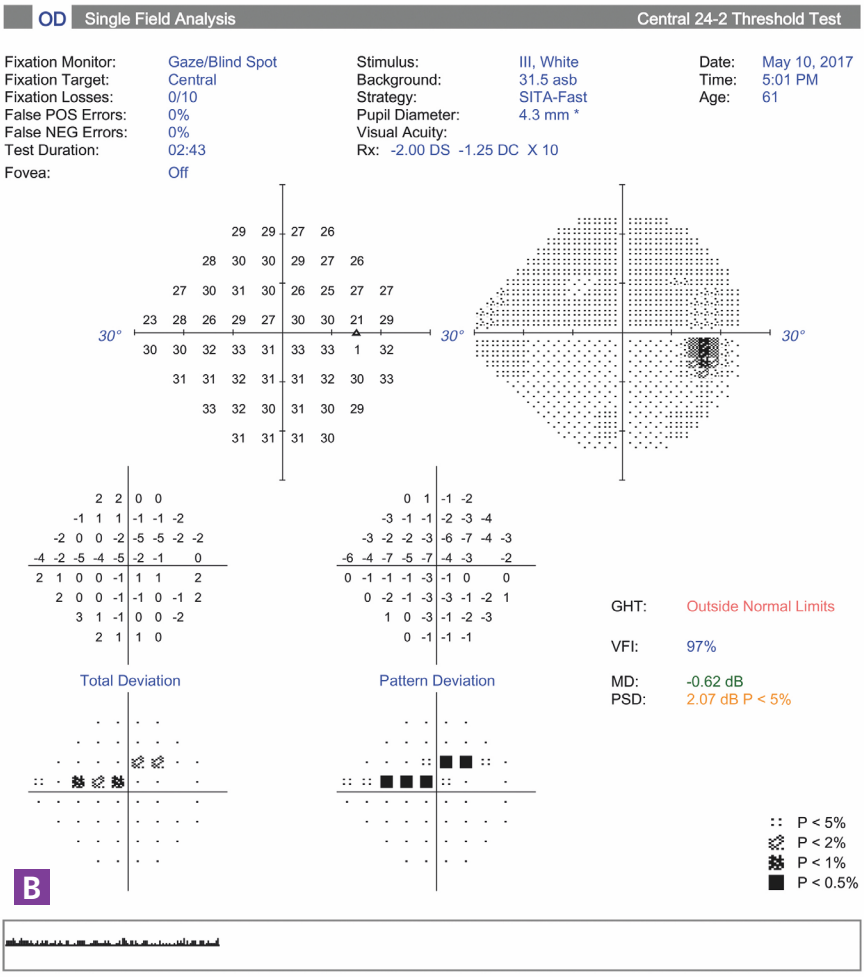


Figure 9-5 continued **SITA Fast**

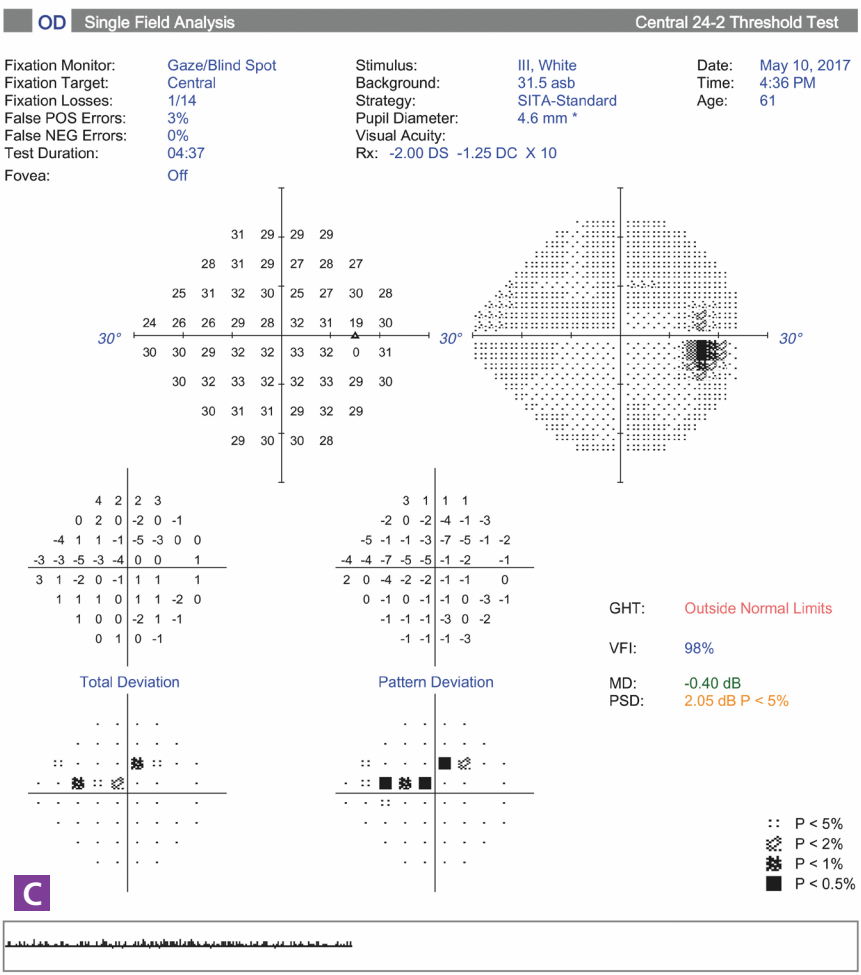
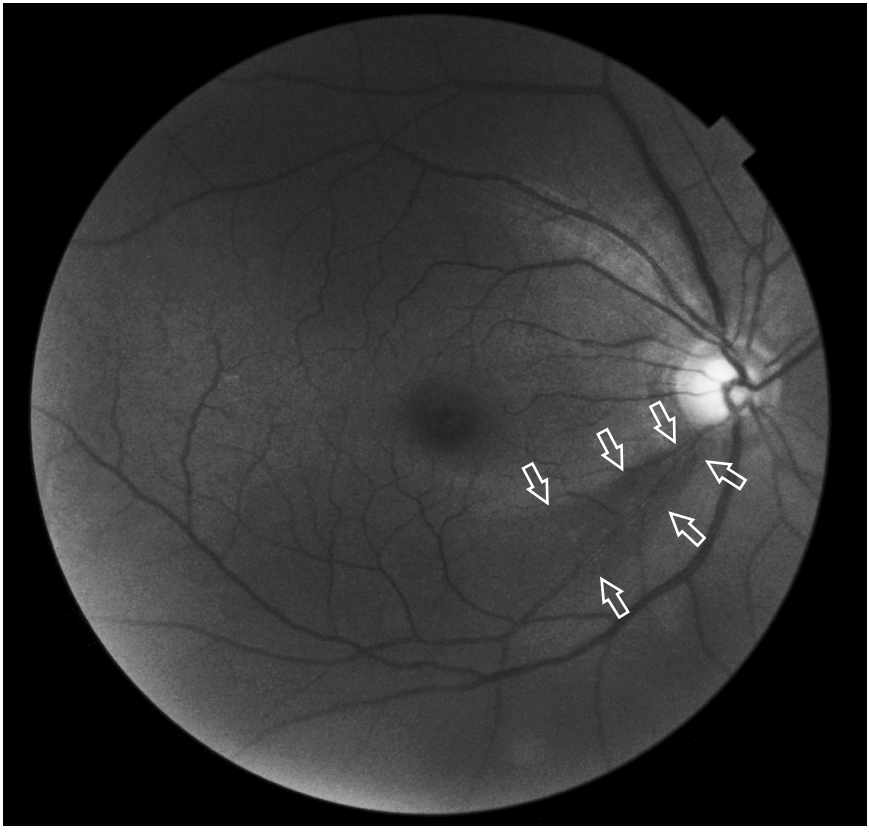


Figure 9-5 continued **SITA Standard**



D

Figure 9-5 continued

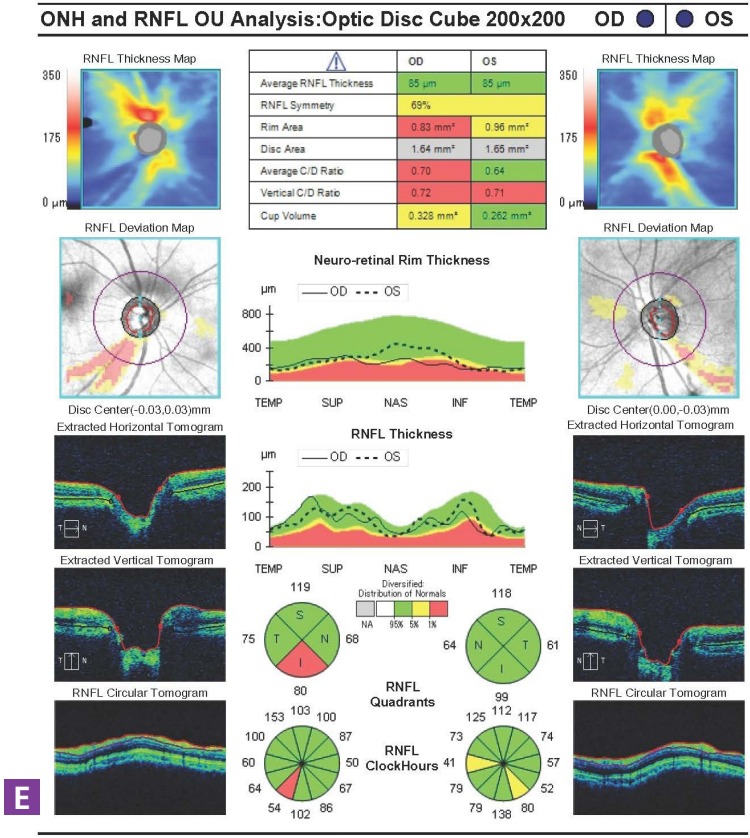


Figure 9-5 continued

perimeter has been designed with exactly this task in mind, and the single-page GPA Summary Report is our preferred GPA option (Figure 9-6). Our favorite GPA report is the Bilateral GPA Summary (Figure 9-10).

EVOLVING VISUAL FIELD PROGRESSION PARADIGMS

The Early Manifest Glaucoma Trial demonstrated that most glaucoma eyes will show some level of progression if followed long enough, even if treated and even if the intraocular pressure is always measured to be within the statistically normal range.[29-31] Thus, progression is the rule, not the exception, in glaucoma, and that fact has altered the interpretation of perimetric change. Treatment is no longer automatically escalated just because small but definite progression has been demonstrated. Instead, therapeutic decisions are driven by the risk to the patient's quality of life, considering the degree of existing field loss, observed rate of progression, and the patient's estimated life expectancy.[32]

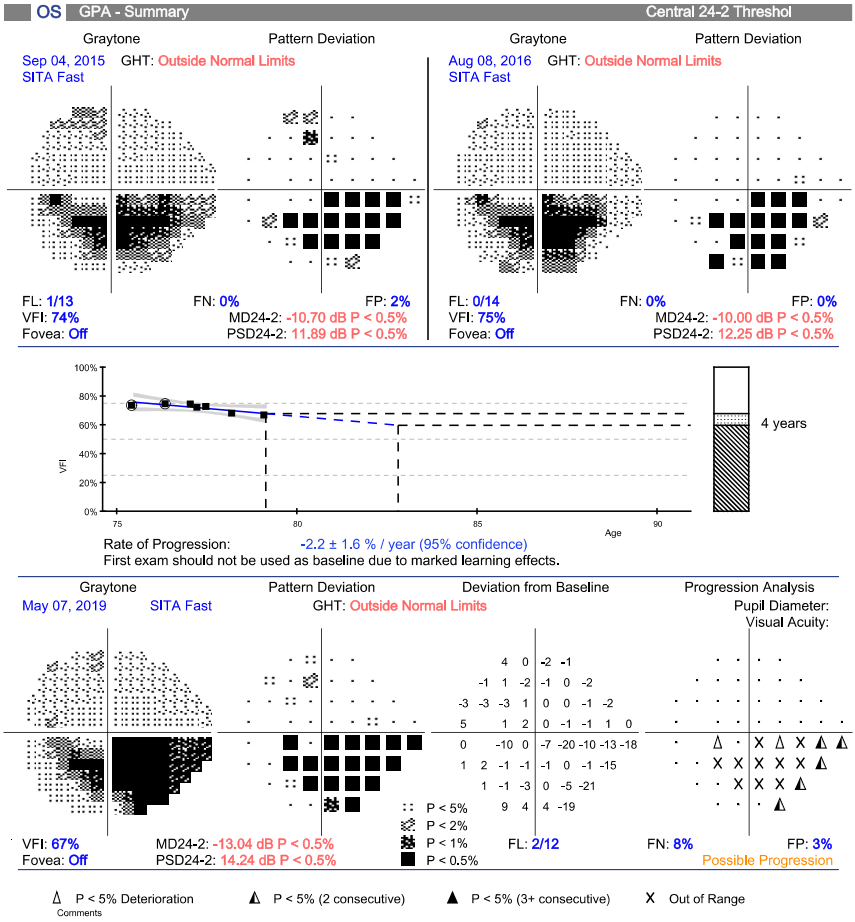


Figure 9-6

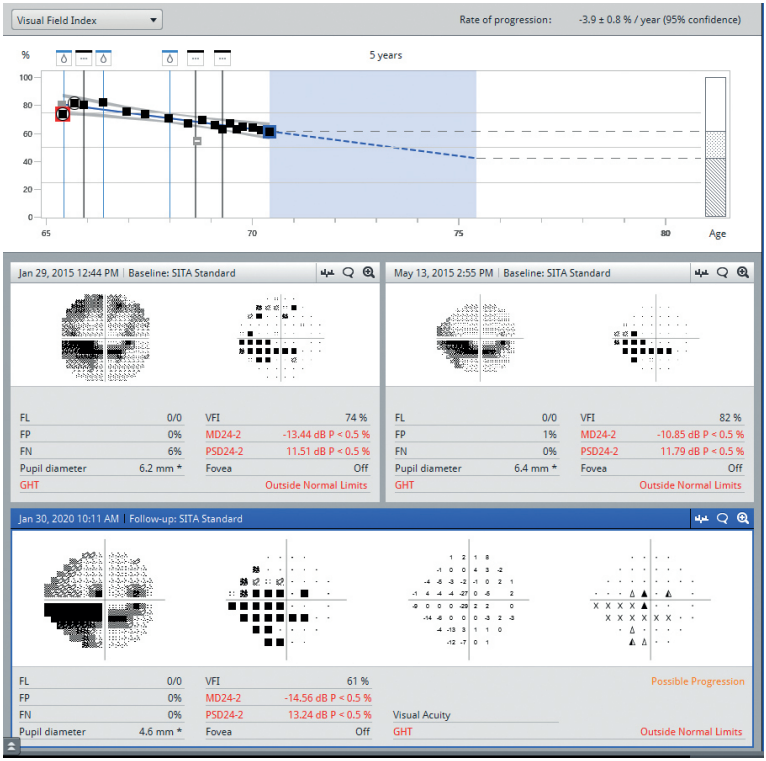
Guided Progression Analysis Summary Report. This summary report provides a very useful and compact picture of the patient's perimetric evolution over time, including the overall global rate of progression and the specific areas of the visual field that show statistically significant progression. The GPA summary is available both as a printed report and as a computer screen presentation when using Zeiss Glaucoma Workplace software.

ESTABLISHING A BASELINE

Guidelines for choosing baseline tests are discussed in chapter 6. We would emphasize here that obtaining representative baseline tests is foundational to future management decisions. For example, if a visual field a year after diagnosis seems different from a single baseline test at diagnosis, you can never know whether there was progression or the first field was faulty, even if a third test then confirms the new finding. Thus, it is almost always worthwhile to obtain two similar and representative baseline tests early in the course of follow-up, even if that means bringing a patient back for an extra test.

GPA by default chooses the two first tests as baseline, which is often a good choice. However, there are exceptions, when the doctor should change or repeat a baseline test. One example is perimetric learning, in which the second test result shows higher overall visual field sensitivity than the first test. Significant learning occurs in a minority of patients, and effects usually are small.[33-36] GPA helps to identify whether statistically significant learning has occurred by highlighting the first test result in the regression series if that test is significantly out of line with and worse than the trend shown in later tests (Figure 9-7). However, this can only be done when at least five tests are available, which may take 2 or 3 years, or even longer. Thus, it is often up to the doctor to recognize situations in which differences between the two baseline tests are so large as to suggest that one of the tests is not representative of current patient status, in which case it may be wise to obtain an additional baseline field soon.

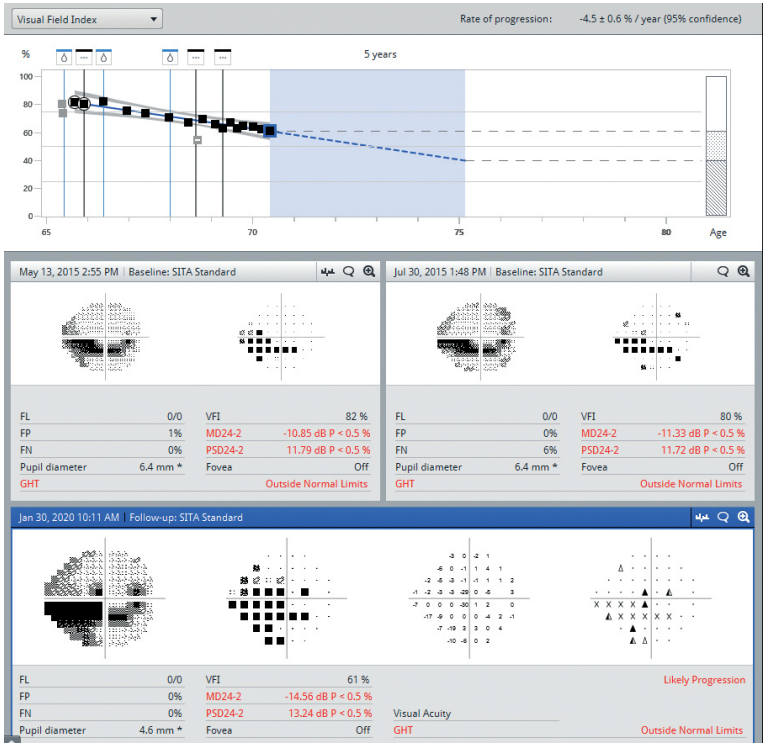
There also will be times when previously chosen baseline tests are no longer applicable and a new baseline must be established, such as after filtration surgery (Figure 9-12). Baselines also should be updated when VFI or Mean Deviation (MD) data points are arranged in the regression analysis in a definitely nonlinear fashion. For example, in some glaucoma suspects, or in eyes with very early disease, a patient's visual field may remain stable for many years and then rather suddenly start to deteriorate—very often at a rather constant and linear rate. In such cases, tests performed prior to the sudden change will no longer be relevant when calculating the current rate of progression, and new baseline fields should be selected around the time when the visual field deterioration appears to have started or accelerated (Figure 9-8). Thus, in patients with ocular hypertension who start developing field loss, it is appropriate to move the baseline to around the time when field loss first appears. It is easy to choose updated baselines when using Glaucoma Workplace, simply because it can be accessed from a desktop computer, but baseline tests also may be changed on the perimeter itself.



A

Figure 9-7

Perimetric learning. (A) This eye demonstrated some improvement after the first test, probably due to perimetric learning. The VFI data points are not lined up in a linear fashion, and Glaucoma Workplace, therefore, flagged the first baseline test in red. (B) The user then defined the third and fourth tests as a more appropriate baseline, leading to higher and more accurate estimation of the rate of progression. Note also, in the lower right-hand corner of (B), that with a more meaningful baseline, the Early Manifest Glaucoma Trial Progression event analysis went from Possible Progression to Likely Progression.



B

Figure 9-7 continued

RATES OF PROGRESSION AND RISKS TO VISION-RELATED QUALITY OF LIFE

Perimetric rate of progression (RoP) is routinely calculated by the HFA's GPA program whenever at least five visual field tests are available. Use of RoP information to assess the adequacy of current therapy is recommended in national and international glaucoma management guidelines.[2,32,37,38] Perimetric progression rates vary widely from one glaucoma patient to the next, and risk factors alone are poor predictors of which patients will progress at dangerously rapid rates.[39-43]

Thus, while some patients progress slowly and need only minimal therapy, an important minority of treated glaucoma patients with field loss—perhaps one patient in six, depending upon practice type—will progress at rates

that could soon lead to impairment if left unchecked (Figures 9-8, 9-9, and 9-13).[13,43,65] This is the basis for current guideline recommendations, which suggest more frequent perimetric testing in the first 2 years of follow-up of newly diagnosed patients with glaucomatous visual field loss.

Interpretation of rates of progression is intuitive if one considers the patient's current level of visual function and life expectancy (Figure 9-10). In Figure 9-7, we showed examples of nonlinear progression, but we must emphasize that in patients who already have glaucomatous visual field loss, nonlinearity is the exception and not the rule. In the absence of effective therapeutic changes, past rates of progression can be strongly predictive of future rates,[43] and other studies have also shown that linear regression is usually the best model for calculating RoP.[45-47] Therefore, when considering a possible change in glaucoma therapy in a patient who already has glaucomatous field loss, it often is helpful to extrapolate the observed rate of progression several or many years into the future, depending upon estimates of the patient's life expectancy.

Quality of life is clearly reduced by severe field loss in a patient's better eye,[13] and a minimal goal could be trying to retain at least a Visual Field Index (VFI) of 50% in the better eye during the patient's entire lifetime (Figure 9-10). The US Social Security Administration has defined a 30-2 MD of -22 dB in the better eye as the threshold for legal blindness,[48] which corresponds to a VFI of approximately 30%.

An acceptable progression rate must be smaller in a younger patient than in somebody who is older, and also must be smaller in an eye with more visual field loss than in an eye with less loss. Thus, elderly patients with early field defects and slow progression may not need intensified treatment, while patients of the same age having advanced field loss may require more aggressive management. Younger patients with early disease but moderate or even relatively slow progression rates on present therapy may require early therapeutic escalation (Figures 9-11B and 9-12).

OPTICAL COHERENCE TOMOGRAPHY AND GLAUCOMA PROGRESSION

Glaucoma progression can of course also be seen using optical coherence tomography (see chapter 8), but OCT has several disadvantages compared to visual fields when used to assess glaucoma progression.[32,49] Most importantly, the treatment goals in glaucoma are in the visual function domain, and we have knowledge about the relationship between visual field status and quality of life. We have nothing similar for relationships between quality of life and any structural parameters. There also is a floor effect in OCT

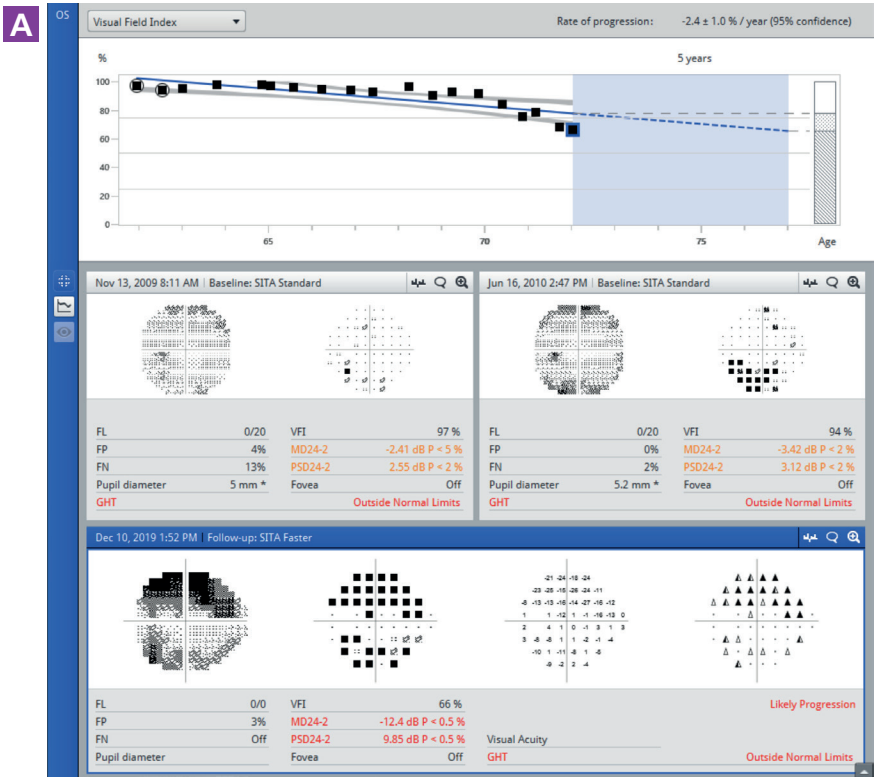


Figure 9-8

Nonlinear progression. This 72-year-old glaucoma patient was followed for more than 8 years with medical therapy that included three classes of intraocular pressure–lowering drugs and field loss that was small and nonprogressive. However, as can be seen in the Visual Field Index plot at the top of the report, visual function then started to deteriorate much faster. This is an example of nonlinear progression, which is typically seen in eyes that have had a long history of normal fields. With the original default baseline in (A), we see that the calculated progression rate is lower than the updated rate in (B). With the updated baseline, the most recent seven fields (B) are shown to be progressing at the very unsafe rate of 10.2% per year, more than 4 times as fast as the previous estimate, in this case leading to filtering surgery.

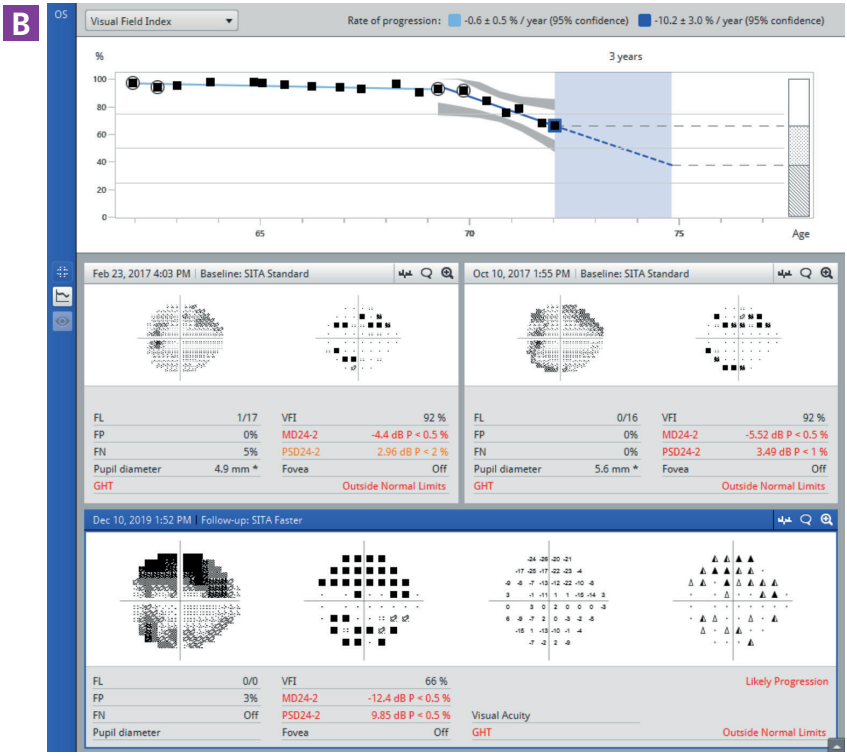


Figure 9-8 continued

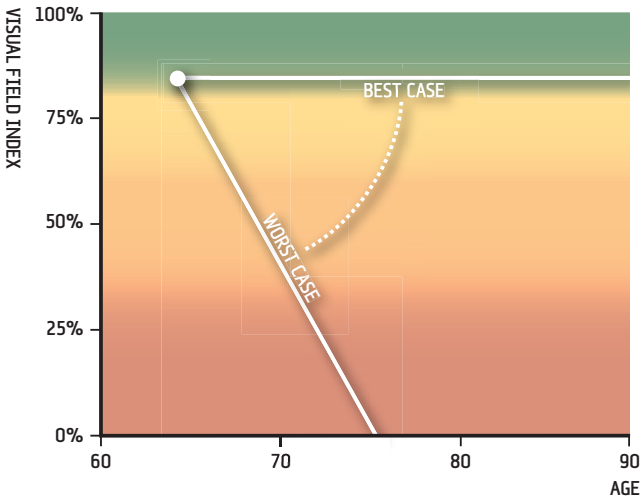


Figure 9-9

Highly variable rates of progression in glaucoma. Here are the 5th and 95th percentile rates of progression found in a group of almost 600 glaucoma eyes under ordinary clinical care.[65] Unless considerable progression is evident early, the degree of clinical control of the glaucoma will be uncertain until the rate of progression can be estimated.

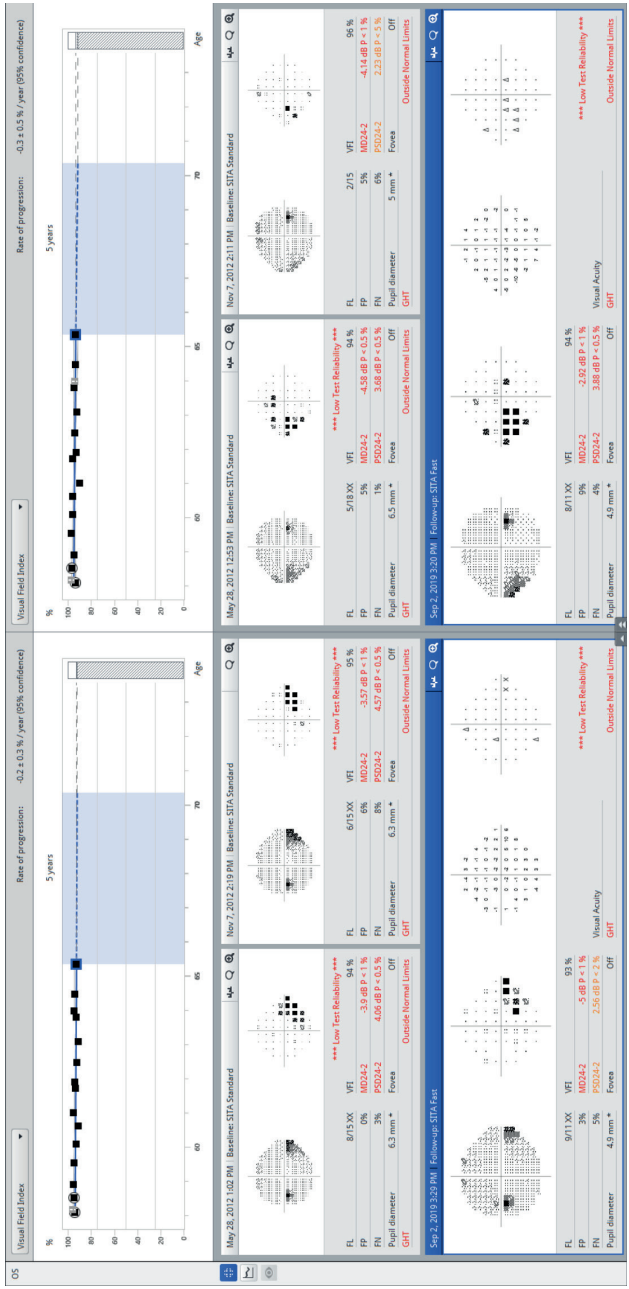


Figure 9-10

Bilateral GPA summary. The bilateral Glaucoma Workplace GPA summary can facilitate quick and comprehensive assessment of how a glaucoma patient is doing. (A) These fields are from a 65-year-old woman with normal-tension glaucoma diagnosed 7 years ago. Treatment was initiated with a prostaglandin drop immediately after diagnosis. Her pressures have been in the low teens or even lower, and the progression rates are very slow and quite acceptable, despite the patient's relatively young age.

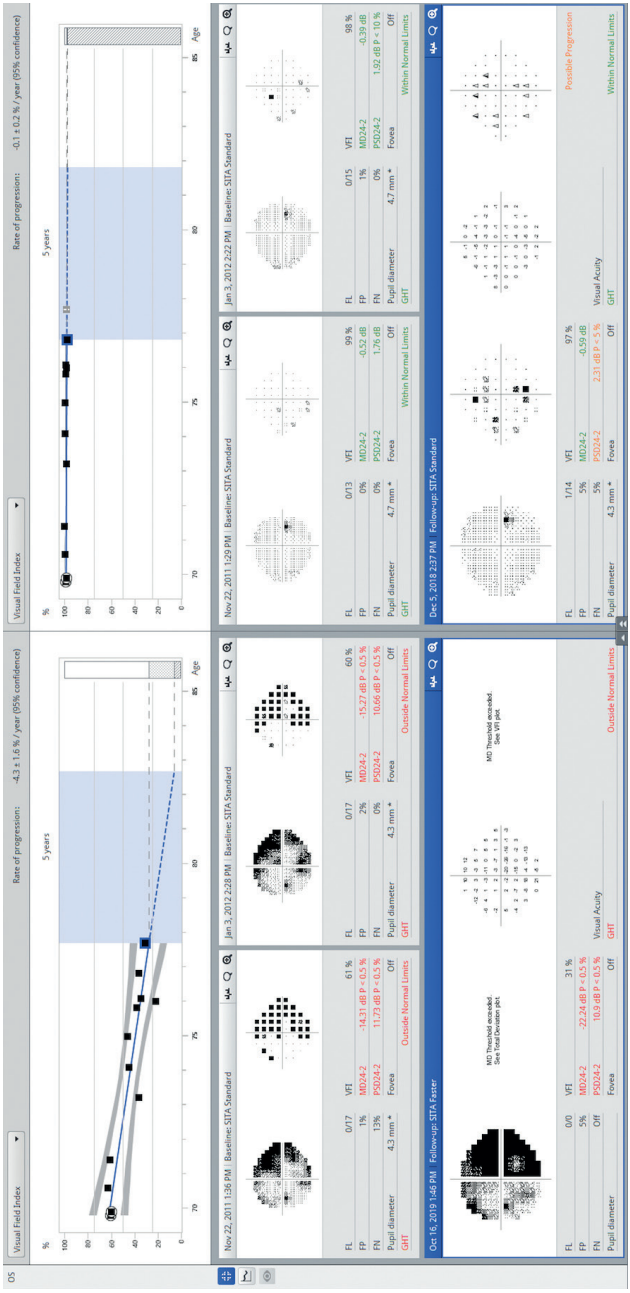
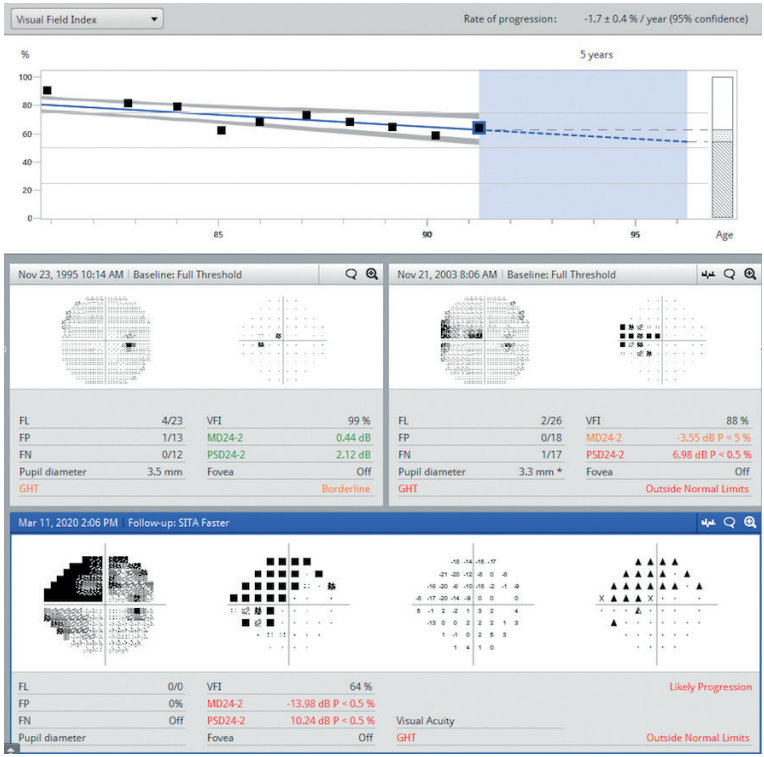


Figure 9-10 continued

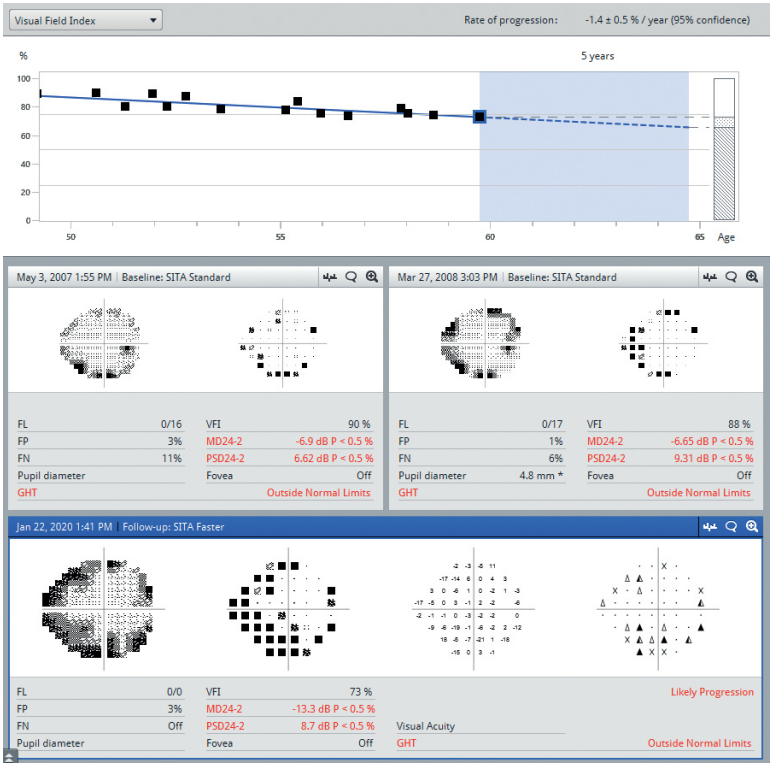
Bilateral GPA summary. (B) In this 76-year-old male glaucoma patient, a quick look at the GPA analysis immediately reveals that while the right eye is still normal and fine, the left eye is already at an advanced stage of visual field loss and is losing vision at an unacceptable rate, requiring further lowering of intraocular pressure.



A

Figure 9-11

Importance of life expectancy when assessing rates of progression. These two patients have similar levels of visual field loss and similar rates of progression. Nevertheless, they have very different risk levels for losing vision-related quality of life during their lifetimes, simply because they differ in age by more than 20 years. The rate of progression in the older patient (A) is quite acceptable, while a similarly moderate progression rate definitely poses a large risk of visual impairment in the younger patient (B), in whom treatment should be intensified.



B

Figure 9-11 continued

measurements, which makes it impossible to find any further deterioration in eyes with moderate to severe field loss.[50] We therefore strongly agree with the statement in the recently published 5th edition of the guidelines of the European Glaucoma Society: "OCT progression analysis cannot replace VF [visual field] progression analysis."[32, 49]

RATE OF PERIMETRIC PROGRESSION AND TARGET INTRAOCULAR PRESSURE

Lowering IOP slows glaucomatous progression, and progression rates have been reported to slow when pressures are lowered substantially, such as after surgery.[14,15,51-54]

When encountering a progression rate that we believe to be unsafe, how can we then assess what we have to do therapeutically? The effect of lowering intraocular pressure has been calculated in multiple large, randomized clinical

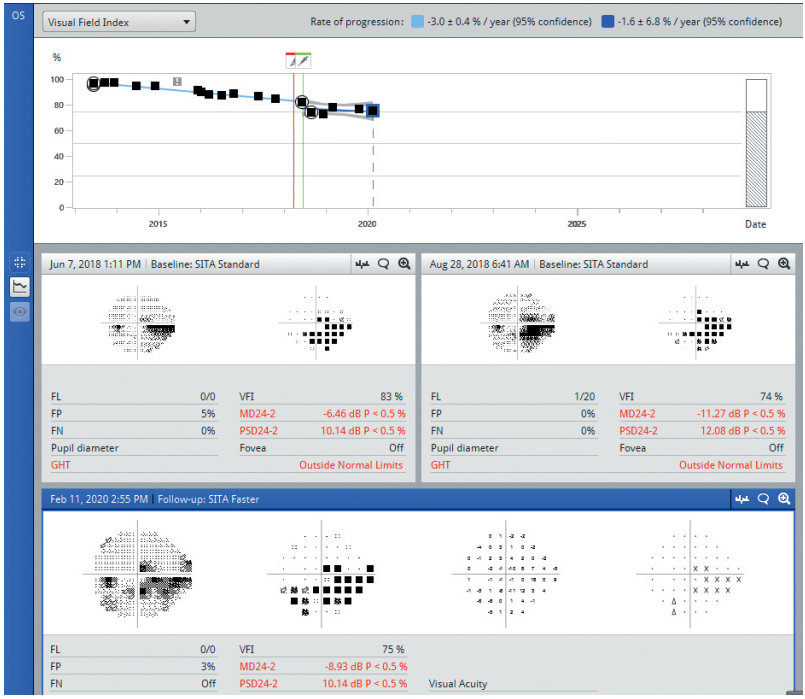


Figure 9-12

Effective consideration of patient age in therapeutic decision-making. The left eye of a 60-year-old woman had a relatively modest rate of progression on maximum medical therapy, which was not considered acceptable at her relatively young age. A XEN stent procedure was performed (indicated by the red-tagged scalpel symbol in the regression analysis timeline), which reduced intraocular pressure only temporarily. After needling (indicated by the green-tagged syringe), IOP was reduced considerably. This example shows two consecutive regression lines, in which a second baseline has been established around the time of the needling. While confirmatory testing will be required, the patient's most recent fields suggest that the rate of progression in VFI has been reduced from 3% per year to 1.6% per year.

trials. Reduction of progression risk for eyes with manifest glaucoma has been assessed in the Early Manifest Glaucoma Trial and the Canadian Glaucoma Study.[14,15] The risk of converting to glaucoma in ocular hypertension has been assessed in the Ocular Hypertension Treatment Study and in the European Glaucoma Prevention Study.[26,55-57] The risk reduction in these studies ranged from 10% to 19% for each millimeter of mercury (mmHg) of IOP reduction.

Risk reduction in such studies is calculated using time to progression or conversion as an input variable. For example, if time to detection of progression doubles, this corresponds to a reduction of rate of progression by

50%. Therefore, it is reasonable to assume that rate of progression ought to be reduced by approximately the same amount as the risk of progression, that is by 10% to 19% per mmHg of IOP lowering. So, if we are content with decreasing the slope just a little bit (say, 20% to 25% of the measured rate), it might be enough to decrease target IOP by 2 mmHg, corresponding, for instance, to changing from a prostaglandin drop to a combination of a prostaglandin and timolol. On the other hand, if we believe that a 70% decrease in slope is necessary, we might aim to decrease target IOP by at least another 6 mmHg or even 10 mmHg, compared to the mean IOP during the time of follow-up (Figures 9-13 and 9-14; Table 9-1).

Thus, it makes sense to immediately aim for large reductions of IOP in patients whose perimetric rates of progression are totally unacceptable. In addition, it is overly optimistic to hope that the progression rate might decrease in the absence of a therapeutic increase just because IOP measurements have always been at "normal" or seemingly "acceptable" levels. A rapid progression rate might be due to the treatment being insufficient, or sometimes because of nonadherence. We would first discuss treatment and adherence with the patient—and then we would step up treatment.

If, instead, we just increase therapy in small steps, such as going from monotherapy to a combo drop, or adding a second drop, or adding laser to monotherapy or a combo drop, the resulting extra lowering of IOP usually will be just a few mmHg. Then it will take at least 2 years to determine whether the new rate of progression is safe, and perhaps more years to reach the correct target pressure. In the meantime, the patient may well have lost considerable vision quite unnecessarily. In the absence of effective changes in therapy, past rates of progression are likely to be strongly predictive of future rates.[44]

CALCULATING TARGET INTRAOCULAR PRESSURE

In the previous section, we discussed how a number of major clinical trials have provided reasonably consistent estimates of the amount of perimetric RoP reduction we can expect per mmHg of IOP reduction (Table 9-1). The percentages seem to be good educated guesses at IOP levels that are commonly encountered in treated glaucoma patients, such as when we are following patients after having treated them to the initial target IOP, based on the factors available at diagnosis, such as age, level of field loss, untreated IOP level, and risk factors. After that, we follow them to see how their disease develops under initial treatment. At that time, IOP levels often may be 14 to 18 mmHg. It is, however, reasonable to assume an interaction between IOP and IOP reduction; thus, each mmHg of reduction at lower IOP levels may reduce risk more than each mmHg of reduction at higher IOP levels.

A

Figure 9-13

Rapid progression rates. Figures 9-13A and 13B show rapid and totally unsafe Visual Field Index progression rates of approximately 7% per year in two male patients of similar age. In (A), the extrapolation shown in the Guided Progression Analysis VFI regression analysis indicates that, absent some sort of a strong therapeutic change, this eye is at risk of losing another third of its visual function over the next 5 years, putting the eye into the realm of legal blindness. In (B), the GPA has produced no progression rate extrapolation, for statistical reasons. However, the data points are lined up with a very clear direction and show a very high progression rate of 7.6% per year, which threatens to leave this eye at a VFI below 50% 5 years from now. The risk of serious vision loss in the upcoming 5 years is high. Therefore, in the absence of some deadly comorbidity, clinical judgment suggested prompt and strong action.

Thus, the percentages of decreases in RoP associated with a 12% reduction per mmHg of IOP reduction (shown in Table 9-1) cannot be expected at high pressure levels. For instance, we cannot expect to reduce progression rate by almost 100% by lowering IOP from 28 mmHg to 20 mmHg. On the other hand, this caveat may have little relevance, simply because it is unlikely

B

Figure 9-13 continued

that we would follow patients with manifest glaucoma at 28 mmHg waiting to assess rate of progression.

With these estimates, plus knowledge of a patient's historical RoP, we can estimate how much further the IOP must be reduced in order to keep the VFI above a particular level during the patient's expected lifetime. If we assume 12% reduction in the initial RoP for every extra mmHg IOP lowering, a simple formula for RoP reduction might be [IOP reduction x 12%] (Table 9-1, middle column). If we assume that each incremental millimeter of pressure reduction reduces the remaining RoP by, for instance, 12%, the right-hand column in Table 9-1 might provide better estimates. For small to moderate reductions in RoP, the differences between the two columns are small. If a large reduction in RoP is required, then comparison of the two tables can provide a range for target pressures. One example of a rapidly progressing eye and possible future progression scenarios is shown in Figure 9-14.

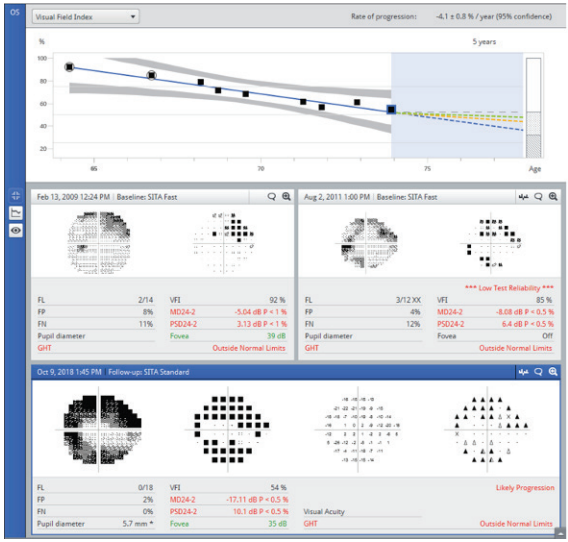


Figure 9-14

This is the left eye of a 74-year-old patient diagnosed with primary open-angle glaucoma 10 years ago. The progression rate is high, 4.1%/year, and Visual Field Index is close to 50%. The extrapolated regression line (blue) suggests that this eye may pass the 50% level in one year and that VFI might be under 40% by the time the patient turns 78. This is obviously rather alarming. Two alternative extrapolation lines are presented: a yellow line, where the rate of progression has been reduced by 50%, and a green line, with the progression rate reduced by75%. If we use the middle column in Table 9-1, we can see that achieving the yellow rate, IOP might have to be reduced by 4 mmHg; with the more ambitious green line, a 6 mmHg reduction might be needed. If instead we apply the values in the right-hand column of Table 9-1, the corresponding IOP reductions would be 5 to 6 mmHg and > 8 mmHg, respectively, in both cases emphasizing that a larger IOP reduction is needed for a larger reduction of the rate of progression.

REDUCTION OF PERIMETRIC RATE OF PROGRESSION WITH IOP LOWERING		
Decrease in Intraocular Pressure	Assuming Linearity	Assuming Nonlinearity
1 mm	12%	12%
2 mm	24%	23%
3 mm	36%	32%
4 mm	48%	40%
5 mm	60%	47%
6 mm	72%	53%
7 mm	84%	59%
8 mm	96%	64%

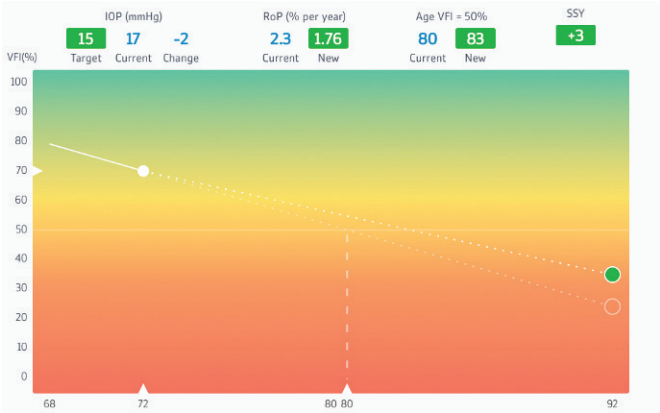
Table 9-1

This table assumes that the rate of perimetric progression (RoP) decreases 12% per mm of decrease in intraocular pressure, which is the median rate found in four large clinical trials.[14,15,55-57] The middle column assumes a 12% reduction of the initial RoP for every mmHg of IOP lowering, while the right-hand column assumes that each incremental millimeter of pressure reduction reduces the remaining RoP by 12%.

One of the authors (Anders Heijl) has developed a web-based tool called the SSY Engine, in cooperation with Allergan, to facilitate calculation of new target IOPs in glaucoma patients who have been observed to progress perimetrically at unsafe rates.[58] This tool is available in many countries (see ssyengine.com) and uses an age-function diagram that is very similar to that of the GPA regression analysis to help doctors estimate new target IOP levels (Figure 9-15).

FREQUENCY OF PERIMETRIC TESTING IN GLAUCOMA MANAGEMENT

European Glaucoma Society practice guidelines have for many years recommended collection of three fields per year—including baseline tests—in the first 2 years after a patient has been diagnosed with glaucoma.[1] This approach also is mentioned in the recently published 5th edition of those guidelines.[32] Such an amount of testing usually is enough to have a very good chance of detecting eyes progressing at the high rate of 2 dB per year.[16] Detection of slower but perhaps still unacceptable rates may take longer than 2 years, which simply means that we must remain vigilant, perhaps while gradually reducing test frequency. The World Glaucoma Association's 2011 consensus statement on glaucoma progression makes similar suggestions,[38] and others



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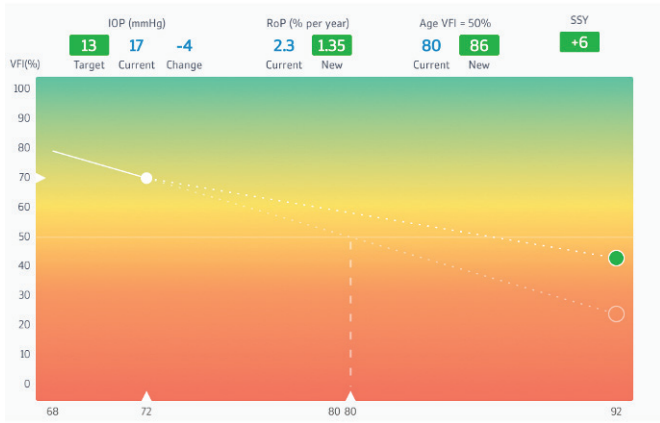

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Figure 9-15

Example from the SSY Engine. This is from a 72-year-old patient diagnosed 4 years ago and treated with a prostaglandin drop. The measured progression rate is 2.3% per year and the current Visual Field Index value is 70%. The observed progression is the solid white line. The extrapolation, the inferior dotted white line, suggests that vision in this eye may drop to a VFI of 50% by the age of 80, signifying loss of half the eye's visual field. This is far from ideal, and two different scenarios have been calculated. In (A), the progression rate has been reduced by about 25% (filled green circle), which the SSY Engine suggests will require a further reduction of IOP by 2 mmHg. In (B), the reduction in rate of progression is 50% and the suggested extra IOP reduction is 4 mmHg. Considering that the patient currently is only taking a single eyedrop, the second alternative ought to be achievable by adding drops and/or through laser treatment. Further IOP reduction might be discussed with the patient if the goal is to keep VFI above 50% until, for instance, age 92.

have suggested variations on this approach. In any case, RoP estimates based upon linear regression require at least five tests.

While increased testing frequency has been found to lead to earlier detection of rapidly progressing patients,[18,59] there are, of course, practical limits on perimetric testing frequency. With the recently developed SITA Faster testing strategy,[60] such frequent testing should be more acceptable than before. Three tests per year for the first 2 years after diagnosis are desirable, but if in a particular setting that cannot be done, two tests per year during the first 3 years after diagnosis is very much better than just one test per year. Without an assessment of rate of progression, we are basing treatment on tonometry, target pressure, and general risk factors alone, whereas if we base our treatment decisions on how each patient has done perimetrically over the past few years, we are making a truly individualized risk assessment and prediction.

It also is important to understand that the frequency of field testing does not have to remain high forever. Once we have enough follow-up data to confirm that a patient is either stable or progressing at a low and reasonably safe rate, testing intervals can be extended, perhaps to once a year. And after 6 to 8 years, if rate of progression remains low, it may be reasonable to extend intervals between field tests even farther, as long as IOP and other clinical observations do not change.

If, on the other hand, a patient is found to have an unacceptable rate of progression, and we therefore reduce IOP much further, such as by using surgery, we will again need to determine whether the new rate of progression is acceptable. This will require testing that is as frequent as in a newly diagnosed patient. One can create a second trend line in Glaucoma Workplace and thus begin quantifying the new RoP. Adding a symbol for the surgery to the trend line will help clarify interpretation and future management (Figures 9-12 and 9-16).

In summary, in patients with manifest glaucoma and field loss, we need to perform field testing more frequently until they are shown to be reasonably stable or progressing at an acceptable rate. Thereafter, in clearly stable or almost stable patients, and in elderly patients with early visual field defects and slow rates of progression, one may further reduce the frequency of field testing, perhaps in some cases to one field every second year.

In glaucoma suspects with normal fields, such as patients with ocular hypertension, field tests are not needed nearly as often. One test per year or even every second year may be quite sufficient.

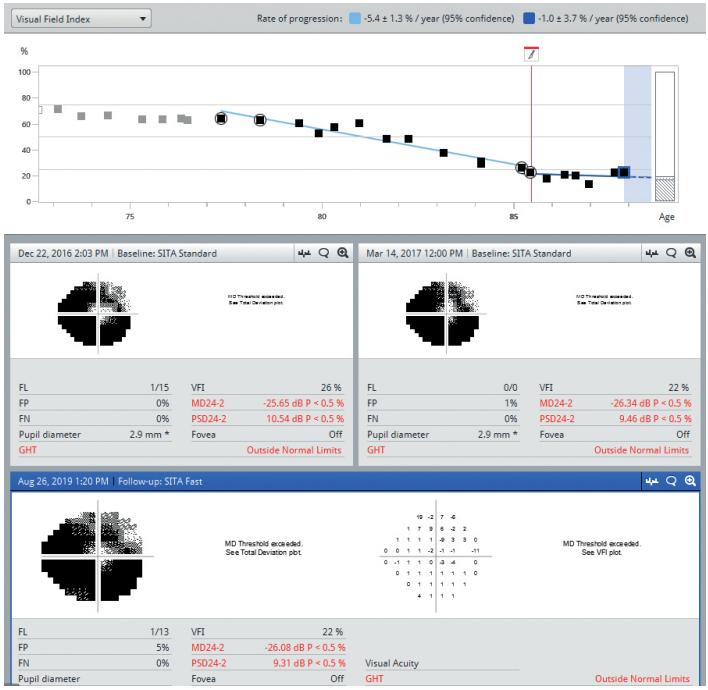

Figure 9-16

Lowering of intraocular pressure when it is already low. This eye underwent trabeculectomy (indicated by the red-tagged scalpel symbol) when the patient was 85 years of age, after a long period of rapid progression despite IOP values in the low teens. Postoperatively, IOP was around 9 to 10 mmHg. Seven fields have been obtained during the previous 2 or 3 years, and a second baseline has been established around the time of the surgery. Note that Glaucoma Workplace allows use of dual regression lines. The second regression line indicates that rate of progression improved very much after the surgical intervention.

Location of Field Loss and Risk to Quality of Life

Visual fields where defects come close to the point of fixation, such as by affecting one or more of the four most central test points in the 24-2 and 30-2 test point patterns, has often been classified as presenting a "threat to fixation." Many glaucomatous eyes already have such loss at the time of diagnosis. Fortunately, it seems clear that a patient's risk of future visual disability or blindness can be forecast just as well by use of the MD or VFI value as by taking "threat to fixation" into account, and such eyes should not be considered to have high-risk disease solely because of the central defect.[61]

At the same time, very central field loss should still motivate higher vigilance and more ambitious treatment goals, because central field loss affects daily living more than peripheral loss does and is more highly associated with a lower quality of life.[62] Loss in the central 12 test points of the 24-2 test also has been shown to be associated with higher rates of global progressive field loss,[63] but generally we believe that it is more important to consider the stage of field loss than the location of the loss when deciding on management strategy, such as frequency of testing.[64]

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10

Neurological Visual Field Loss

THE VISUAL PATHWAY OCCUPIES and passes through much of the brain, and lesions caused by neurological disease at various locations often cause quite specific patterns of visual field loss (Figure 2-3). Before the advent of neuroimaging, visual field loss frequently was the best indicator of the location and sometimes even the nature of central nervous system disease. Even today, perimetry often can provide a simple and cost-effective aid in making neurological diagnoses. Neurological disease often is identified inadvertently during visual field testing, such as in follow-up examination of glaucoma patients. Modern practice emphasizes testing in the central field for assessing neurological field loss, and SITA tests are preferred.[1-3]

Optic Nerve Disease

Unilateral optic nerve disease naturally produces field defects in just the affected eye. A central scotoma is a common pattern of field loss in several types of optic nerve disease, such as optic neuritis (Figure 10-1), in many toxic optic neuropathies, and in compressive optic nerve lesions. The size of the visual field defect varies, and reduced visual acuity often is associated with larger scotomas. If the damage is small enough that visual acuity still is normal or only slightly affected, the scotoma may be so small that sensitivity is only marginally depressed at one or more of the four most central points in the standard 30-2 or 24-2 test point patterns and might be better quantified with a 10-2 test. Optic neuritis (Figure 10-2) can cause a large variety of both diffuse and localized visual field defects, some of which may even resemble those typical of glaucoma.[4,5]

Ischemic optic neuropathy usually results in sudden and large loss of visual function. Field loss frequently encompasses sizeable areas of absolute defects, that is, areas of visual field loss where even the brightest stimulus of the perimeter is not seen. Many different patterns are possible, with altitudinal and arcuate defects being the most common. Visual field loss in the affected hemifield often is incomplete, and it is common to see areas of diminished function in the less affected hemifield as well (Figure 10-3).

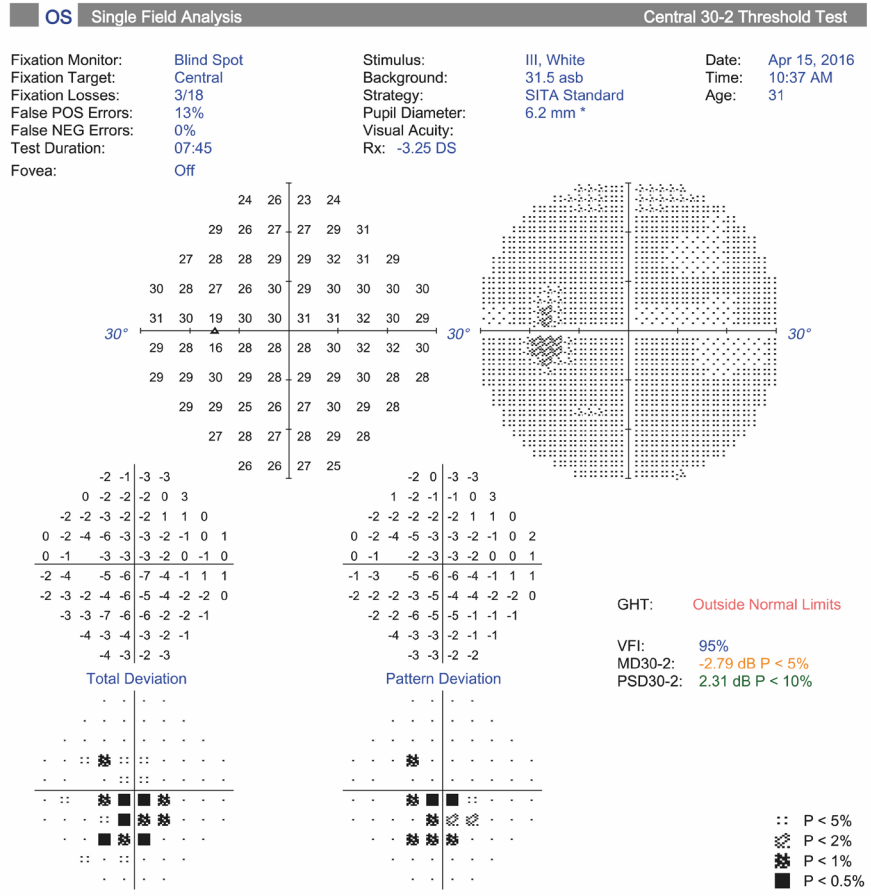
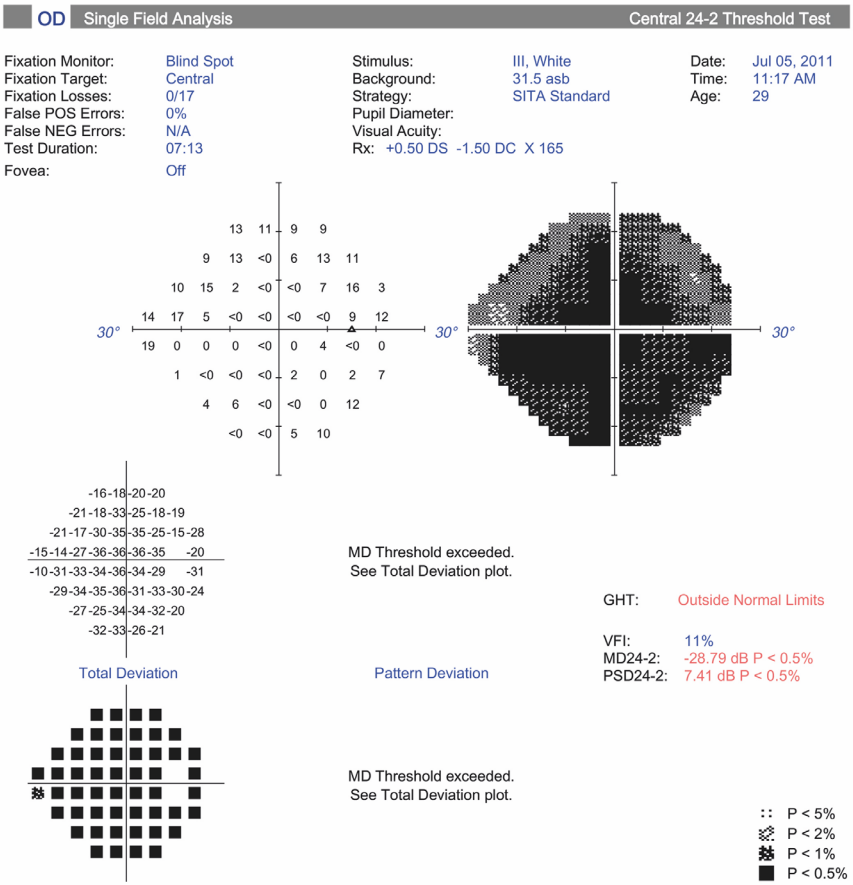


Figure 10-1

Optic neuritis. This 31-year-old woman had a medical history of bilateral relapsing optic neuritis in both eyes, with poor response to steroids. She came to the ophthalmology department complaining of a dark blur in the left eye and a sense of flickering. Visual acuity was 0.5 (20/40), the left optic disc was slightly pale, and the visual field showed central defects visible in the probability maps.



A

Figure 10-2

Optic neuritis. A 29-year-old male presented with a 10-day history of tenderness behind the right eye and pain on eye movements. Visual acuity was 0.1 (20/200) and the right optic disc was edematous. The patient returned the following day, reporting worsening of vision, and visual acuity was only hand movements. Perimetry a few days after the second visit showed the very extensive field loss shown (A). Twenty days after the first visual field, visual acuity was 1.0 (20/20) and the visual field was much improved (B).

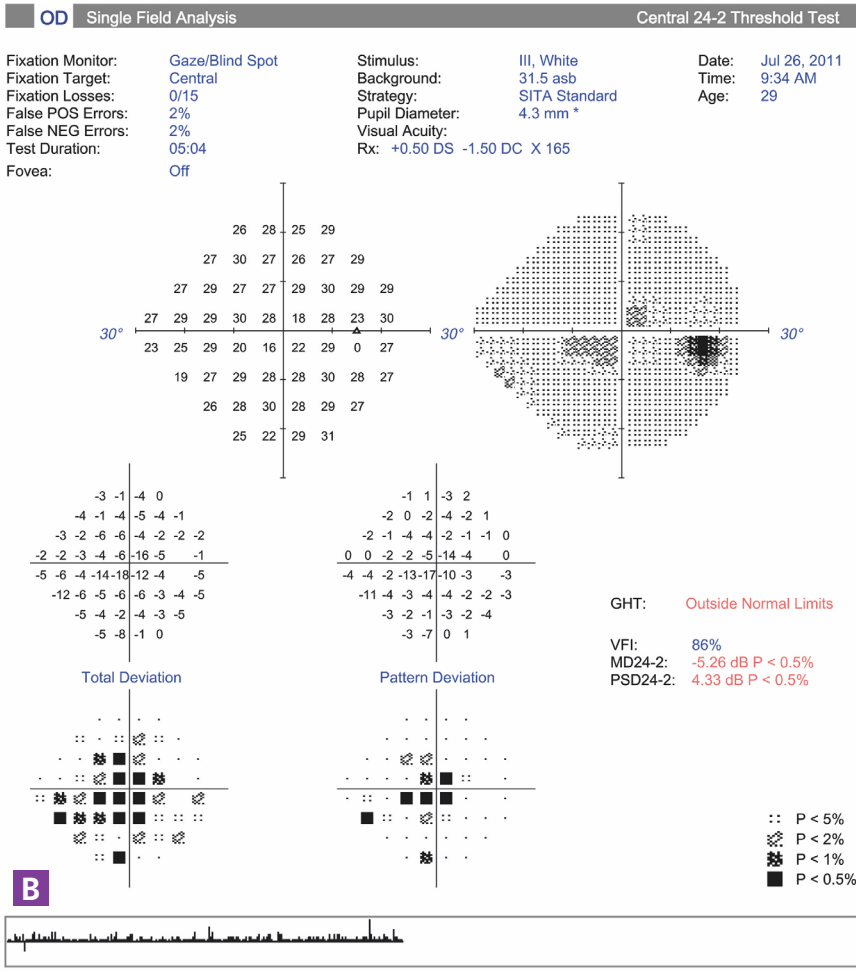


Figure 10-2 continued

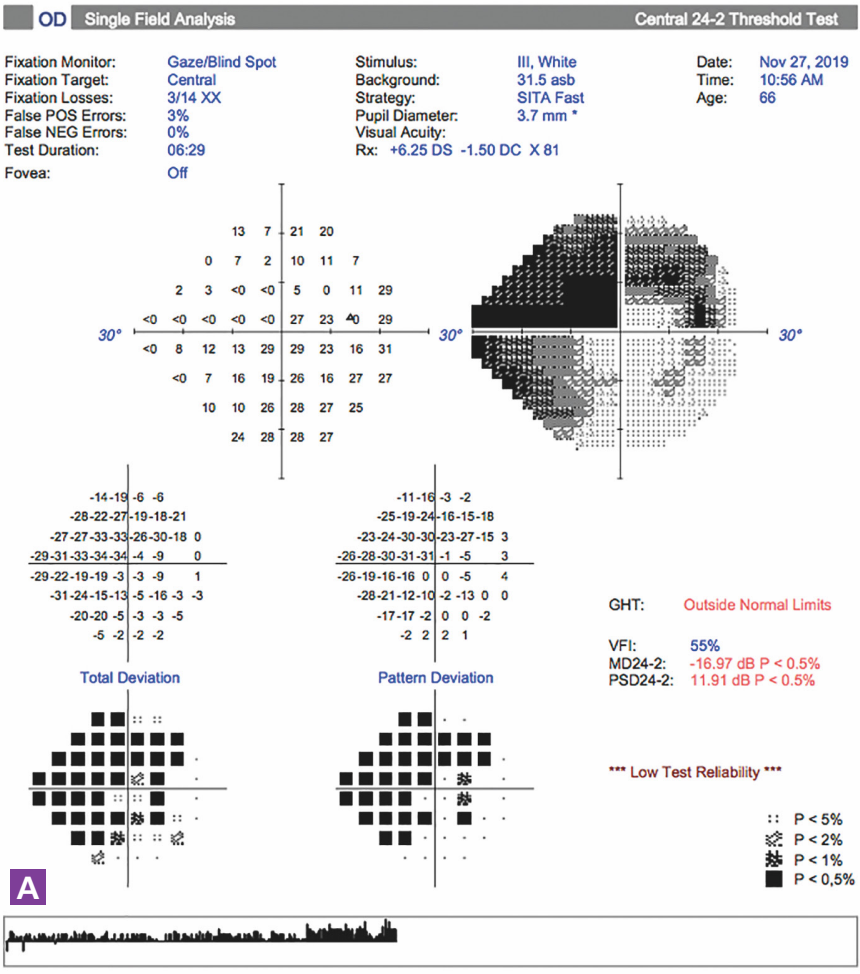


Figure 10-3

Ischemic optic neuropathy. This 66-year-old male patient developed bilateral posterior ischemic optic neuropathy after a 10-hour surgical procedure for a bladder tumor. During surgery, the patient lost 1.25 liters of blood, was treated with vasoconstrictive drugs, and put in a supine Trendelenburg position, all of which are risk factors for this rather rare complication. The right eye shows predominantly nasal field loss, while the left eye displays a classical altitudinal field defect.

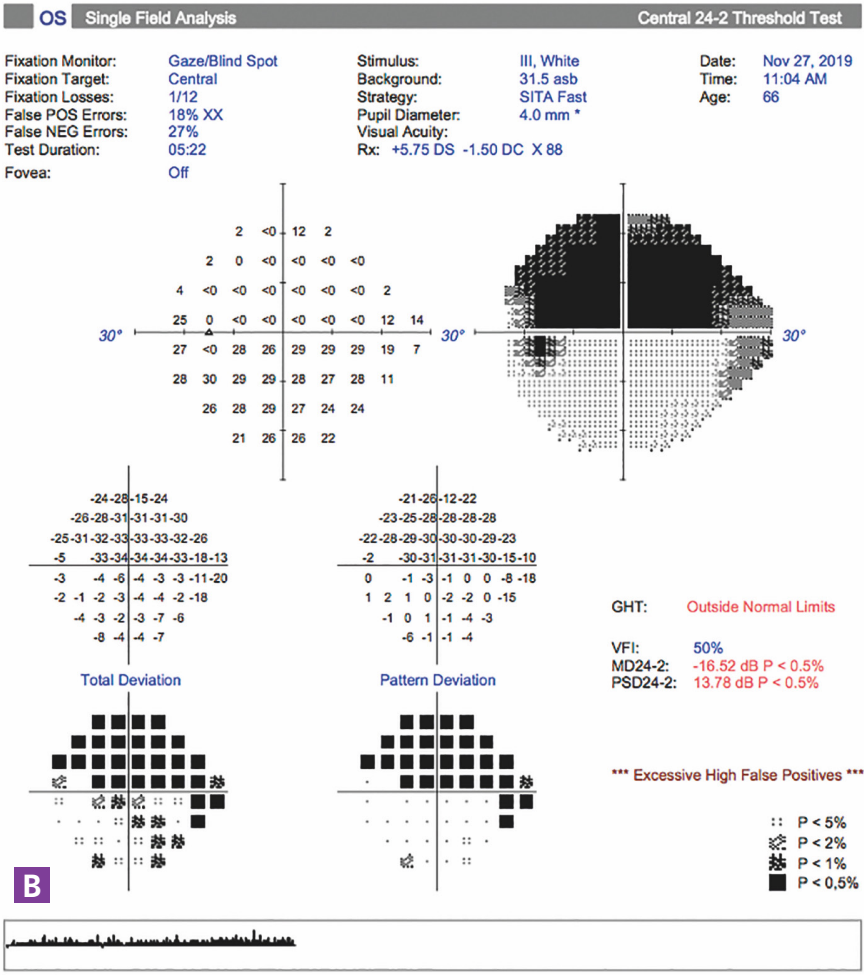


Figure 10-3 continued

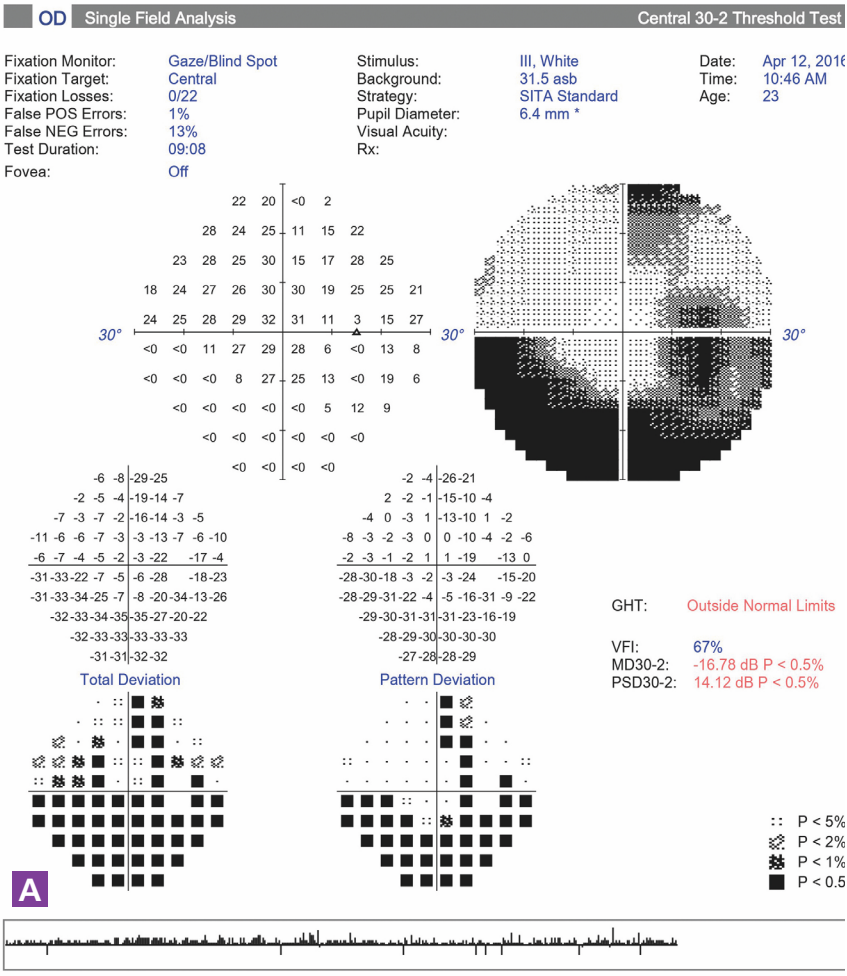
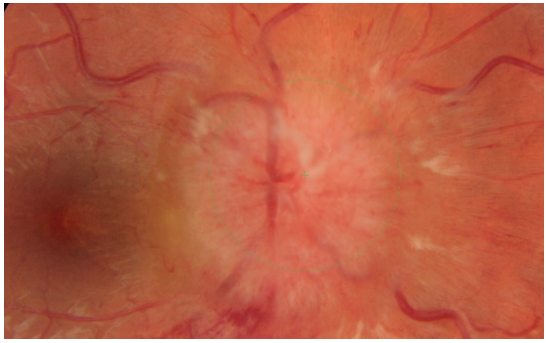


Figure 10-4

Optic disc edema and associated field loss in idiopathic intracranial hypertension. Field and photograph (A and B) are from a 23-year-old woman who was diagnosed with idiopathic intracranial hypertension, most likely secondary to tetracycline medication. The opening pressure on lumbar puncture was 46 cm water, indicating significantly raised intracranial pressure. The visual field from the right eye showed large visual field defects, and the fundus image showed optic disc edema. A ventriculoperitoneal shunt was inserted. Three years later, the optic disc showed secondary optic atrophy and the visual field had improved somewhat (C and D).



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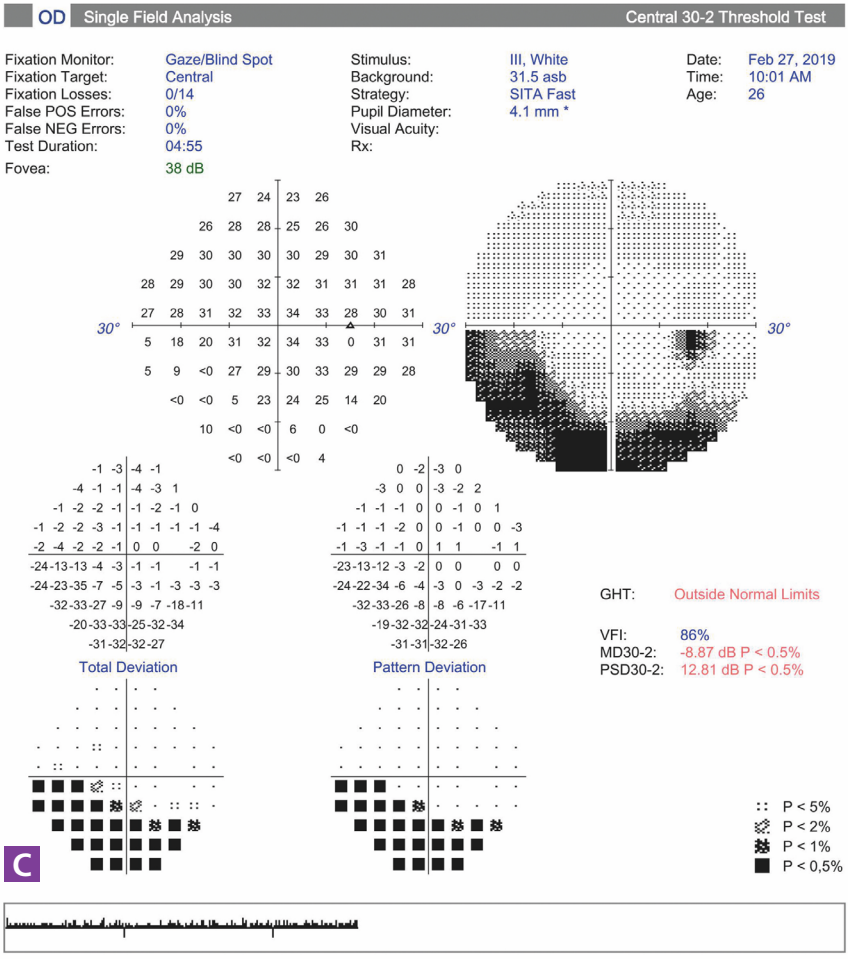

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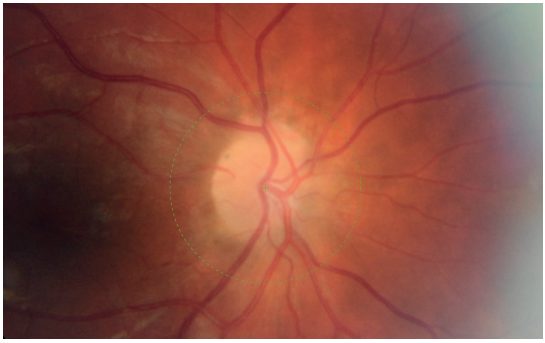
Figure 10-4 continued



D

Figure 10-4 continued

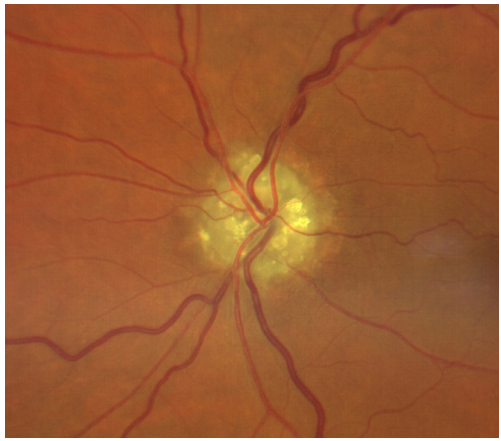
Visual fields of patients with early phase optic disc edema typically show only an enlargement of the physiological blind spot, which may be surrounded by a zone of relative loss of sensitivity, and which may or may not be seen with the common 24-2 and 30-2 test point patterns. Diagnosis is most often made with ophthalmoscopy or fundus imaging. Nevertheless, patients with long-standing optic disc edema should undergo regular visual field testing, because in such cases secondary progressive optic atrophy can occur. Perimetry may show field loss in such cases (Figure 10-4). Threshold tests using the 30-2 and 24-2 patterns are suitable for following these patients. Idiopathic intracranial hypertension is a condition that can result in a great variety of field defects, many mimicking glaucoma defects.[6]

Drusen of the optic disc may produce arcuate defects that may vary but sometimes are indistinguishable from those caused by glaucoma (Figure 10-5). Field defects are more common at higher age. Findings tend to be bilateral and associated visual field loss tends to be progressive in the long run.[7-9]

Severe thyroid eye disease can cause visual field defects because of compressive optic neuropathy. The defects commonly are arcuate or cecocentral, that is, extending from the fovea to the blind spot, but can manifest themselves in many different patterns.[10] Defects may progress rapidly but also regress or even disappear quite rapidly after successful treatment of the ophthalmopathy (Figure 10-6).

Figure 10-5

Optic disc drusen (A). Associated visual field findings are quite variable but often are similar to those in glaucoma (B). The field has deep field defects, particularly in the inferior nasal area. This patient's identical twin was found to have similar optic nerve drusen and similar visual field damage.



A

Single Field Analysis — Eye: Left

Name: — DOB:

ID:

Central 24-2 Threshold Test

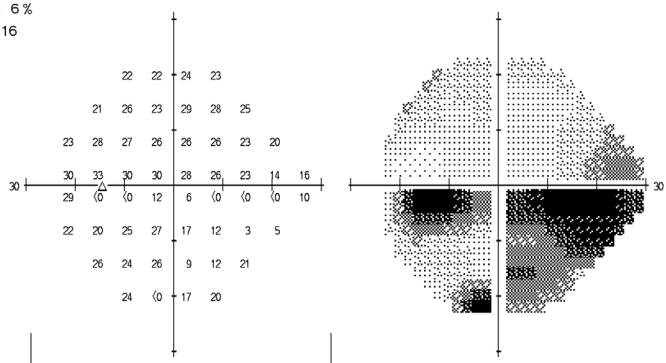
Fixation Monitor: Gaze/Blind Spot
Fixation Target: Central
Fixation Losses: 5/16 xx
False POS Errors: 13 %
False NEG Errors: 6 %
Test Duration: 07:16

Stimulus: III, White
Background: 31.5 ASB
Strategy: SITA-Standard

Pupil Diameter: 4.7 mm
Visual Acuity:
RX: +4.00 DS DC X

Date: 03-06-2020
Time: 11:57 AM
Age: 62

Fovea: 31 dB



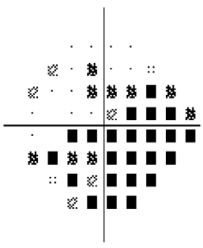
*** Low Test Reliability ***

GHT
Outside Normal Limits

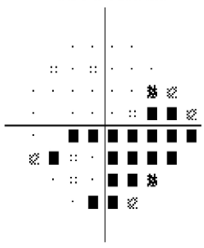
VFI 69%

MD -11.68 dB P < 0.5%
PSD 11.42 dB P < 0.5%

Total Deviation

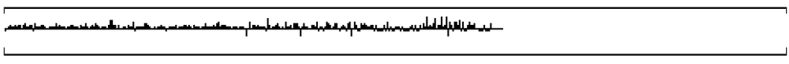


Pattern Deviation



:: < 5%
▒ < 2%
▓ < 1%
■ < 0.5%

B



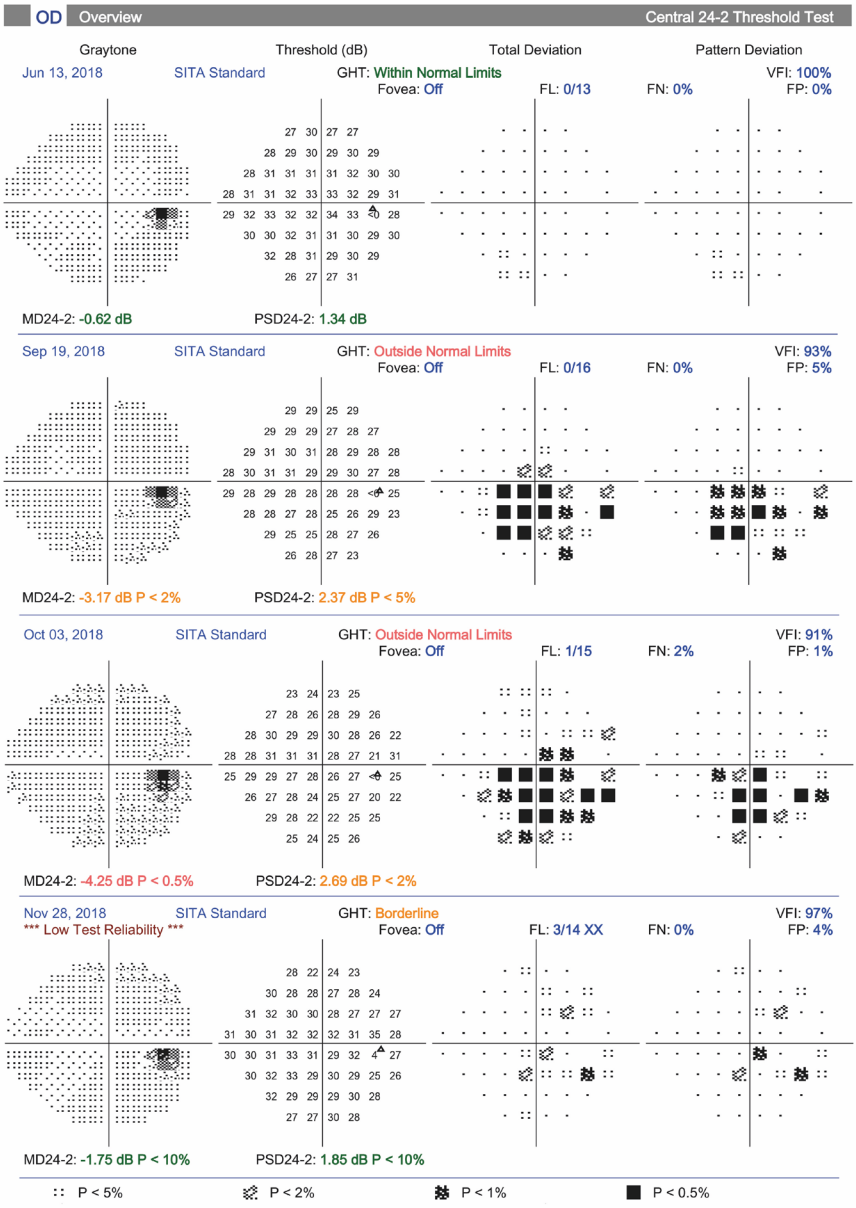


Figure 10-6

Thyroid eye disease. Field defects in thyroid eye disease may regress or even disappear after successful treatment. This 46-year-old man was diagnosed with Graves' ophthalmopathy in January 2018 and was treated with steroids. Field defects appeared in September 2018, in the absence of optic disc edema, and remained largely unchanged upon confirmation testing two weeks later. Surgical decompression was performed and the fields improved.

Lesions of the Optic Chiasm

The optic chiasm may be damaged by a variety of pathologies, the most common being pituitary adenomas, craniopharyngiomas, suprasellar meningiomas, or aneurysms coming off the arterial circle of Willis. Complete bitemporal hemianopia is uncommon, with most patients presenting with incomplete and asymmetric bitemporal field loss. Crossing fibers are frequently affected first, resulting in bitemporal visual field defects. In early stages of the disease process, midline defects caused by infrachiasmal pathology may be limited to the superior part of the hemifield, sometimes with wedge-like defects which respect the vertical meridian. Involvement often is asymmetrical, with more damage in one eye. Defects may resolve or diminish after surgery (Figure 10-7). Pathologies in the chiasmal area that are not centered on the midline may result in visual field defects of many different types in one or both eyes (Figure 10-8).[11]

Postchiasmal Lesions

Postchiasmal disease of the optic pathways results in partial or complete homonymous hemianopic defects (Figure 2-3), that is, matching defects in the same visual field of both eyes. Such hemianopic defects tend to respect the vertical meridian even if they affect only part of the hemifield; such is the case with hemianopic wedge-like defects, quadrantanopias (Figure 10-9), and homonymous hemianopic scotomas. A complete lesion involving all postchiasmal nerve fibers, whether 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.

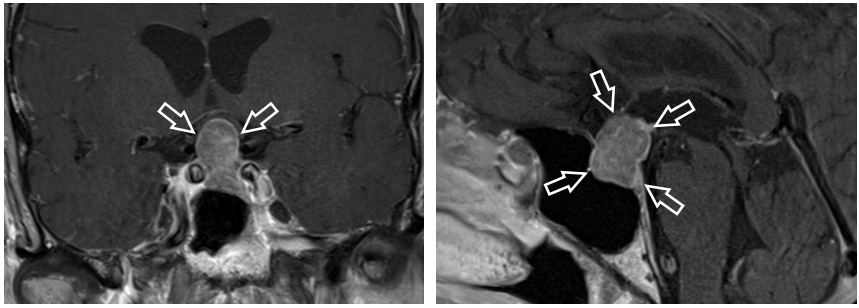


Figure 10-7

Fields and MRIs from 74-year-old man with a large pituitary tumor producing both prolactin and growth hormone and bitemporal hemianopia. The second fields were obtained after surgery and show improvement at least in the left eye.

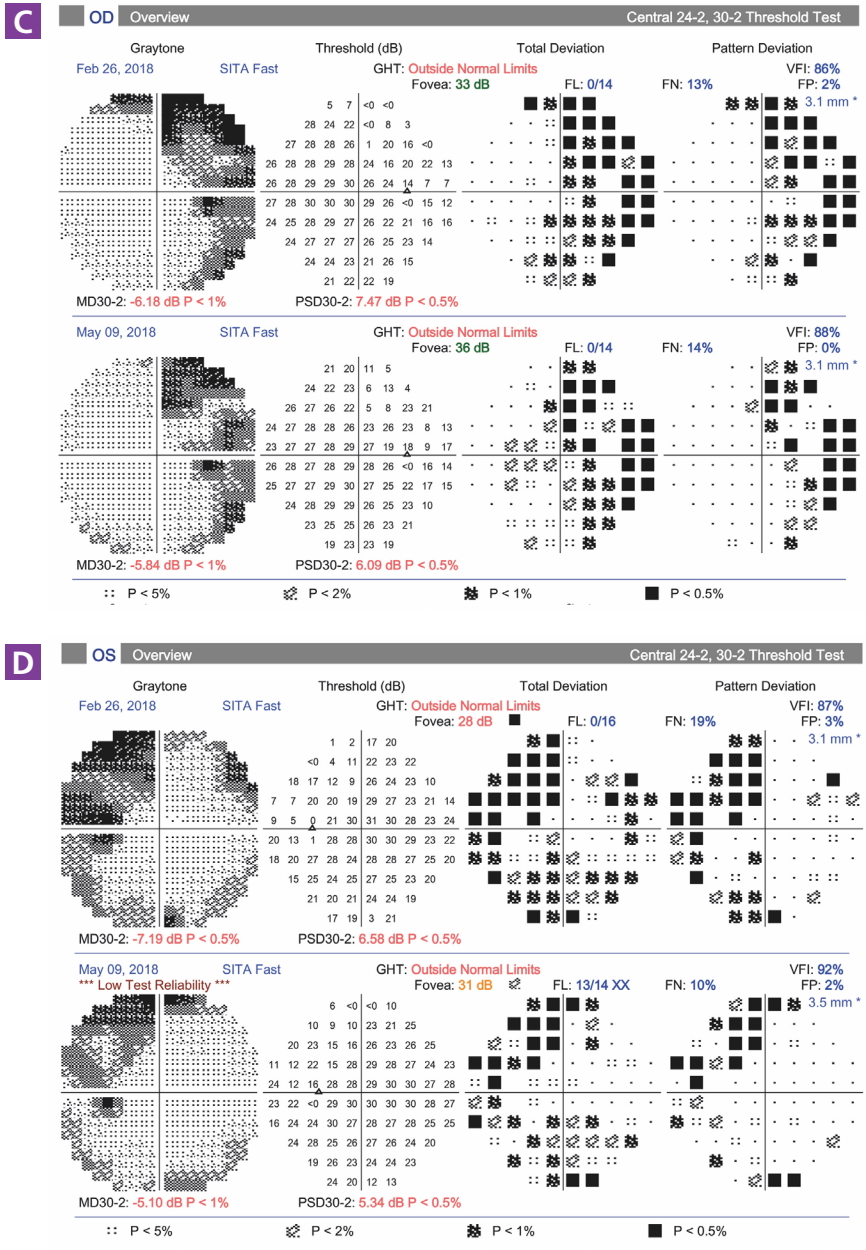


Figure 10-7 continued

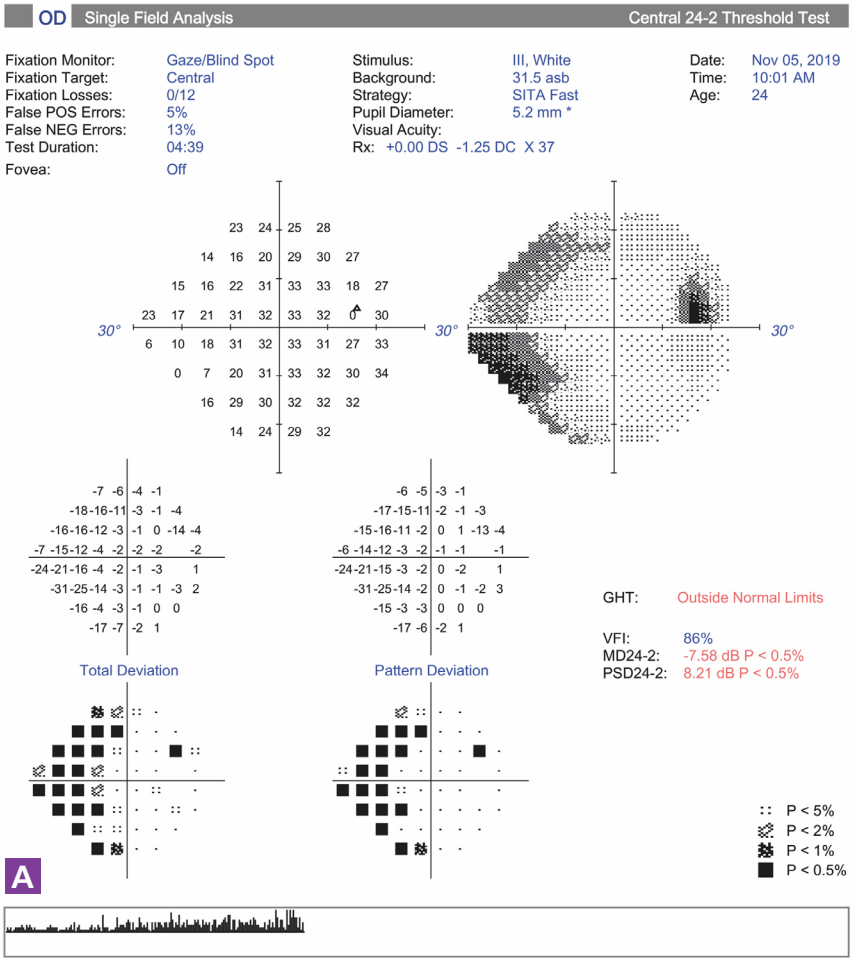


Figure 10-8

Homonymous incongruent left-sided hemianopia in pituitary adenoma. This 24-year-old man presented with a history of headache. The work-up showed a pituitary tumor affecting the right optic tract.

Congruity—the degree to which defects in the two eyes match or slightly differ—may be used to help localize the lesion. Postchiasmal visual field defects become increasingly congruous the more posterior the lesions are situated toward the occipital cortex. Damage to the visual cortex itself should in principle result in perfectly matching congruent defects in the two eyes, but complete homynymous hemianopias can occur with extensive lesions anywhere from the optic tracts to the visual cortex.

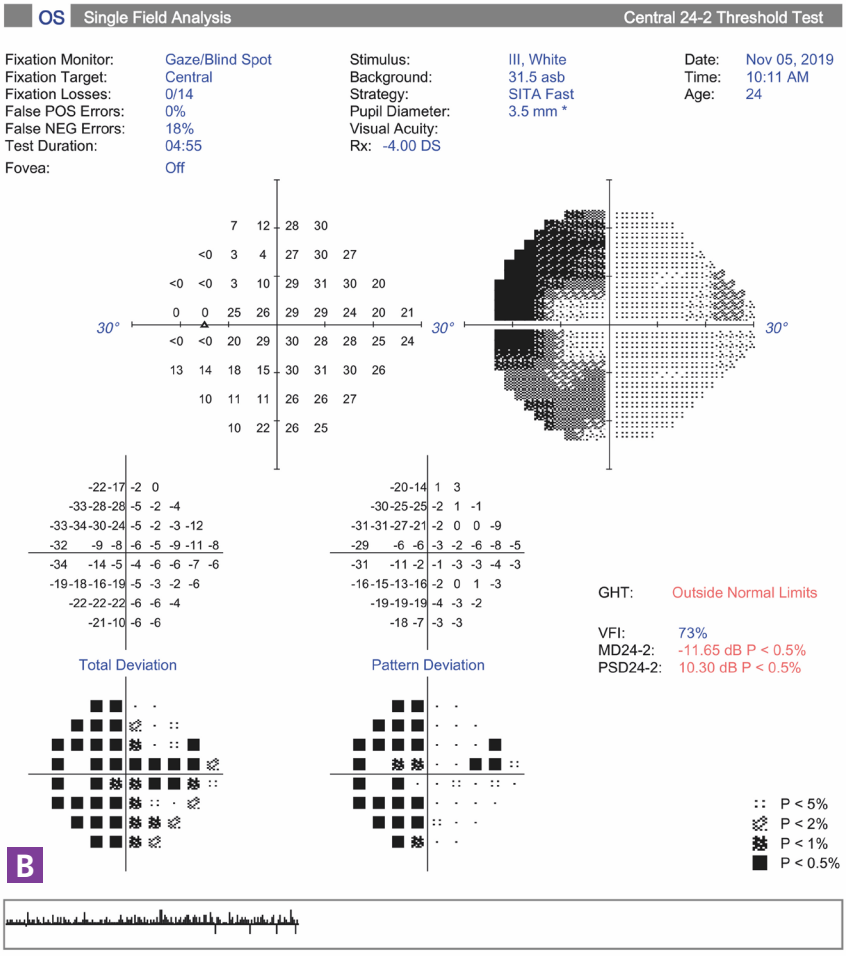


Figure 10-8 continued

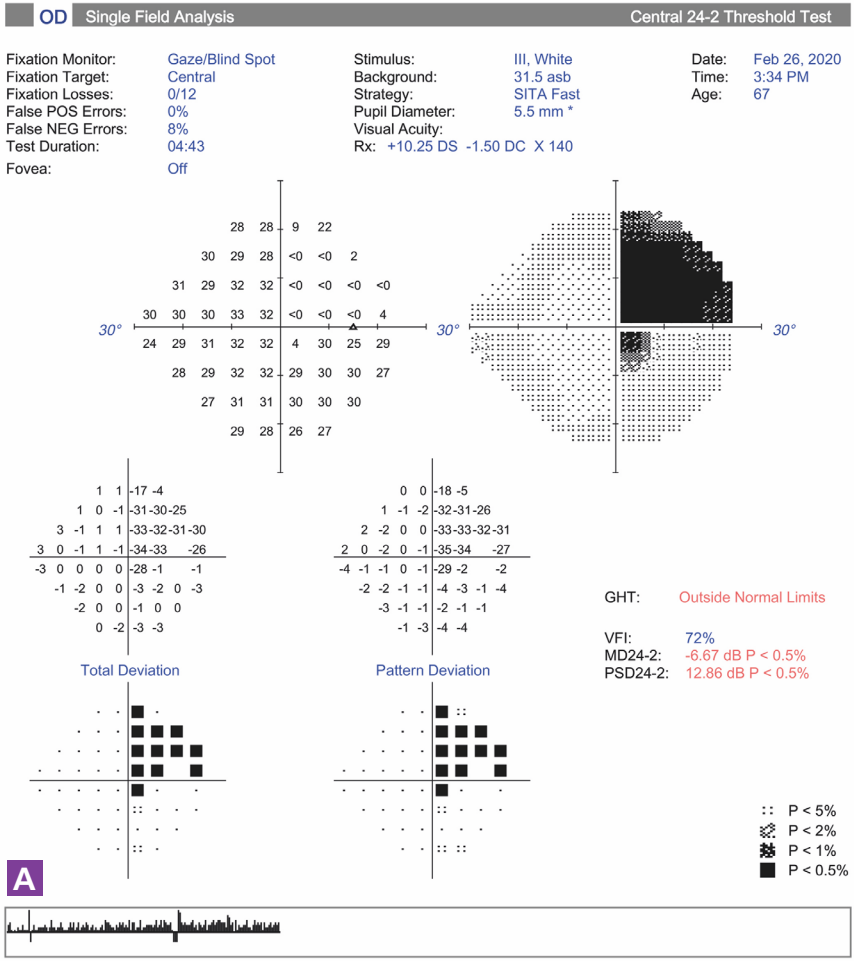
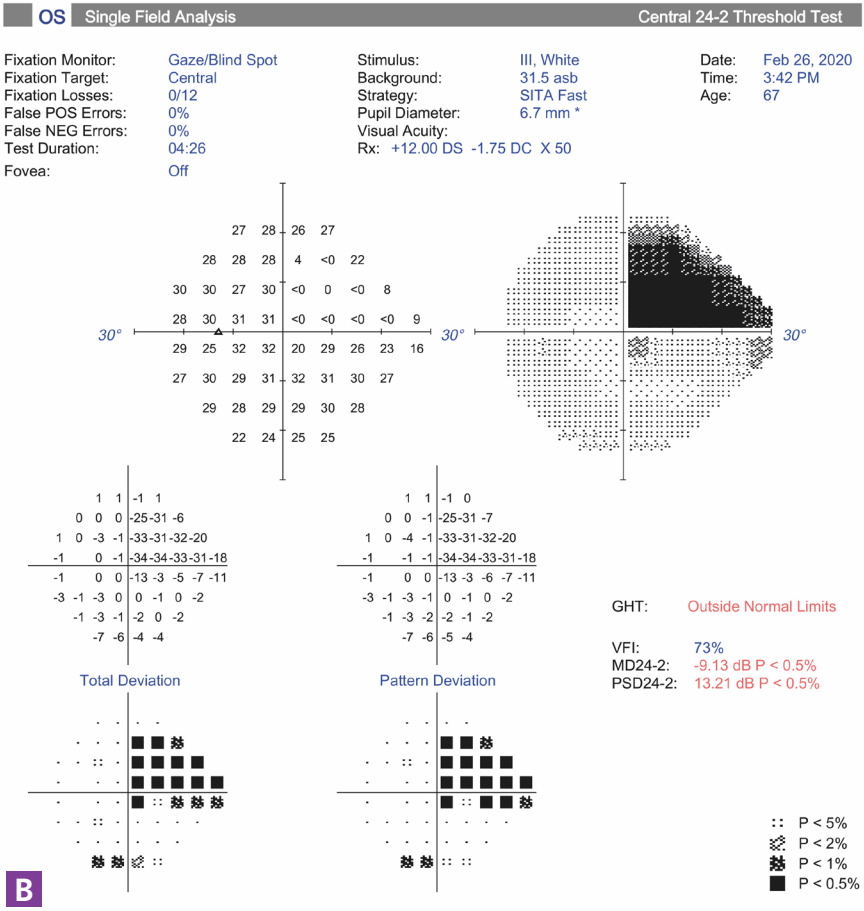
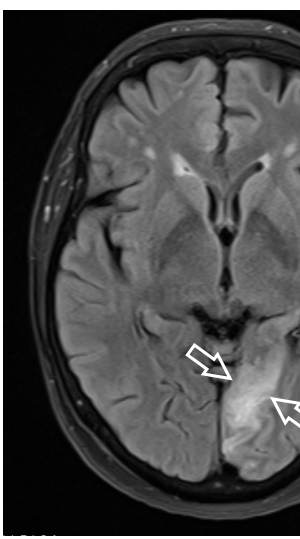


Figure 10-9

Congruent right-sided upper quadrantanopia (A and B). A 67-year-old woman presented with a 2-week history of headache, vision loss, and numbness in her right body half. MRI shows a left-sided occipital infarct (C). The MRI image is presented as viewed from below.





C

Figure 10-9 continued

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11

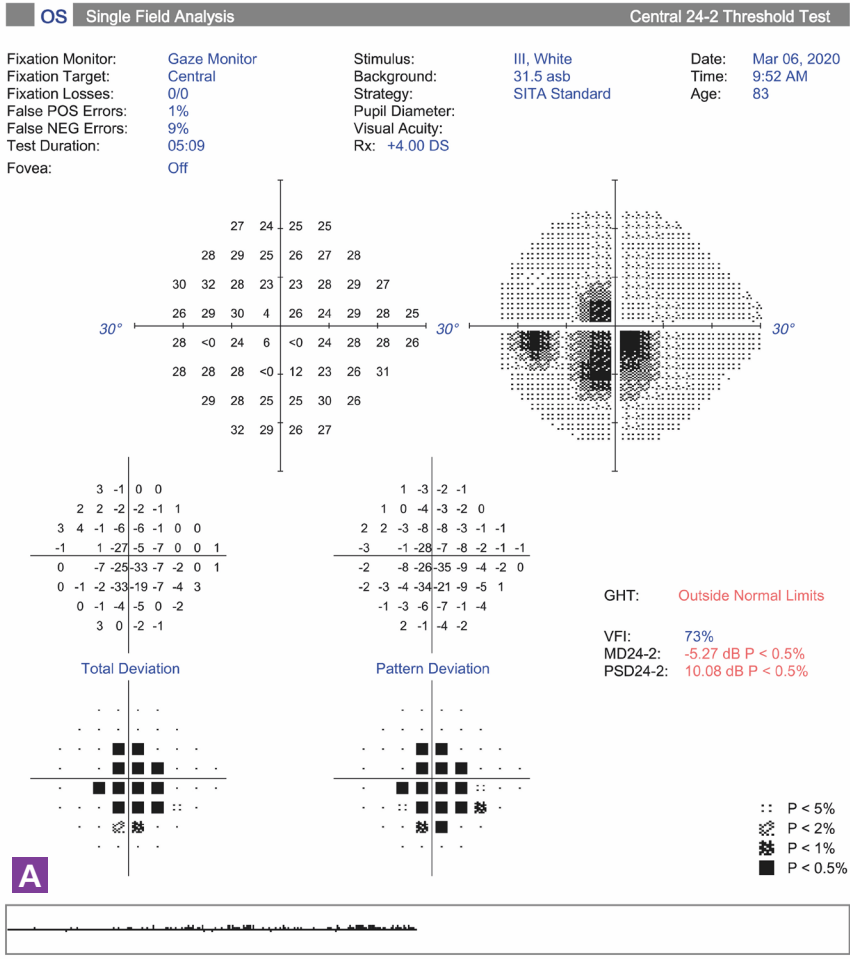
Visual Field Loss in Retinal Diseases

ALTHOUGH ANY DISEASE THAT disrupts retinal structures can cause corresponding visual field defects, perimetry is not the most important tool for diagnosing or monitoring retinal disease, simply because most such lesions are visible on ophthalmoscopy or fundus imaging. Nevertheless, retinal disease sometimes is identified because of field defects inadvertently discovered, for instance, during the routine management of glaucoma patients. Perhaps more importantly, multiple diseases can coexist in the same eye, including glaucoma and age-related macular disease or diabetic retinopathy, making it necessary to identify which disease is causing observed field loss or observed changes from baseline. In any case, a working knowledge of how retinal disease can affect the visual field is necessary in clinical care.

Because this book is a primer on perimetry and not a retina textbook, we will not attempt to chronicle the perimetric effects of all possible chorioretinal disorders. Instead, we will focus on just a few of the more common diseases. Suffice it to say that if a disease causes a retinal scar or other visible retinal disruption, you should expect to see corresponding visual field damage. See chapter 2 for a more general discussion of this topic.

A common field defect caused by retinal disease is the central scotoma associated with age-related macular degeneration (Figure 11-1). In many cases of AMD, just a few central test points may be affected on a 24-2 or 30-2 test, but higher-resolution 10-2 testing of the macula will show a more detailed picture. Patients having deep central scotomas, who need perimetric examination because of concurrent glaucoma or neurological symptoms, can and should be tested using the HFA's Large Diamond fixation target instead of the standard Central Fixation light-emitting diode, even if visual acuity is very low (see chapter 3 and Figure 3-5).[1]

Central serous retinopathy also results in reduced central visual function, and therefore in central visual field loss. Visual acuity is often only moderately reduced, and the resulting field loss may be apparent only in probability maps. If one wants to map field loss caused by AMD, central serous retinopathy, or other macular disease, a SITA 10-2 test is preferable.



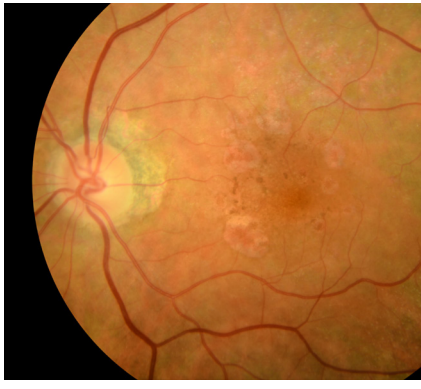


Figure 11-1

Unusually large field defects associated with macular degeneration.

Retinochoroiditis may cause arcuate or wedge-like defects that can be mistaken for glaucomatous lesions, especially when located near the optic nerve (Figure 11-2). The cause of the defect is identified, of course, when lesions are seen during ophthalmoscopy. The visual field findings themselves may offer clues that can help refine the diagnosis. Field defects caused by retinal lesions often are deep and sharply defined, and they tend to show much less variability from test to test than do comparable glaucomatous lesions.[2]

Field loss from diabetic retinopathy often is relative and multifocal, giving the field a mottled appearance.[3] Subtle losses have been reported in mild background retinopathy,[4,5] while clear perimetric defects are more common in moderate and advanced stages (43 and higher on the Early Treatment Diabetic Retinopathy Study scale).[6] Macular (10-2) short-wavelength automated perimetry (SWAP) testing has been reported to be more sensitive than standard white-on-white perimetry to diabetic damage in the foveal and perifoveal capillary network.[7,8] After laser scatter treatment, associated field defects are usually much more substantial (Figure 11-3). However, no changes were seen in SITA 10-2 fields after macular focal/grid laser treatment in eyes with clinically significant macular edema.[9]

Retinal detachments and retinoschises cause field defects, but since such defects commonly are located in the peripheral field, they often are not seen

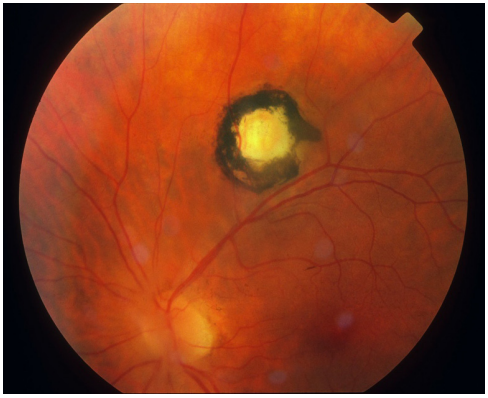
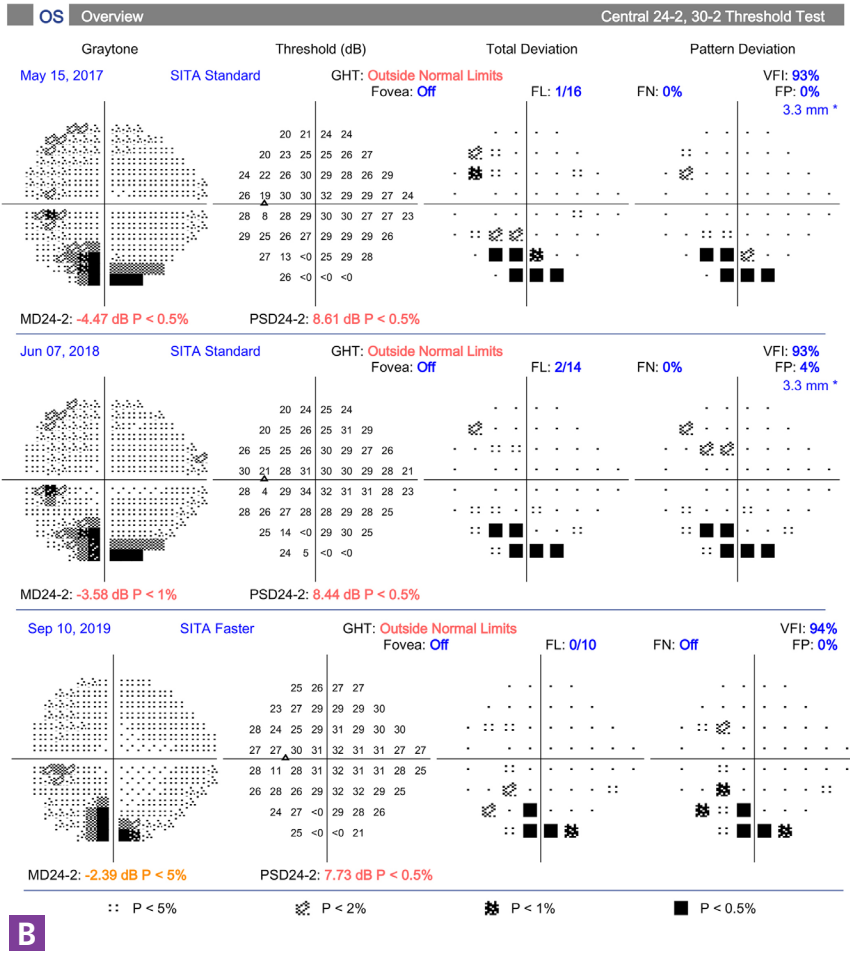


Figure 11-2

Visual field loss associated with retinochoroiditis in a patient being monitored because of ocular hypertension. Retinochoroiditis destroys the retinal nerve fiber bundles passing through it and can therefore result in arcuate field defects of the same type as those seen in glaucoma (A). Defects are deep and can be remarkably reproducible, often with sharp borders. The diagnosis is unlikely to be missed if the lesion is located close to the disc (B). Sometimes, in the absence of careful fundus examination, less obvious cases may be classified as glaucomatous.



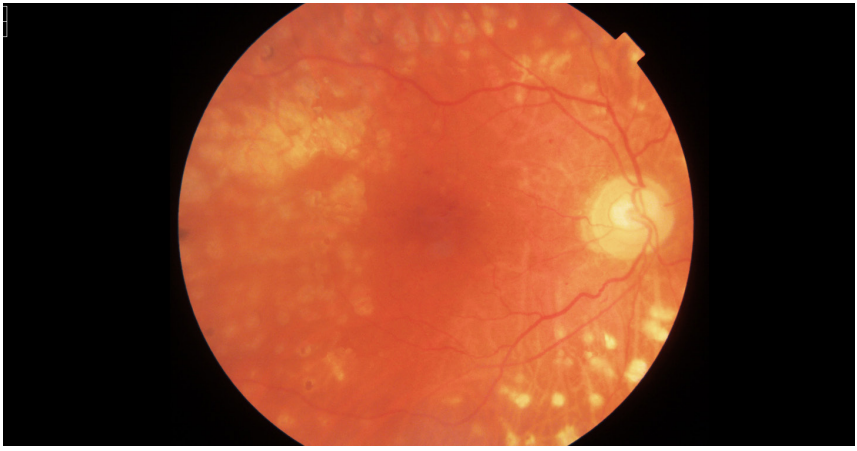
B

Figure 11-2 continued

in conventional central visual field testing. Retinal detachments will typically cause relative defects, while retinoschises produce absolute defects with sharp borders, because the inner and outer retinal layers are split apart.

Perimetry is often of value in diagnosing retinal degenerative diseases such as retinitis pigmentosa. Typical field loss in this disease is circular and initially located in the 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 24-2 or 30-2 threshold test may not be the best choice. A suprathreshold test that includes the peripheral field may be preferable, particularly because field defects in retinitis pigmentosa often are deep and easily identified.

Of course, retinal vascular occlusions are primarily diagnosed with ophthalmoscopy, but it is important when following patients with glaucoma, for instance, to understand what sort of defects can be caused by retinal vascular disease. 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 retinal vein occlusions may sometimes be associated with profound and widespread field loss.



A

Figure 11-3

Field defects associated with laser scatter therapy in diabetic retinopathy. After laser scatter treatment, the field defects are sometimes much more substantial than before the treatment.[10]

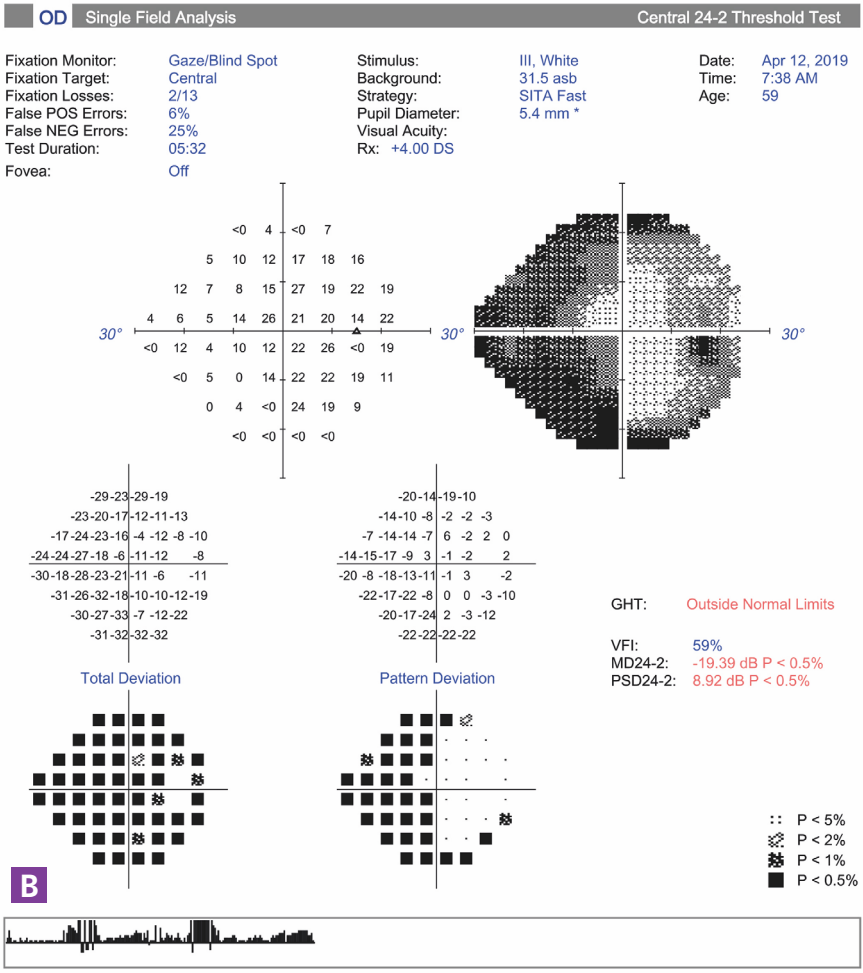


Figure 11-3 continued

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12

Artifactual Test Results

Because of testing artifacts, perimetric test results can sometimes suggest falsely abnormal or inaccurate findings. Fortunately, the patterns of such artifactual findings often are easily recognized. False patterns may be caused by such things as blepharoptosis, prominent brows, misaligned correction lenses, lack of proper patient instruction, inadequate patient supervision, patient inattention, or patient anxiety.

Artifactually false test results often occur in the more peripheral part of the tested visual field. Therefore, artifactual test results are less commonly seen in 24-2 fields compared to 30-2 tests. It is also fortunate that many of these effects can be remedied by more careful patient instruction and supervision.

Inexperienced Patients and Perimetric Learning

Some patients show *learning effects,* in which we see lower visual field sensitivity on their first perimetry test compared to subsequent testing.[1-4] Learning effects in normal fields are usually most obvious in the midperiphery, 20° to 30° from fixation, while the very central part of the field appears to be unaffected (Figure 12-1). In eyes with abnormal visual fields, learning effects may be larger than in normal fields and not limited to the midperiphery (Figure 12-2). Such midperipheral constrictions in normal and nearly normal fields are quite common in 30-2 test results (Figure 12-1) but are less common in the now more widely used 24-2 test pattern (Figure 12-3).

Learning effects seldom are so large that a test cannot be used as a follow-up examination and must be redone. However, use of such results as baseline fields may be unwise (Figure 9-7). First fields of perimetrically naive patients usually can be used in clinical care (see chapter 9). If tests showing a typical untrained pattern with midperipheral loss are repeated, results usually will improve, especially if the patient has been carefully reinstructed and supervised. A minority of patients may require more than one testing session before producing consistent results. Areas of reduced sensitivity associated with learning effects usually do not resemble defects caused by disease and are confusing only if not recognized as an artifact, or if they distract attention from genuine defects also present.

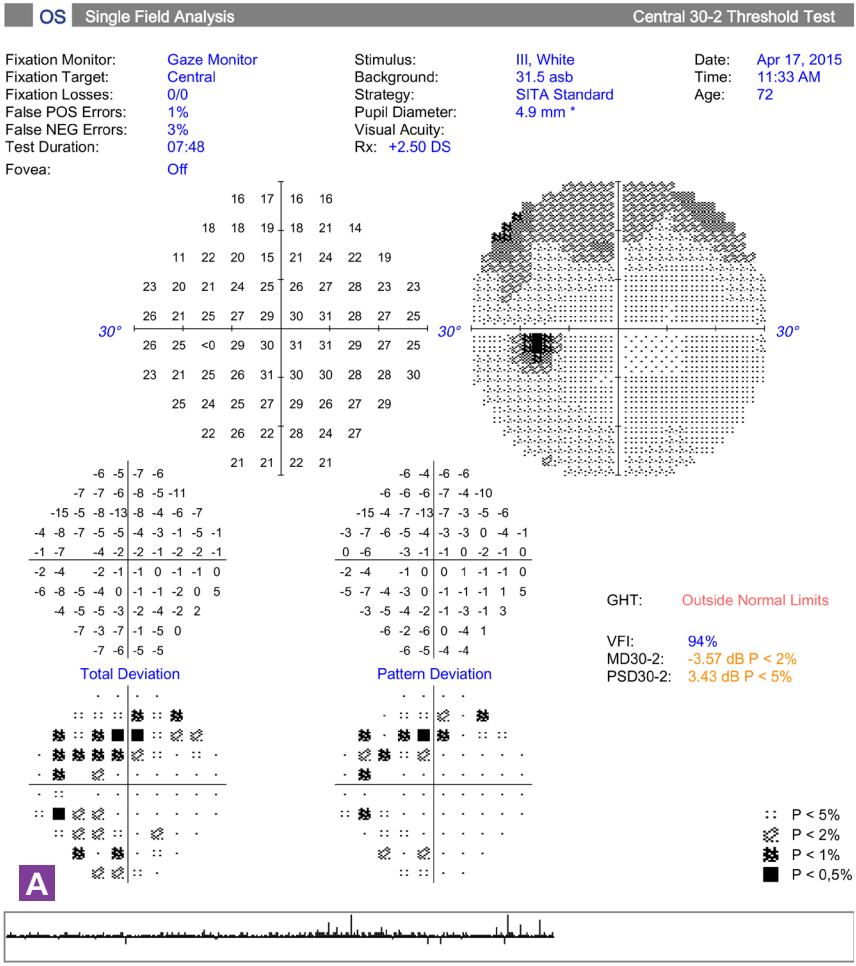


Figure 12-1

(A) Artifactual sensitivity losses, mainly in the midperiphery, associated with learning effects, in a perimetrically inexperienced patient. (B) Retest, in which some midperipheral loss has remained.

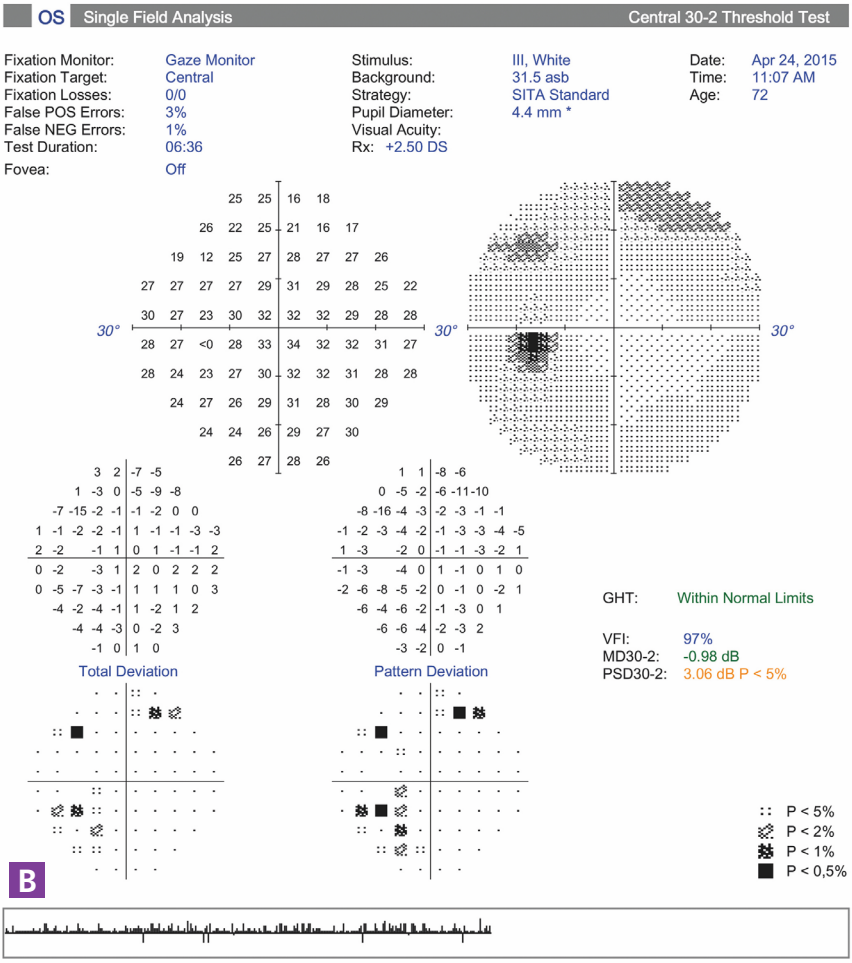


Figure 12-1 continued

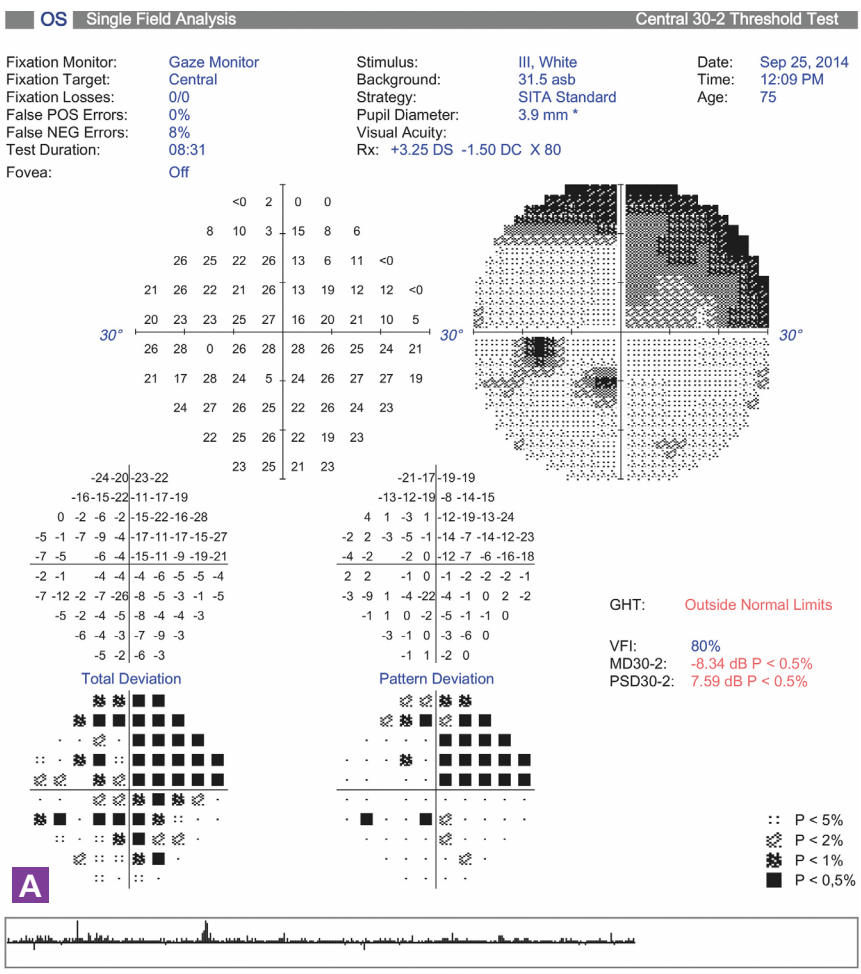


Figure 12-2

Learning effects in an eye with glaucomatous field defects. There is quite a large improvement between the first and the second tests, not limited to the midperiphery but also appearing more centrally.

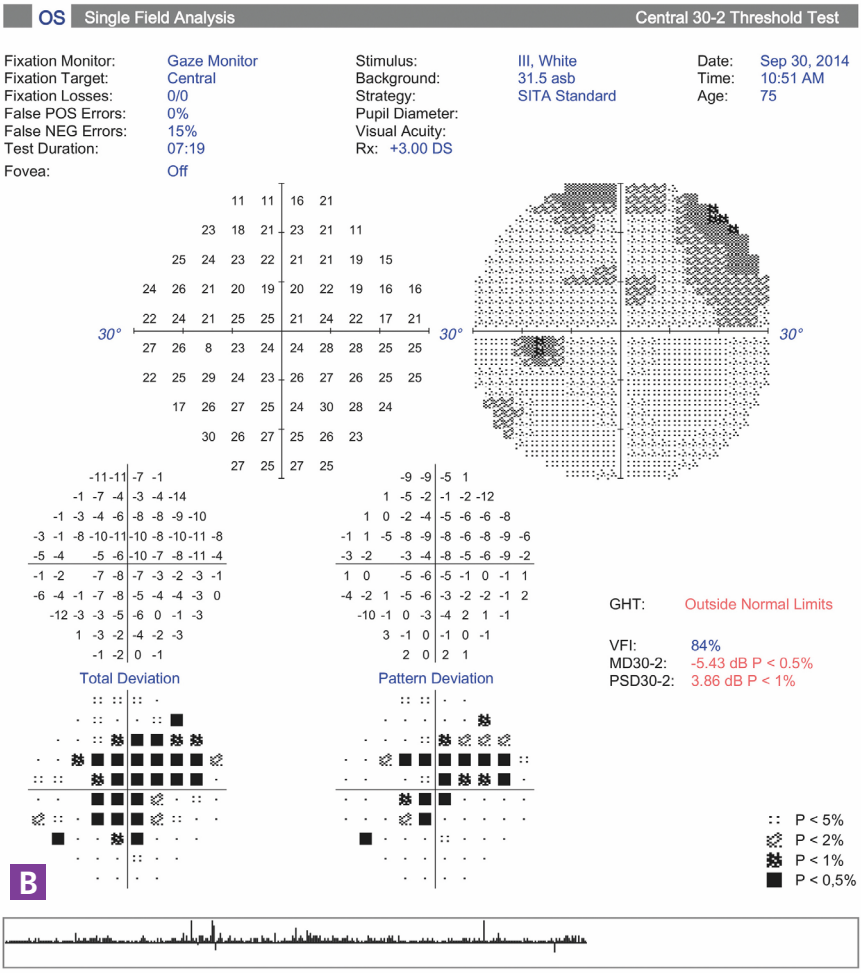


Figure 12-2 continued

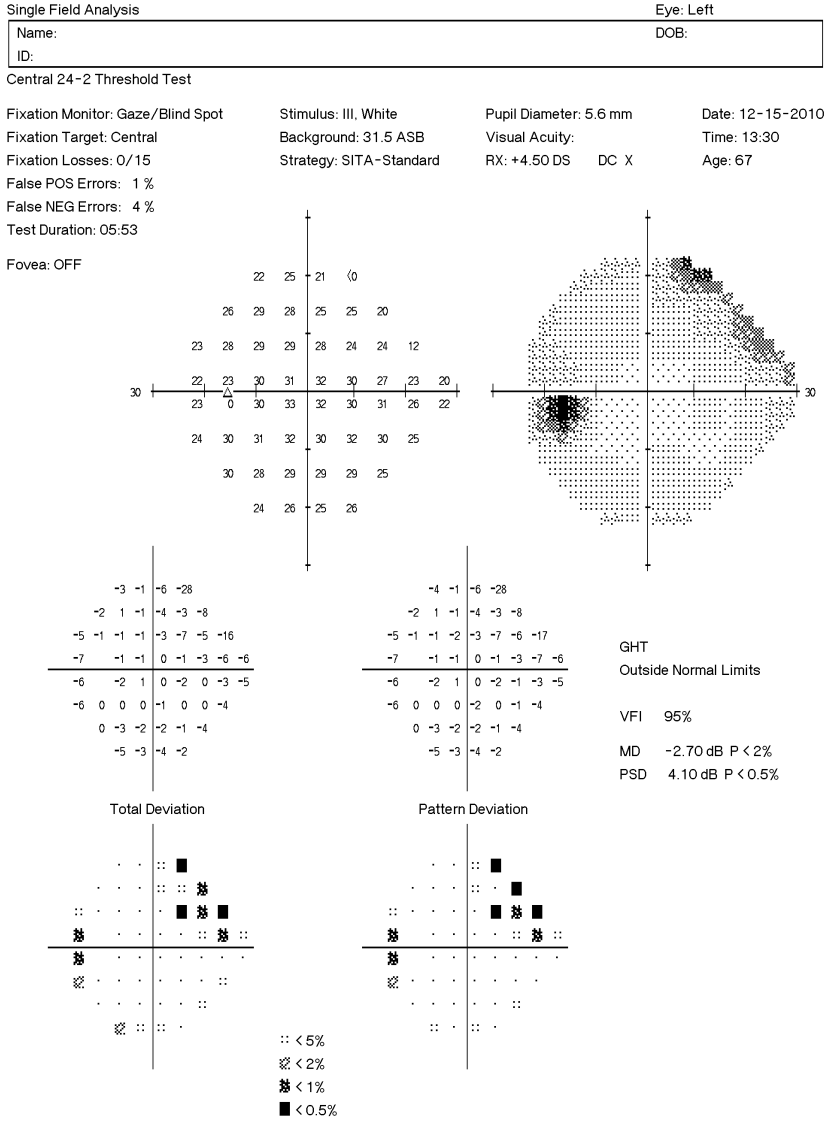


Figure 12-3

Learning effects in 24-2 tests. While learning effects seem to be less common with 24-2 tests than with 30-2, a minority of patients still may not produce entirely representative results on their first field examination (A). In such cases, it typically is the most peripheral test point locations that are somewhat depressed. A second test (B) shows only modest improvement.

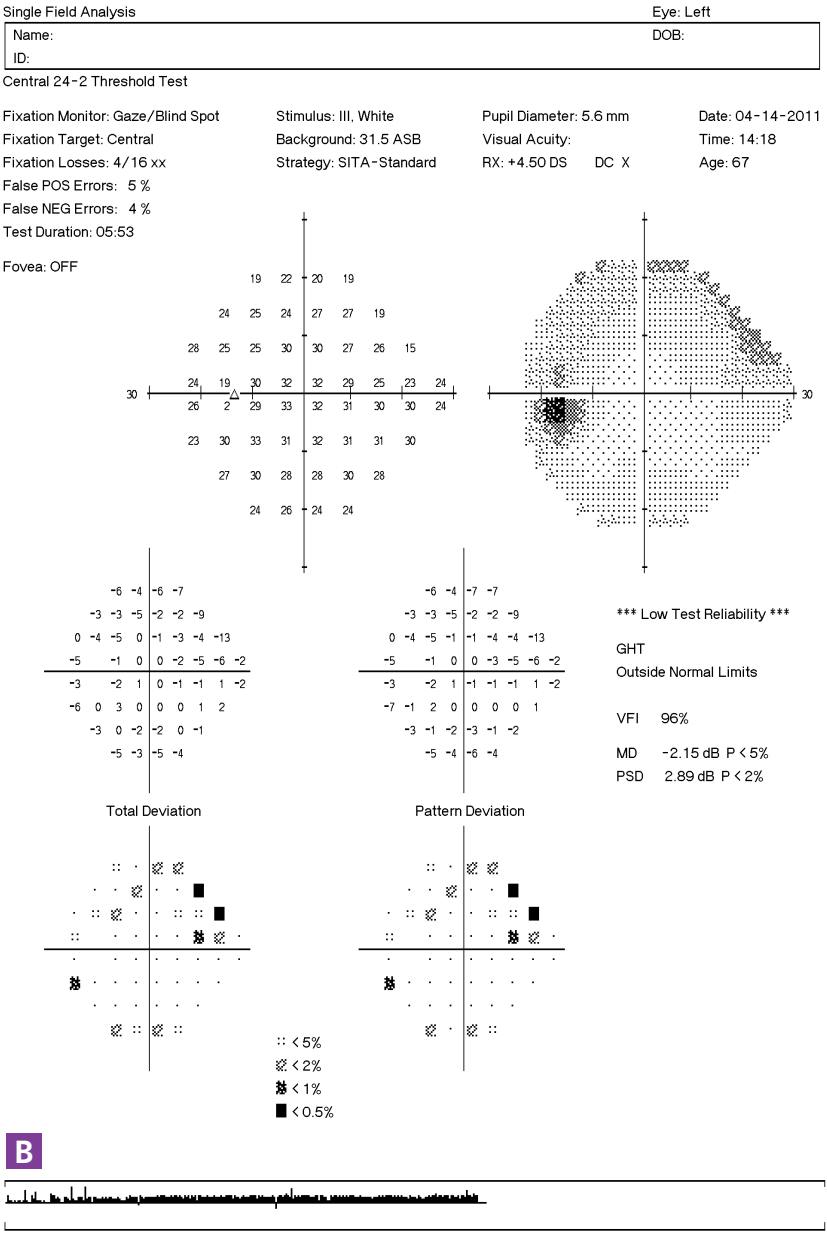


Figure 12-3 continued

Patient experience gained with one type of perimetric testing may not be directly transferable to another test modality, such as in switching from Frequency Doubling Technology visual field testing to standard Humphrey perimetry.

Eyelid and Brow Artifacts

Some degree of partial eyelid ptosis is quite common and may produce artifactual field defects. Such defects are much more common in 30-2 fields than in 24-2 fields and often are most apparent on the grayscale printout. Probability maps may not show artifacts caused by mild ptosis, simply because this type of pattern is normal and not uncommon and thus is allowed for in the normative limits (Figures 12-4 and 2-11). In patients with more marked ptosis or patients who have almost fallen asleep during perimetric testing, lid artifacts may occur also in 24-2 fields (Figure 12-5). If necessary, the upper lid may be temporarily elevated, for instance with surgical tape, in order to rule out other possible causes of such superior field defects. Perimetry is sometimes used to document ptosis effects prior to blepharoplasty (Figure 12-6).

Shading of the upper field by the brow rather than the eyelid sometimes occurs in deep-set eyes, but it can also occur as a testing artifact if the chin is not fully forward in the chinrest, effectively testing the patient while they are in up-gaze. This may happen if the perimeter has been adjusted to be too low for the patient.

Trial Lens Artifacts

Strong, positively powered trial lenses may magnify the visual field to the point that peripheral parts of the test pattern are obscured by the lens rim or the lens holder (Figure 12-7). More moderate positive lens corrections will simply increase the likelihood that small misalignments of the eye relative to the lens holder will result in blockage of peripheral test points. Conversely, negative lens corrections tend to reduce the likelihood of such artifacts, compared to plus lenses; however, any lens may create artifactual field loss if the patient is significantly misaligned or has moved back from the lens. Trial lens artifacts are less common in 24-2 tests than in 30-2 tests.

Trial lens artifacts usually are easily recognized if appearing in otherwise normal fields, as they most often involve a partial or complete ring of peripheral points having strikingly low sensitivities, which produces an organized false defect with sharp borders. Trial lens artifacts sometimes can be difficult to differentiate from real field loss in eyes with visual field damage.

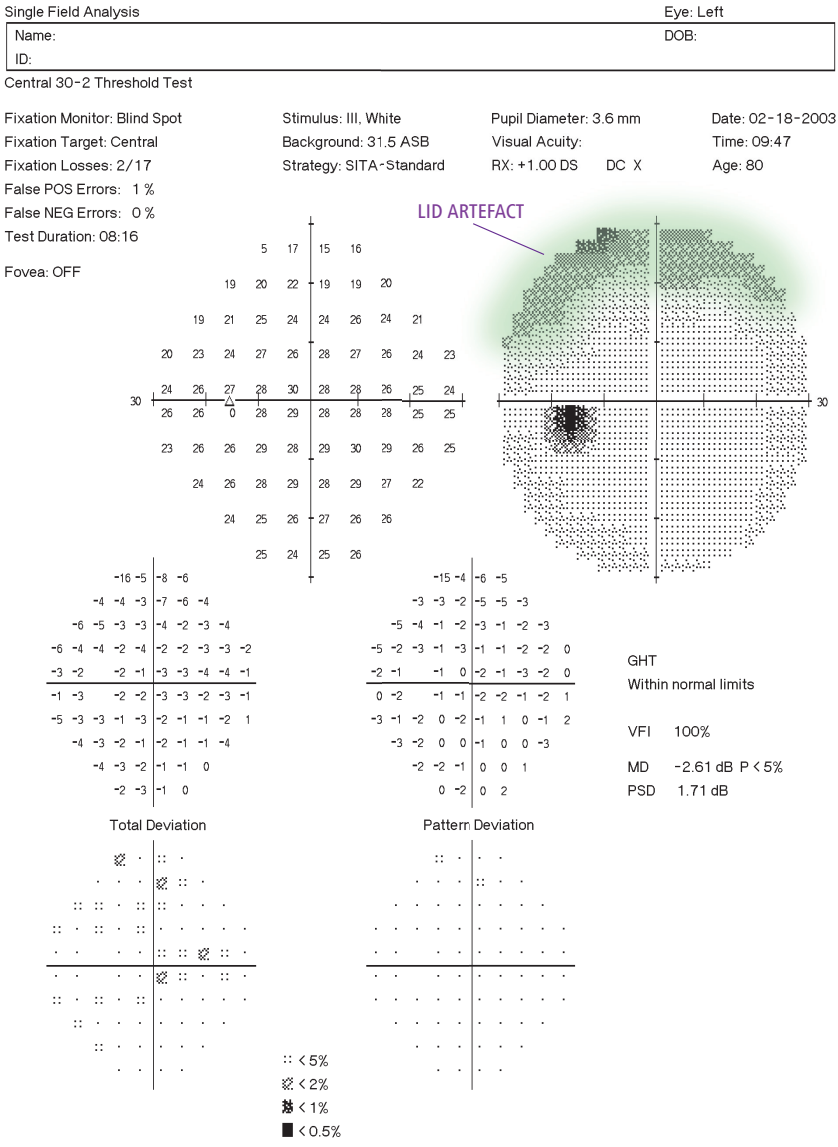


Figure 12-4

Visual field artifacts caused by droopy eyelids. Artifacts caused by a drooping upper eyelid are quite common in 30-2 tests, as seen it the grayscale map here. In fact, mild lid effects are so common that they usually are not indicated as being outside normal limits on probability maps, nor do they usually trigger such a finding on the Glaucoma Hemifield Test. In 24-2 tests, the uppermost row of 30-2 test points is not examined, and the frequency of apparent but false field loss due to droopy eyelids is lower.

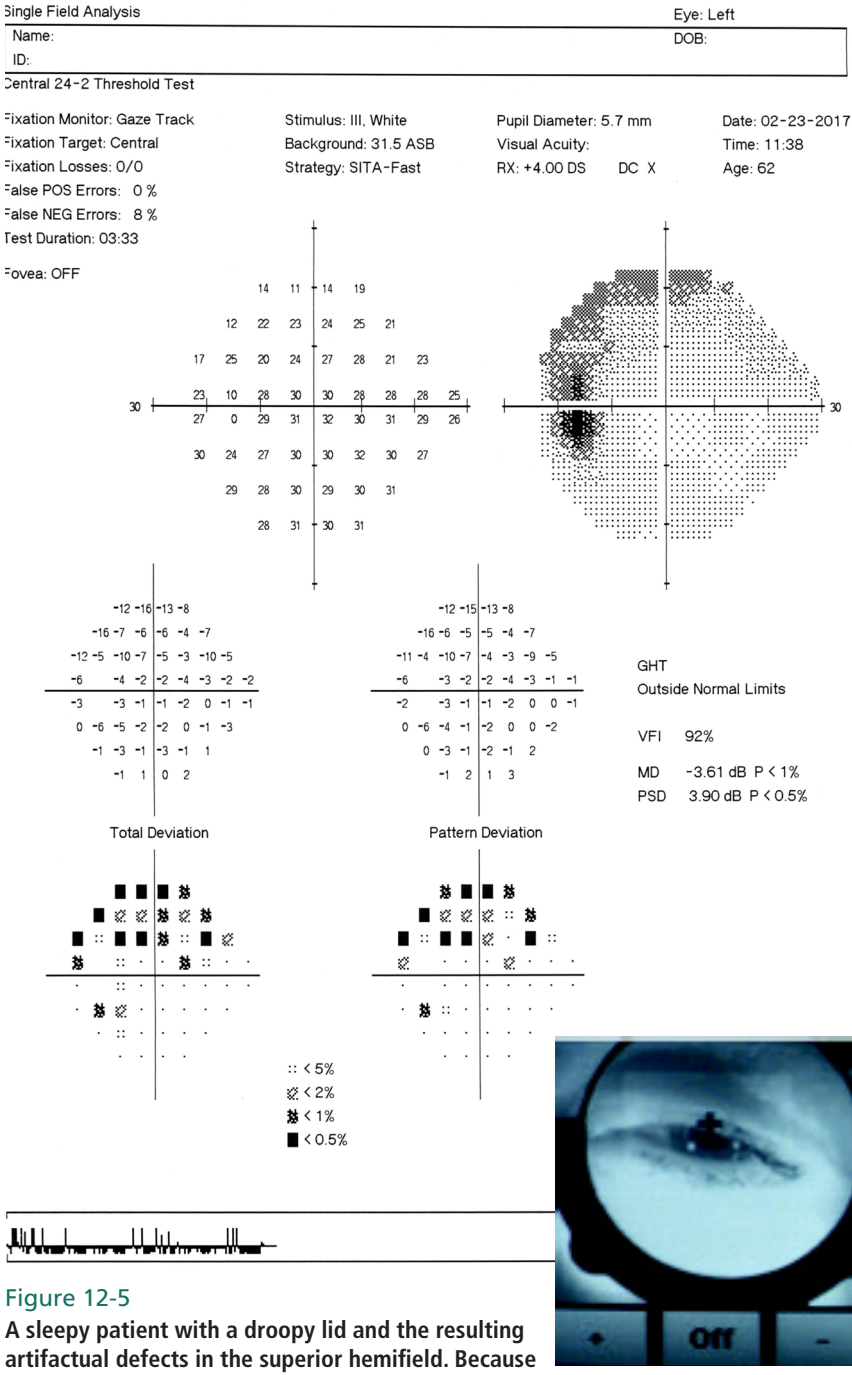


Figure 12-5

A sleepy patient with a droopy lid and the resulting artifactual defects in the superior hemifield. Because the sensitivity is markedly diminished, it is evident in the Total Deviation and Pattern Deviation probability maps, the Glaucoma Hemifield Test, and even in the Mean Deviation, Visual Field Index, and Pattern Standard Deviation global indices. The many small downward markings in the gaze tracker record indicate that the system was often unable to determine the direction of gaze, because of the droopy lid.

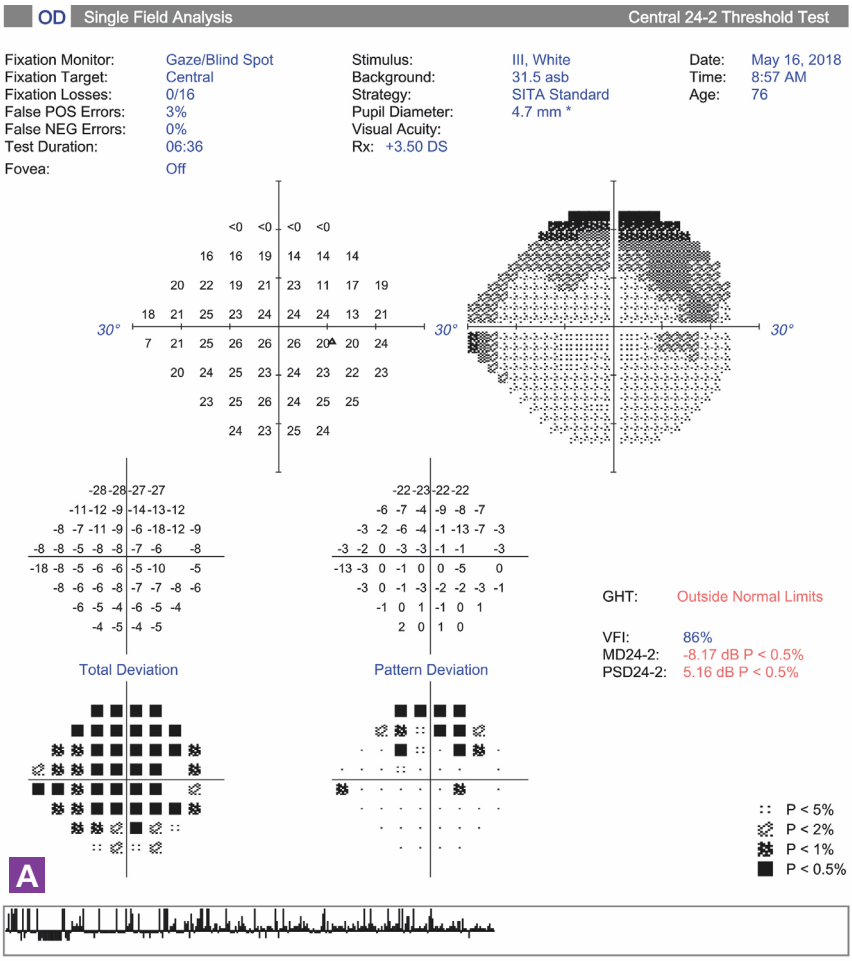


Figure 12-6

Field loss due to ptosis and cataract. (A) The Pattern Deviation map suggests considerable loss of superior visual field. Additionally, the Total Deviation map shows a generalized depression typical of media opacities such as cataract. (B) After blepharoplasty, while still awaiting cataract surgery, the superior field has improved. The second test's Total Deviation probability map also suggests that general visual field depression may have lessened, perhaps secondary to learning effects. Note that, in this case, the drooping eyelid does not seem to have affected gaze tracking results, perhaps because the Humphrey Field Analyzer's gaze tracker can function with only a partial view of the pupil.

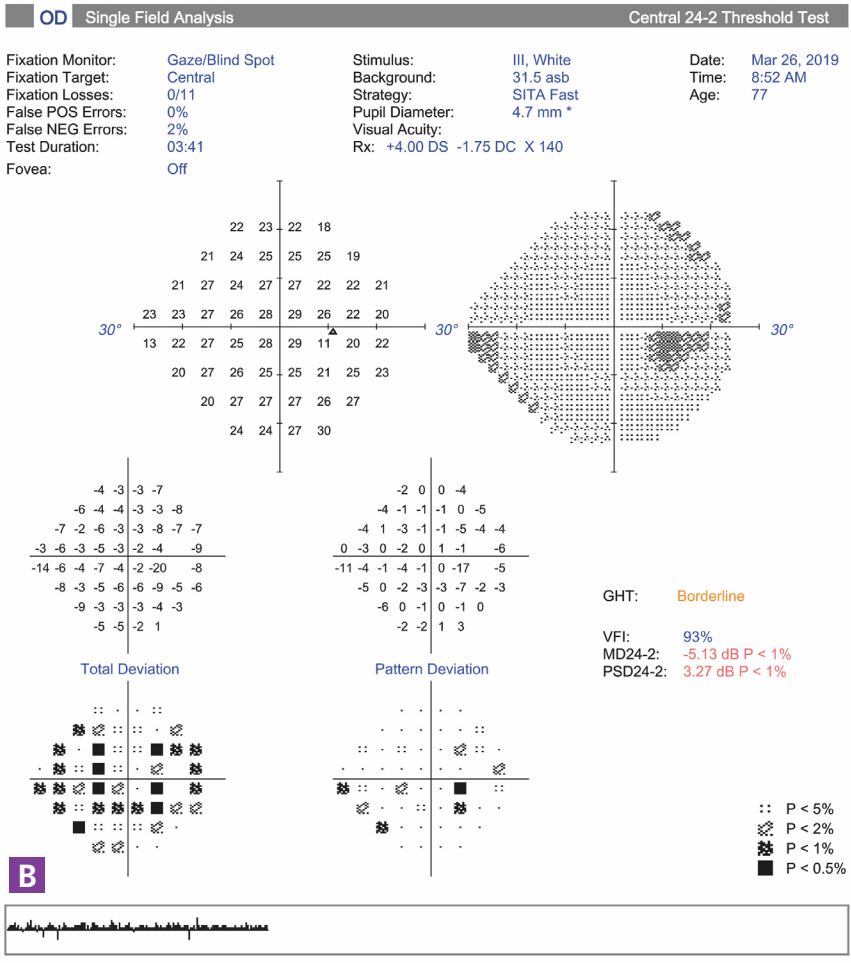


Figure 12-6 continued

Six millimeters of decentration of the eye relative to the lens center may produce a trial lens artifact when using a +3 D correction at a vertex distance of 15 mm. With a +10 D lens, less than 3 mm of decentration can be allowed at a vertex distance of 15 mm. More decentration can be tolerated at shorter-vertex distances and less at larger-vertex distances. Thus, it is generally good practice to place trial lenses as close to the eye as is practical, with the limiting factors usually being the brow and the eyelashes. Trial lens artifacts are likely to disappear upon further testing if the patient is carefully reinstructed and well supervised.

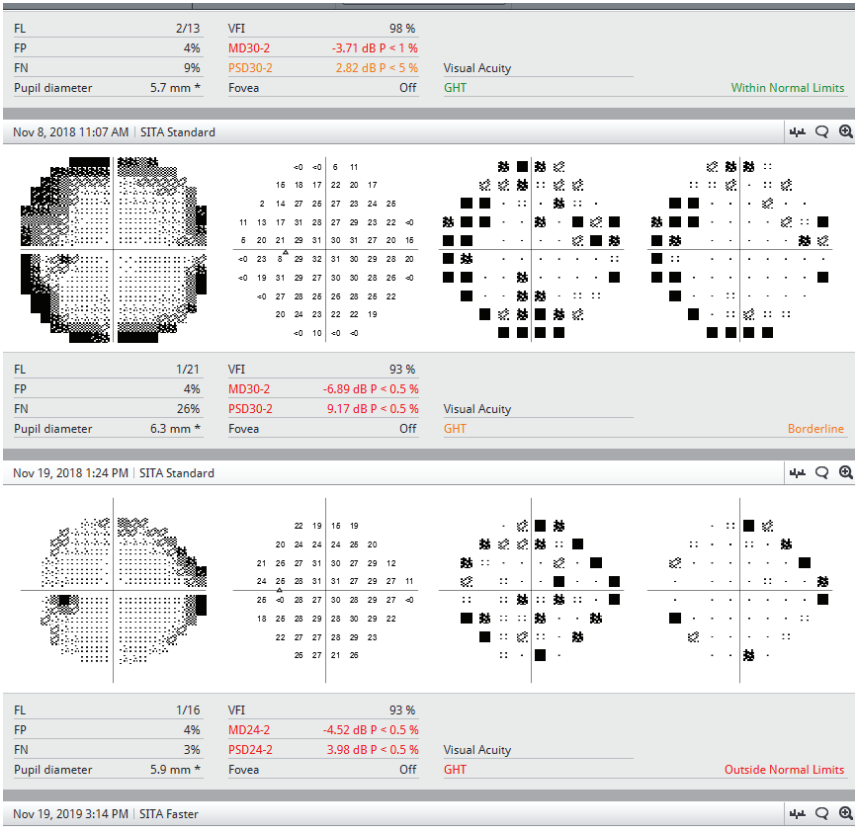


Figure 12-7

Trial lens artifacts in a highly hyperopic patient. Switching from 30-2 to 24-2 and close monitoring of the patient on a subsequent testing session greatly reduced the artifact.

The Inattentive Patient and the Cloverleaf Field

The cloverleaf field is a very characteristic artifactual pattern associated with increasing patient inattention as the test proceeds (Figure 12-8). This pattern occurs when the patient has responded more or less normally during the very first part of the test but then has given up, perhaps as a result of misunderstanding or insufficient supervision. The patient may have wished to ask the operator for a rest, or whether the test was over, or how to respond. However, if the operator was no longer in the room, the patient may not have known what to do and may have decided to do nothing.

If you see many cloverleaf fields in your practice, your staff may need more training in how to instruct and supervise perimetric patients. Some patients may simply need a word of encouragement, such as "Okay. Good. Keep going."

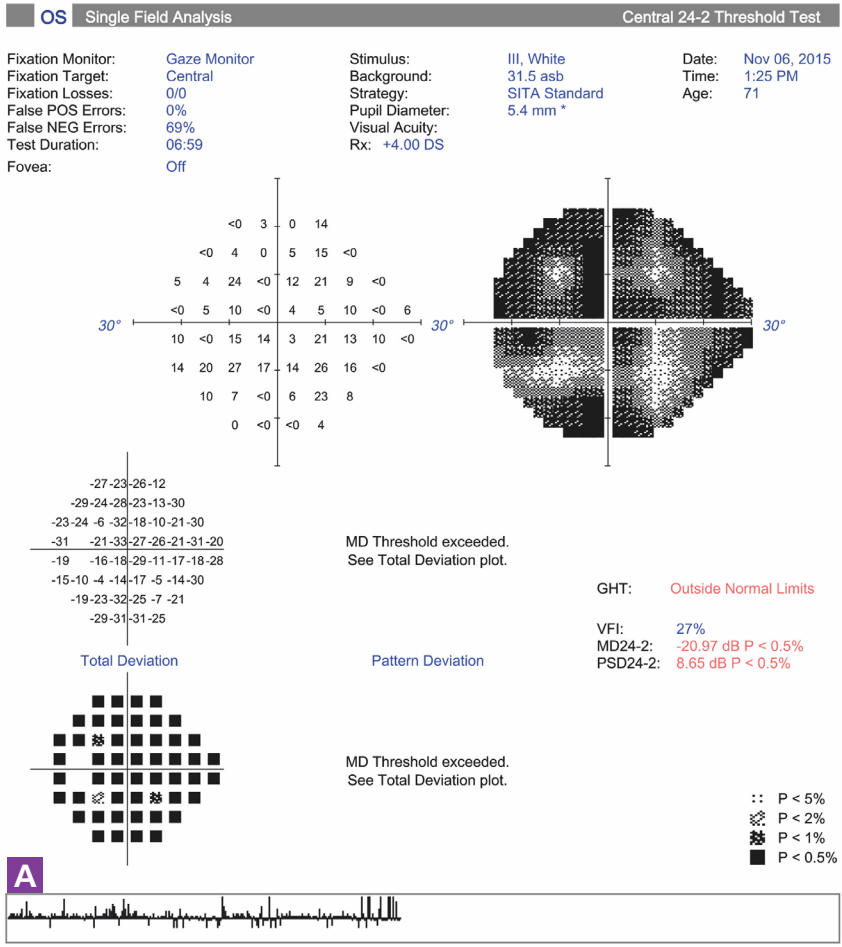


Figure 12-8

(A) A characteristic cloverleaf field, in which the patient stopped responding soon after the beginning of the test. (B) Threshold testing begins at the four primary points (labeled 1), one point in each quadrant. In order to save testing time, initial stimulus intensities presented at secondary test points (labeled 2) are based upon the measured sensitivity at adjacent primary points, and so on. The pattern shown in Figure 12-8A appears if the patient gives up soon after the primary points have been tested. (C) After reinstruction, a second field test gave a very different result, and a superior paracentral scotoma was uncovered. However, the retest also seems to show an inferior trial lens artifact. Perhaps these two fields together suggest that this patient may need closer attention during future testing.

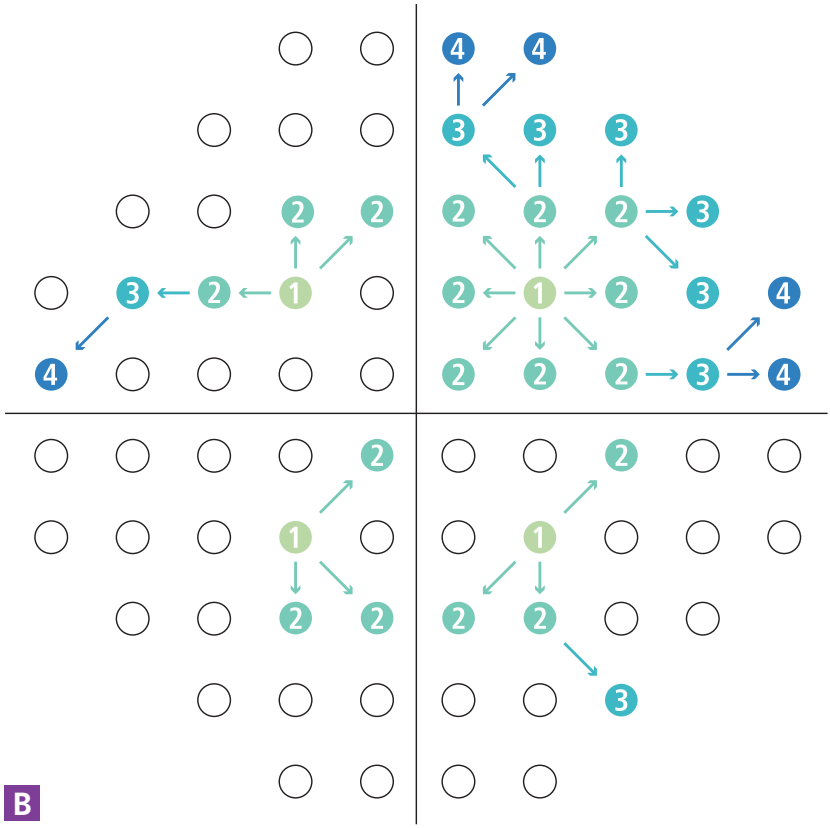


Figure 12-8 continued

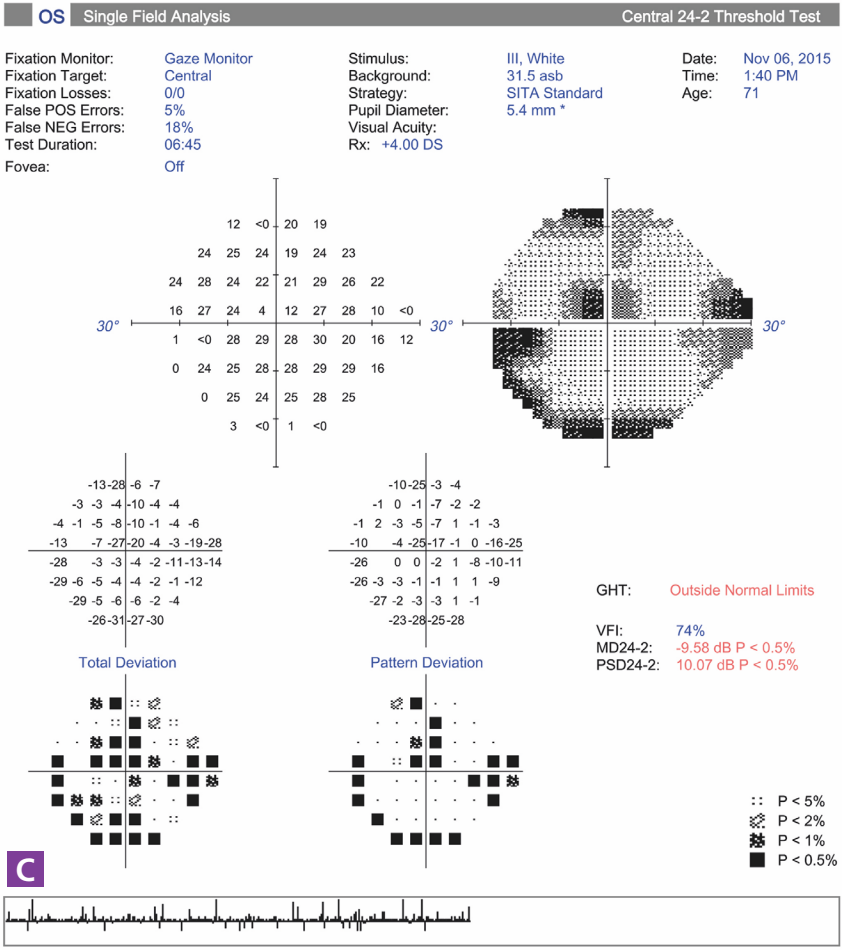


Figure 12-8 continued

The Trigger-Happy Field

Some patients, particularly if they are anxious or impatient, may press the response button even when the stimulus is too dim to be seen, resulting in large numbers of false positive, or "trigger-happy," responses. Trigger-happy responses can artificially raise measured threshold sensitivities to levels beyond the range of human vision. In such cases, the Pattern Deviation probability map may artifactually show more defective test points than are seen in the Total Deviation map, thus obscuring the actual pattern of any visual field loss that may be present. Mean Deviation may also be artificially elevated, either compared to normative limits or compared to the patient's earlier visual field tests.

As discussed in chapter 5, high False Positive (FP) rates are certainly associated with compromised test results, but it is not an absolute relationship. It is common to have useful test results with FP rates higher than the commonly used upper limit of 15% (Figure 5-6). Thus, an elevated FP rate is a signal to look more closely for confirmatory findings suggesting that test results may have been compromised, and it is not necessarily a sign compelling us to discard the test result.

Be alert to the qualitative signs of trigger-happy patient behavior, as illustrated in Figure 12-9, regardless of the FP rate. Except at the fovea, the eye cannot see Size III stimuli of 40 dB or more, and findings of such sensitivities must be viewed as clear evidence of false positive patient responses. Such non-physiological test results appear in the grayscale analysis as "white scotomas," such as the one shown above the blind spot in Figure 12-9. The Glaucoma Hemifield Test will present a message saying "Abnormally High Sensitivity" when sensitivity levels at the most sensitive test points exceed the level found in 99.5% of normal subjects. Excessive false positive patient responses can artifactually produce many more defective test points in the Pattern Deviation probability plot than are seen in the Total Deviation plot; this is called an "inverted or reversed cataract pattern," because it typically looks like the mirror image of the expected finding in a patient having cataract. Absence of the physiological blind spot in the grayscale map also is associated with false positive patient responses; however, this is not a strong relationship. More subtle examples of trigger-happy fields are shown in Figures 12-10 and 5-4.

When one encounters a trigger-happy test result, one should reinstruct and retest the patient and then supervise the patient more closely than usual during the retesting process. It may be helpful to tell the patient that it is not necessary to respond quickly, because the machine will wait a certain length of time for a response before moving on with the test. The patient should not respond just because they think it is time for another stimulus, but only when he or she is reasonably sure that there was a visible flash of light.

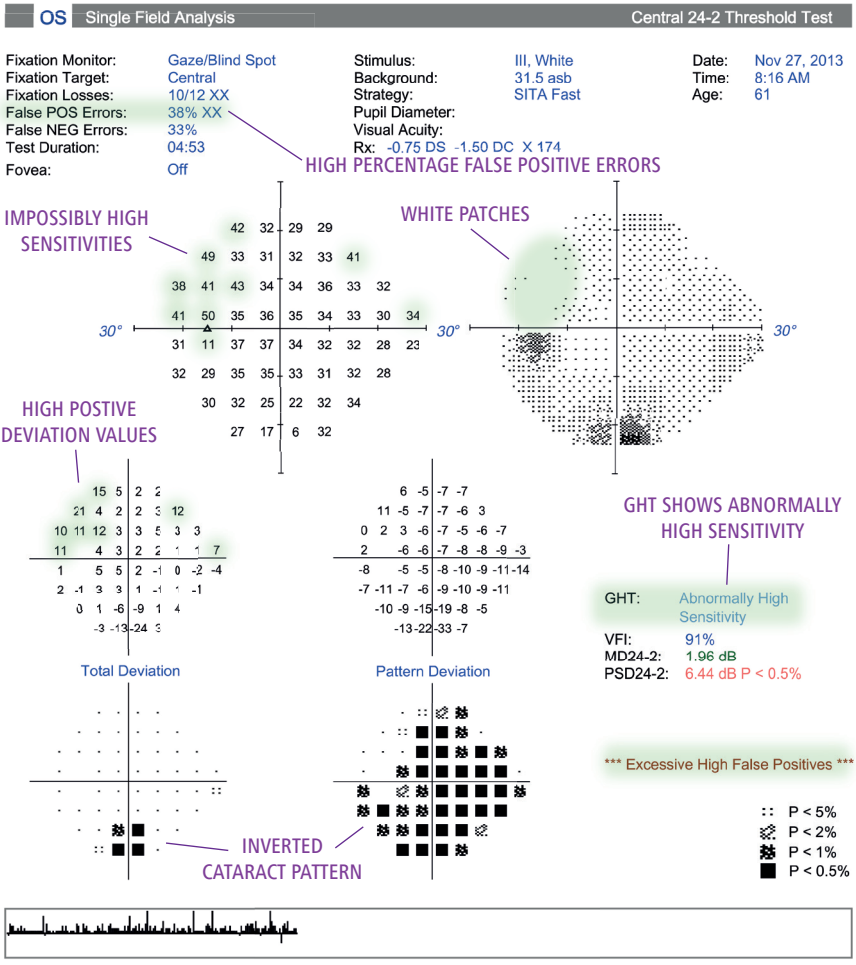


Figure 12-9

Effect of false positive responses. This so-called trigger-happy field was caused by a high number of False Positive responses by the patient. In this example, four distinct signs are present that are commonly associated with high levels of false positive patient responses: (1) At 38%, the false positive error rate is very high and has resulted in a printed message saying "Excessive High False Positives." (2) Many measured threshold sensitivities are above the eye's physiological limits, with values of 10 or 20 dB above age-normal in the numerical Total Deviation map, threshold sensitivity measurements ≥ 40 dB, and white patches in the grayscale map. (3) The Glaucoma Hemifield Test shows a message saying "Abnormally High Sensitivity." (4) There is an "inverted cataract pattern" in the probability maps, in which there are many more significant points in the Pattern Deviation probability map than in the Total Deviation probability map. A fifth sign, absent in this example but sometimes seen, is that the physiological blind spot is not indicated on the grayscale plot.

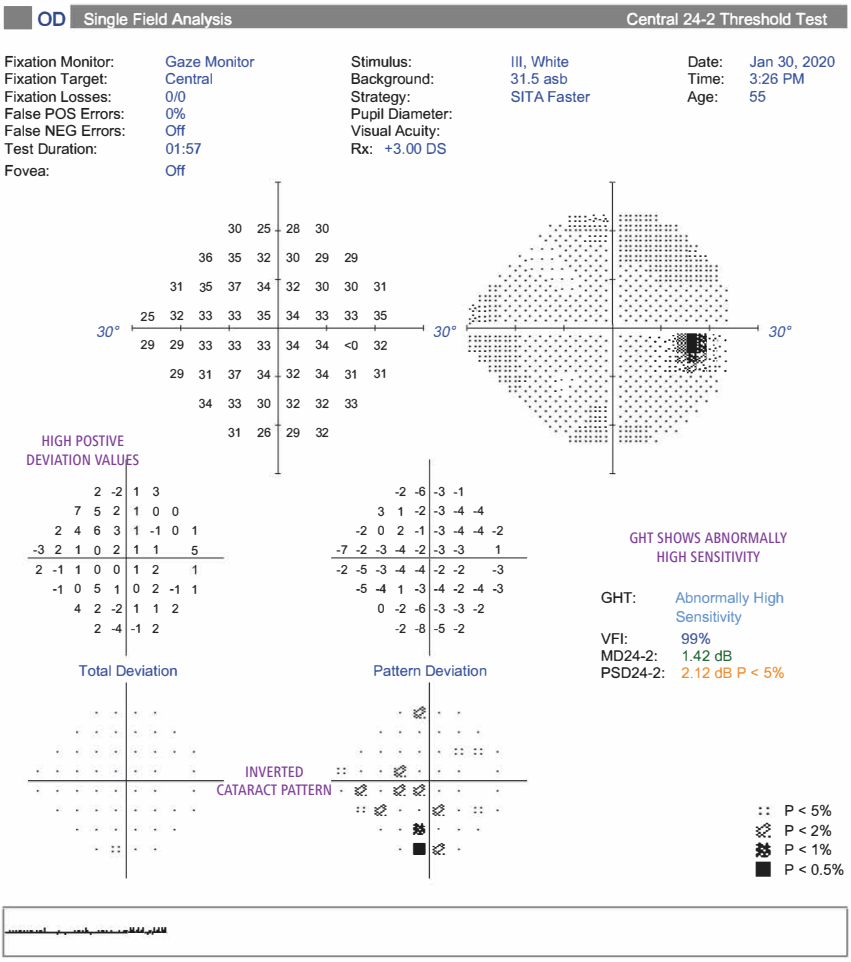


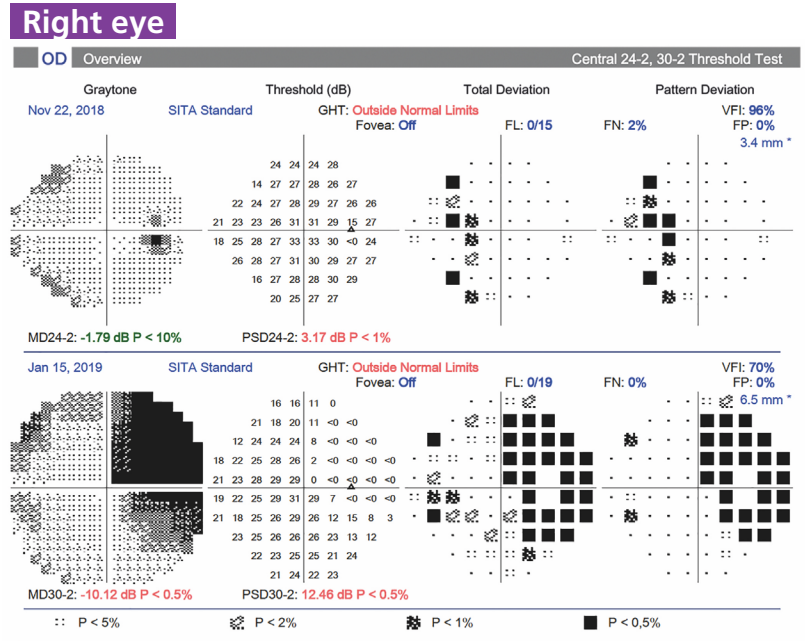
Figure 12-10

A subtler example of what probably is a trigger-happy field, compared to Figure 12-9. Although the False Positive rate is zero, this test result shows three signs that the results may have been adversely affected by trigger-happy behavior: (1) The Pattern Deviation probability map is worse than the Total Deviation map (the "inverted cataract pattern"). (2) The Glaucoma Hemifield Test analysis has flagged the test as having abnormally high sensitivity, meaning that measured thresholds at the most sensitive test points have exceeded the age-corrected sensitivities seen in 99.5% of normal subjects. (3) The Total Deviation map shows five test points that are 5 to 7 dB above age-normal sensitivity. While some might argue that this might be a legitimate "super normal" test result, we advise reinstructing and retesting such a patient.

Sudden and Unexpected Change

We know that it is not unusual for eyes that have potentially blinding eye disease to show progressive visual field loss. The most common example is glaucoma, of course, but there are many other such conditions, such as pituitary tumors and retinal dystrophies. However, large observed changes between two consecutive fields may not be the result of progression of the original disease but instead the result of some new condition. For example, a sudden and large visual field change in a glaucoma patient might be due to a stroke (Figure 12-11), or perhaps a retinal vascular occlusion. Stroke can be suspected when the new field loss respects the vertical meridian, but this may be difficult to detect if there already is considerable glaucomatous field loss. If the damage is postchiasmal, 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.

In any case, it is wise to consider and rule out other unexpected disease any time a repeatable large and sudden field progression is observed when following a patient who has a chronic disease.



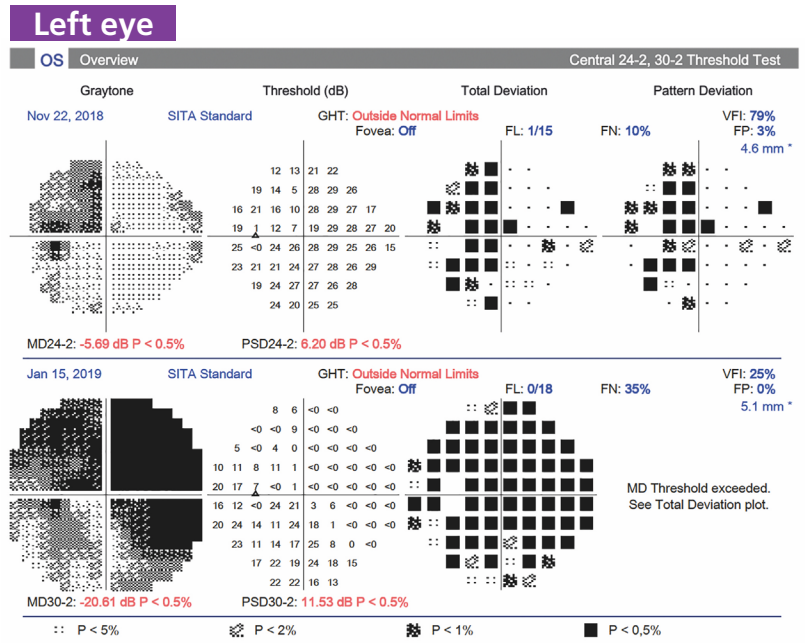


Figure 12-11

Stroke in a patient with glaucoma. This 88-year-old female patient had been followed for bilateral glaucoma for many years. On one follow-up visit, her fields suddenly appeared much worse, due to a left-sided occipital infarct. Sudden field loss is not typical for glaucoma, and such cases are not diagnostically difficult when both eyes have identical new defects.

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13

Perimeter Design

THE HUMPHREY PERIMETER CONSISTS of four basic elements: the bowl, or stimulus projection surface, the optical system, the computer system, and the patient interface. In designing the Humphrey Field Analyzer (HFA), our overall goal was to combine accurate and consistent perimetric testing with ergonomic features that provide as much patient comfort as possible.

The Bowl

HFA2 and HFA3 bowls provide an aspherical or bullet-shaped white surface upon which stimuli are projected (Figure 13-1). This is a departure from classic 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 in the original Goldmann perimeter. The amount of asphericity was chosen so that the surface departs insignificantly from the traditional spherical shape in the central 30°, thus providing very close agreement between modern HFA test results in the central visual field and those of the original Humphrey perimeter, now known as HFA1.[1] This curvature also was chosen to ensure 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. Stimulus intensity outside the central 30° is adjusted to compensate for the difference in testing distance between the aspherical bowl and traditional hemispheric designs. While this adjustment is only an approximation, the amount of compensation is small compared to typical measurement precision.

The bowl surface is textured to provide an almost perfectly matte finish; this is known as a Lambertian surface. Lambertian surfaces are the opposite of mirrors. They 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.

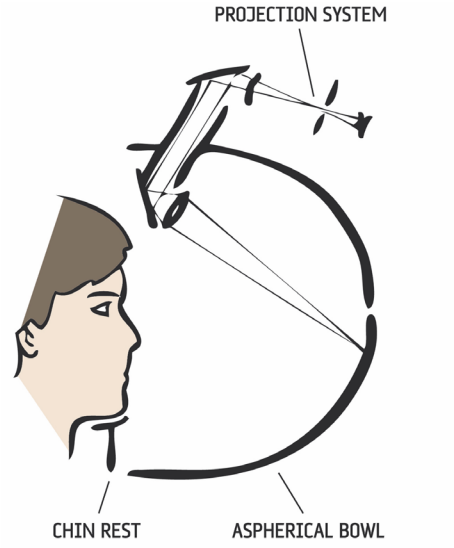

Figure 13-1
Aspherical bowl. The bowl of the Humphrey Field Analyzer is aspherical and bullet-shaped, thus making the perimeter more compact and ergonomic, without compromising the physical requirements of perimetric testing.

The Optical System

The HFA optical system projects stimuli of known size and intensity at a known location for a known amount of time. Stimuli are projected onto a bowl that is uniformly illuminated at a standard intensity. All five standard Goldmann stimulus sizes (I through V) are available, although most testing is done using a Goldmann Size III stimulus. Stimuli are presented by aiming an optical projector at the particular location to be tested, adjusting a set of neutral density filters to obtain the correct stimulus intensity, and then opening a shutter for a standard time period, usually 200 milliseconds. Mechanical motions are constantly monitored by built-in electronics in order to detect any motor failures during testing.

Background intensity—the brightness of the bowl surface itself—is checked at the beginning of each test, and constantly during testing, to adjust for any changes in room illumination. Stimulus intensity is checked every time the instrument is started up. Stimulus intensity is then finely adjusted just before each stimulus is presented, based upon the local background intensity measured at each test location. This fine adjustment is done with the goal of correcting stimulus contrast for any local variations in bowl brightness.

The Computer System

The HFA's computer controls instrument calibration checks, error checking, testing strategy, data analysis protocols, and printing, as well as electronic

transmission and storage of test results. In some cases, data storage and printing may be done using a separate computer. The graphical user interface may be controlled via the instrument's touch screen or via mouse and keyboard.

As with all computers, the HFA is vulnerable to data loss, and all clinical data must be safeguarded by frequent backup. Current HFA models may be networked via Ethernet connection, using Zeiss's Forum software (Figure 13-2). Forum facilitates transmittal of results to a centralized database that can be shared with other Humphrey perimeters and also can store results from other Zeiss products and other Digital Imaging and Communications in Medicine (DICOM)–compatible devices, such as retinal cameras or optical coherence tomography devices (chapter 8). Backup of the centralized database may then be managed in the context of clinic or hospital general data

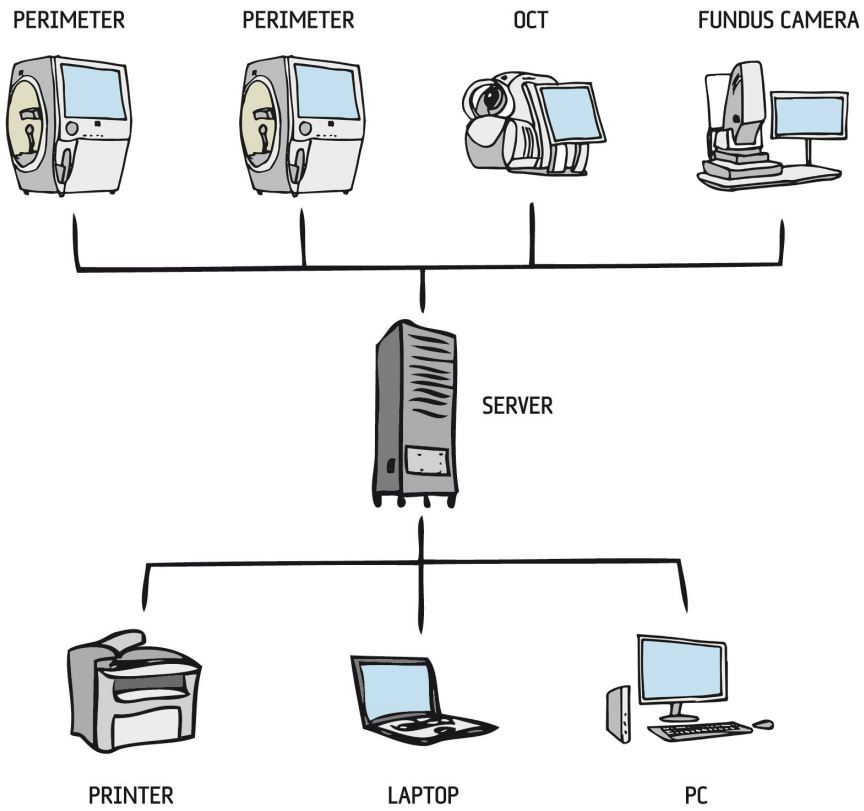

Figure 13-2

Zeiss Forum software facilitates connection of multiple HFAs and other DICOM-compatible products to a common server, allowing storage and backup of test results and reports as well as analysis of test results using Zeiss's Glaucoma Workplace software on a PC or laptop (chapter 8).

backup processes. Using Forum and Glaucoma Workplace software offers distinctive advantages in clinical management (see chapters 8 and 9).

Ergonomics and Patient Comfort

Patient comfort is even more important for perimeters than for instruments such as autorefractors or slit lamps. Autorefraction may take only a few seconds and does not require the patient to concentrate on properly performing a task. Slit lamp examination takes longer than autorefraction but usually is brief compared to visual field testing of both eyes. Comfort is driven by multiple factors, including patient sitting posture during testing, patient response button design, and the amount of time required for testing.

Proper patient interface design improves patient comfort and satisfaction, and also patient alertness, and compliance. For all these reasons, HFA was designed to maximize patient comfort. The bullet bowl minimizes instrument size and allows patients to be rolled right up to the perimeter and to be tested while sitting comfortably upright (chapter 4). Instruments having larger bowls are bulkier, and some patients may not be able to reach the chinrest without having to lean forward uncomfortably. The HFA instrument table was designed to allow wheelchair patients to be rolled into testing position, again without having to lean uncomfortably forward or to stretch to reach the chinrest.

The patient response button was designed for maximum comfort for elderly patients. In those whose fingers have been weakened, for example by arthritis, the button can even be secured, for instance with surgical tape, directly to the perimeter's tabletop or the armrest of the patient's chair and then pressed by the patient with a closed hand.

Quick and efficient testing algorithms reduce patient fatigue and improve patient experience, with the goals of improving clinic workflow and increasing patient comfort and willingness to undergo routine automated perimetry testing. When automated visual field testing was introduced more than 40 years ago, testing could take 20 minutes per eye. Today, testing sometimes can be done in under 2 minutes, and with the recently developed SITA Faster algorithm, testing time generally ranges between 2 and 4 minutes.

In Conclusion

The Humphrey perimeter has been designed to be simple and intuitive for operators to use, and comfortable and quick for patients. This level of performance has only been accomplished through continuous and persistent efforts spanning four decades.

References

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