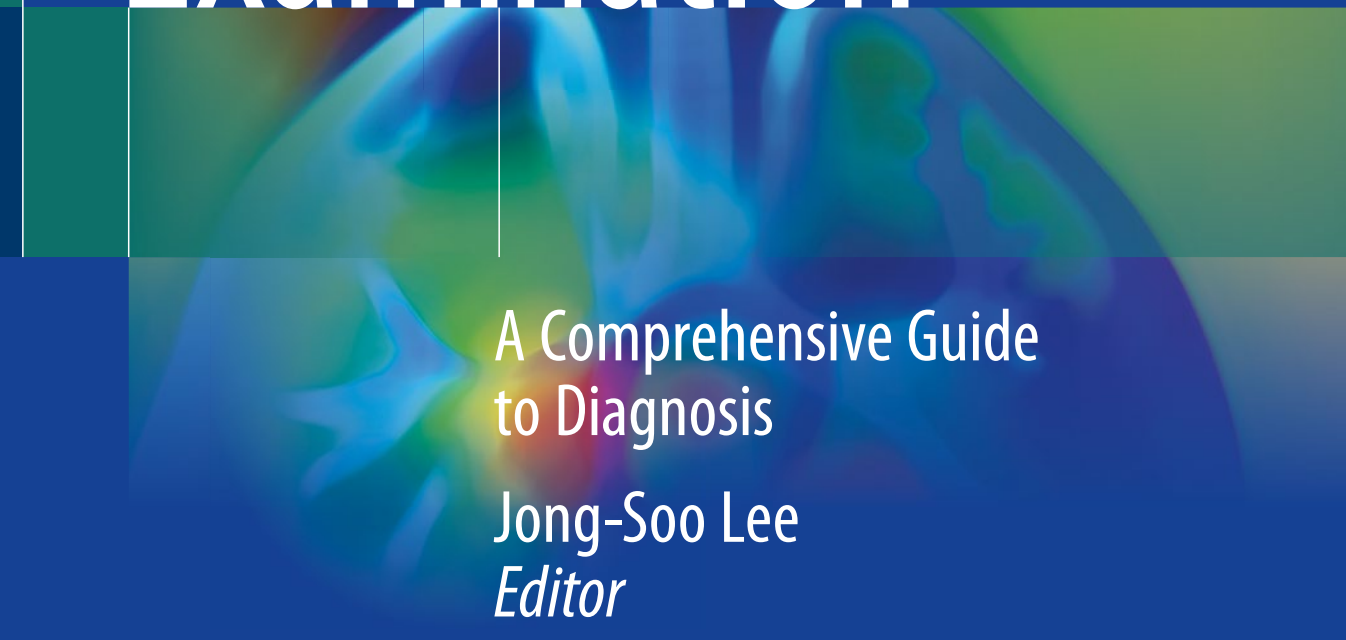
Primary Eye Examination



A Comprehensive Guide to Diagnosis

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Contents

Visual Acuity Test

1

Ji-Eun Lee

The visual acuity test is the best way to show the status of eye. It includes uncorrected and corrected visual acuity, distant and near visual acuity, binocular and monocular visual acuity, decimal and fractional visual acuity, visual acuity measured with one and parallel object, logMAR (minimal angle of resolution) visual acuity, and central and out-of-central visual acuity. In general, visual acuity is the central visual acuity when viewed from the foveola. The visual acuity in ophthalmology refers to the corrected visual acuity which is the corrected visual acuity measured by refraction. If the uncorrected visual acuity is poor and the corrected visual acuity is good, the refractive error should be considered. If the corrected visual acuity is bad, a pathology from the eye to the central nervous system should be considered. The appropriate visual acuity test should be selected and recorded according to the subject and purpose. If the patient has the history of using contact lenses, cataract surgery, or LASIK surgery, record them on your visual acuity chart.

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1.1 Distant Vision Test

1.1.1 Indication

It is possible to examine at 3 years of age or older. At 3–8 years of age, the visual acuity is measured higher when using single object chart than the parallel chart. That is, all persons who can read the target in the visual acuity chart are all candidates.

1.1.2 Purpose

The causes of visual impairment include refractive errors and eye diseases involving visual pathway. The refractive error can be improved by correction, but for the cases of eye diseases, it is difficult to improve the visual acuity only by correcting the refractive error. Therefore, visual acuity test can be a great help in determining the cause of vision impairment.

1.1.3 Method

1.1.3.1 How to Represent Visual Acuity

The minimum separable visual acuity represents the ability to distinguish between two points or two lines. The angle formed by these two points or two lines on the eye is called minimum visual angle and is indicated by visual acuity. In other words, the angle formed by the two straight lines

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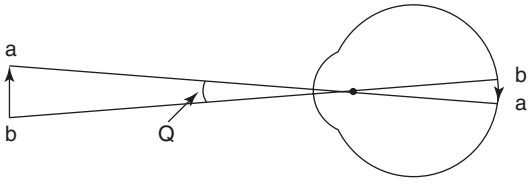


Fig. 1.1 The reciprocal of the minimum visual angle is visual acuity. If the visual angle *Q* is 2 minutes, the visual acuity is 0.5

from the two points of the object under consideration to the nodal point of the eye is referred to as the visual angle, and the size of the retinal image is determined thereby. The closer the distance of the same size object is from the eye, the closer the visual angle becomes. The larger the size of the object at the same distance, the larger is the visual angle. Visual acuity is represented by the reciprocal of visual angle, visual acuity = 1/visual angle (minute) (Fig. 1.1).

1.1.3.2 Visual Acuity Chart

The visual acuity chart includes a decimal visual acuity chart, a fractional visual acuity chart (Snellen visual acuity chart), and a logMAR chart. The devices of the visual acuity chart include reflection type, transmission type, and projection type.

The decimal visual acuity is 0.1 intervals from 0.1 to 1.0 and 1.2, 1.5, and 2.0 afterward. Because it is expressed as a reciprocal of the minimum visual angle, the arrangement does not show the same interval. 0.1 and 0.2 and 0.9 and 1.0 are both one step, but the visual angle is 10 minutes and 5 minutes in the former and 1.1 minutes and 1 minute in the latter. The former is twice the difference, and the latter is 1.1 times, which does not represent the same difference. Therefore, if 0.125 and 0.16 are inserted between 0.1 and 0.2, 0.25 is inserted between 0.2 and 0.3, and 0.7 and 0.9 are subtracted, the arrangement of decimal visual acuity chart becomes almost equal.

The fractional visual acuity (Snellen method) has the same arrangement of visual acuity, and unlike the decimal visual acuity charts, it is possible to indicate by two-step visual acuity increase or decrease.

The logarithmic visual acuity chart displays the visual acuity in logMAR, which is the logarithm of the minimal angle of resolution (MAR). Each step of the visual acuity chart is at the same interval, so an arithmetic average is possible to be calculated.

The logarithmic visual acuity chart has five characters per line, and the left and right character spacing is a spacing of the size of each character, and the size ratio of the large character and the lower character is kept at a constant ratio of about 5:4, respectively. The spacing between the upper and lower lines is the size of the character in the lower row. They are arranged at the same interval at which the index is reduced by 0.1 by one logMAR at the top. This visual acuity chart is used at a distance of 4 m. It can measure up to 20/957, that is, 0.02 at 1 m, which is useful for patients with low vision.

Decimal Visual Acuity

This is the method of displaying the reciprocal of the minimum visual angle as a decimal. That is, when the minimum visual angle is 1 minute, it is displayed as 1.0, and the index number (0.1, 0.15, 0.2, etc.) on the visual acuity chart is displayed as it is.

Fractional Visual Acuity

It is widely used in Europe. Write the test distance on the numerator and the test number on the denominator. The character width of the number 20 will have a visual angle of 1 minute at 20 feet, and if you look at it at 20 feet, your visual acuity will be 20/20, and you will have normal vision. The test distance is usually 20 feet or 6 m. 20/40 is equivalent to 0.5, but does not convert the fraction to a decimal. It is an old custom to use fractional visual acuity in Europe.

Algebraic Visual Acuity

In the United States, logMAR is used to display. Decimal visual acuity (VA) is VA = 1/MAR in which logMAR is the logarithm of MAR. In the reciprocal relationship, the absolute value is the same, but "–" is added so that logVA = −logMAR.

Table 1.1 The comparison of distant visual acuity

Decimal visual acuity	Fractional visual acuity		log MAR
0.10 (0.1)	20/200	6/60	+1.0
0.125	20/160	6/48	+0.9
0.16	20/125	6/38	+0.8
0.20 (0.2)	20/100	6/30	+0.7
0.25	20/80	6/24	+0.6
0.32 (0.3)	20/63	6/20	+0.5
0.40 (0.4)	20/50	6/15	+0.4
0.50 (0.5)	20/40	6/12	+0.3
0.63 (0.6)	20/32	6/10	+0.2
0.80 (0.8)	20/25	6/7.5	+0.1
1.00 (1.0)	20/20	6/6	0.0
1.25 (1.2)	20/16	6/5	−0.1
1.60 (1.5)	20/12.5	6/3.75	−0.2
2.00 (2.0)	20/10	6/3	−0.3

Fig. 1.2 ETDRS visual acuity chart

The logarithm is the logarithm of 10, and the decimal visual acuity comes from $10^{-\log MAR}$. The minimum visual angle of 1 min (1/60°) is 1.0 in decimal visual acuity and 0 in logMAR visual acuity from log 1. Decimal visual acuity, fractional visual acuity, and logMAR conversion are shown in Table 1.1.

ETDRS (diabetic retinopathy study) visual acuity chart by Ferris has been used recently. ETDRS (logMAR indication) visual acuity chart is carried out as follows.

Sit at a distance of 1 m or 4 m to shield the left eye. (Corrected visual acuity is measured after correcting refractive error using chart R). Have an eye chart for the right eye (chart 1), one line at a time, from top to bottom. For example, let's read from left to right and then right to left. Calculate the number of correct answers. In case of low vision, test is performed at 1 m. Place the patient in a 1 m position and insert a +0.75D spherical lens. As in the case of 4 m, calculate the number of character by reading the chart from the top by one line. The visual acuity chart for the left eye (chart 2) is used to perform the same visual acuity test as the right eye (Fig. 1.2).

Unlike the decimal visual acuity test, if the patient reads four or more characters on one line, the next line is checked. If you only read three or less characters, the patient is stopped on that line. The result is not determined from the line read, but logMAR is calculated from the number of characters the patient reads. The difference between each line in the ETDRS chart is 0.1 logMAR, and there are five characters in each line, so one character corresponds to 0.02 logMAR. Therefore, it is possible to evaluate the visual acuity five times as detail as the conventional visual acuity chart and is also useful for measurement of low vision. At the time of 4 m measurement, it is obtained by subtracting the number of character or the number × 0.02. For example, if five of five characters of +0.4 (decimal visual acuity of 0.4) line can be read and two out of five characters at +0.3 (decimal visual acuity of 0.5) line can be read, logMAR is $+0.4 - (0.02 \times 2) = +0.36$.

For low vision, test can be made at 3.2, 2.5, 2.0, 1.6, 1.3, and 1 m, and the measured values at these distances can be added to the logMAR values at 4 m by adding 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 respectively. For example, when 1 m is measured, it is obtained in the same manner as the 4 m measurement, and 0.6 is added to the value. When logMAR is +1.0 at 1 m, $+1.0 + 0.6 = +1.6$.

For the results, it is recommended to use a dedicated result sheet. Check the unread character with an X mark, and calculate the logMAR with the number of read marks. It is general to record the visual acuity results numerically, but

sometimes the number of characters read is recorded together. The test distance of ETDRS chart is usually 4 m, but one character is added when reading the largest character at 1 m. Therefore, if 4 m is used, add 30 characters because reading at 4 m is the same as reading 30 characters.

1.1.3.3 Standard Visual Acuity Measurement

Type of Visual Target

At the 1909 International Eye Society, the Landolt ring was defined as a standard character. The International Organization for Standardization (ISO) agreements between 1980 and 1981 require the use of the Landolt ring as a standard target (Fig. 1.3).

The 1.5 mm wide grating of the Landolt ring with a diameter of 7.5 mm and a width of 1.5 mm is made to be 1 minute at a test distance of 5 m. The visual acuity at this time is 1.0. Snellen "E" is also designed with the same principle. However, the character visual acuity chart is used mainly for the purpose of quick examination of clinical charts. This was determined by a comparative experiment with the Landolt ring, which can be used in semi-standard test equipment.

Illuminance of Visual Acuity Chart

In general, the luminous intensity of the visual acuity chart is 500 ± 125 lux. If the illumination of the visual acuity chart is adjusted to about 500–1000 lux, it is good as a semi-standard chart apparatus.

Test Distance

The distance vision test is performed at a distance of 3–6 m. If a 5 m visual acuity chart is installed, it is accommodated to 0.2 diopter in emmetropic eye. Therefore, myopia of −0.2D is judged on emmetropia. The test distance in foreign countries is 6 m or 20 feet. At this time, the patient faces the chart, and the height of the visual acuity chart is such that the index of 1.0 is the height of the patient's eye.

Indoor Lighting

Indoor illumination affects vision. For example, if only the visual acuity chart is illuminated and when the surroundings are dark, night vision will occur, and the visual acuity will be decreased, and the influence of the pupil should be considered. The vision test is best measured in its natural state and should therefore be done in bright places in principle. The lighting should be evenly brighter than 50 lux.

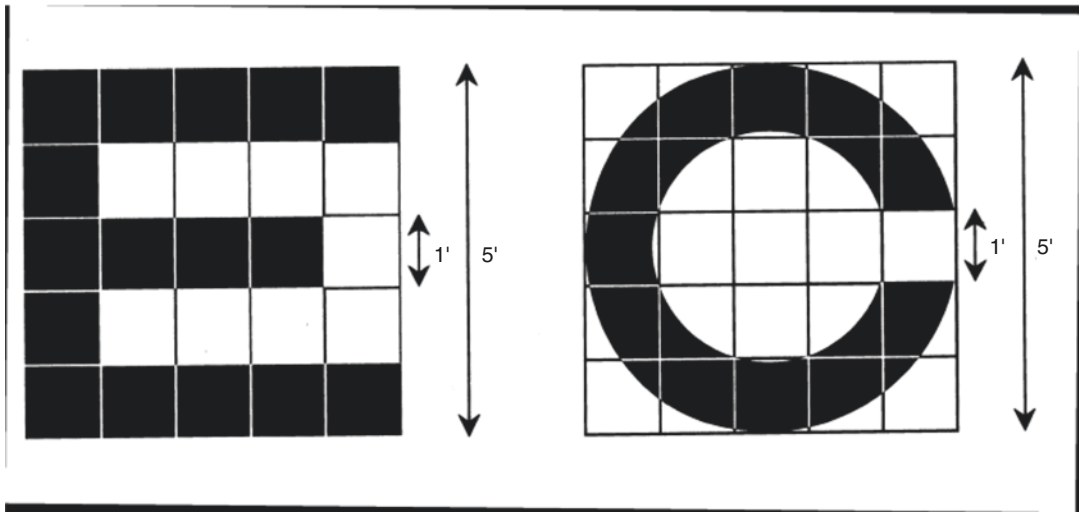


Fig. 1.3 Snellen E and Landolt ring

1.1.3.4 Measurement of Visual Acuity at 5 m

Measure one eye at a distance of 5 m from the chart. When a target of 0.1 is not visible at a distance of 5 m, the target is approached to the position where the target of 0.1 can be seen. If the distance from the target is *X* m, the visual acuity is $0.1 \times X/5$. For example, if you read a 0.1 target at 2 m, your visual acuity will be $0.1 \times 2/5 = 0.04$. If the target of 0.1 is not readable at a distance of 1 m, the number of the target is set by the examiner's finger in front of the eye. For example, if the number of fingers is adjusted to 30 cm, the finger is counted as "FC (finger count)/30 cm." If you cannot count your fingers, but you can only see the motion of your hand shaking in front of your eyes, then your vision is recorded as hand movement (HM). When the patient do not know the movement of your hand and notices the light at darkroom, you should write light perception (LP). The light is projected to the eye in the up, down, left, and right directions, and it is asked about the projection direction. If you answer this accurately, it is said that light projection is good. When the light direction is clear, it can be assumed that there is no significant change in the retina. If there is no light perception, the visual acuity is written as zero. This is a strict definition of blindness.

1.1.4 Interpretation

The subject's visual acuity is used as the visual acuity number when reading more than half of the acuity charts. If the number is less than half, it means that the visual acuity is partially shown, but the visual acuity value of "p" cannot be applied when writing in the paper. According to ISO, if you fail to read more than two, the visual acuity of the preceding step is taken as the visual acuity of the eye (Table 1.2).

You must check the printability of the target, the brightness of the visual acuity chart, and the standard of indoor illumination. Be careful not to squeeze the patient's eyes when the patient covers the eyes. If the patient has strong light stimuli, check after about 5 minutes. During the test, it is recommended to keep the patient eyes open so that you do not frown.

Table 1.2 International visual acuity chart

Visual acuity	Definition
1.0	Normal visual acuity, identifying the interval of the standard Landolt ring (visual angle of 1 minute) at 5 m distance
0.5^{-2}	The patient cannot read two of the characters at 0.5
0.06	Visible to identify the largest target at 3m distance
FC/30 cm	Finger count at 30 cm, also known as CF (counter finger), when the patient cannot read the largest target even at a distance of 50 cm
HM	Although the number of fingers cannot be visible, the patient can notice the hand moving (hand movement or hand motion)
LP	When the patient do not recognize hand motion, you can determine if there is light in the darkroom
LP/proj	The patient can recognize the brightness or direction of the light
LP/no proj	The patient can notice whether there is light or not, but cannot the direction of light
0	The patient cannot detect the light

When the pupil enlargement is performed, a 3 mm pinhole plate can be used. If the pinhole is used, the depth of focus is deepened to increase the visual acuity. If the pinhole visual acuity is decreased, the corneal opacity, cataract, vitreous opacity, or macular abnormality is suspected.

Children under 8 years old, especially children under 6 years old, are precisely measured with using a stand-alone basis visual acuity chart. When observing the progress of visual acuity change, it should be done under the same conditions as before.

1.1.5 Record of Visual Acuity

Uncorrected visual acuity refers to visual acuity without wearing glasses or contact lenses, but radial keratotomy, PRK (photorefractive keratectomy), laser in situ keratomileusis (LASIK) and laser epithelial keratomileusis (LASEK), pseudophakia with intraocular lens implantation, or phakic IOL insertion should be recorded.

The right eye is recorded as VOD, RV, or vd, and the left eye is recorded as VOS, LV, or vs. Both eyes are recorded as OU.

VOD: 0.8 × IOL (1.2 × −1.50 D): 0.8 with pseudophakia and 1.2 with adding glasses

VOS: 0.5 × LASIK (1.0 × −0.5 D): 0.5 with LASIK surgery and 1.0 with adding glasses

Contact lenses, RK, PRK, LASEK, and phakic IOL are also recorded in the same manner. Vcc or VAcc is used for recording the corrected visual acuity, and VAsc is used for recording the uncorrected visual acuity.

1.1.6 Pinhole (PH) Visual Acuity

It is used for the purpose of determining whether vision loss is correctable by glasses. Focal depth is deepened and retina image is cleared by using pinhole. If the patient's visual acuity improves more than two lines, there is a high possibility of refractive error. When using glasses and having visual acuity of 20/30 or less, the pinhole visual acuity test method should be performed and is as follows. One eye is covered, and a pinhole plate with a diameter of less than 2.4 mm is placed in front of the other eye to measure the distant visual acuity. Record the visual acuity of pinhole after corrected distant visual acuity. For example:

VAcc OD: 0.4^{+2}	PH: 0.6
VAsc OD: 0.5^{+1}	PHNI: When there is no improvement in visual acuity (no improvement)

1.2 Near Visual Acuity

1.2.1 Indications and Purposes

1.2.1.1 Accommodation Disturbance due to Presbyopia

Near visual acuity should be tested for the purpose of measuring the degree of near vision disturbace, determining whether the near vision glasses are suitable, and prescribing the lens power suitable for the near vision glasses.

1.2.1.2 Hyperopia

In case of latent hyperopia having good distant visual acuity, it is easy to think that prescription of glasses is unnecessary. However, the patient needs great accommodation effort for near target and does not like reading or complains of asthenopia. In the case of mild hyperopia, the spectacle lens can cause near visual impairment when prescribing only for the distant vision. It is wise to decide the lens power that focuses on near vision even if it is a little overcorrected at a distance.

1.2.1.3 Patients in Bed

If the patient is unable to perform a distant visual acuity test, the visual acuity can be roughly determined by measuring the near visual acuity in a lying state.

1.2.1.4 Amblyopia

According to the Moore-Johnson method or the near penalization method, atropine is instilled in the normal eye, and the near vision is made into the amblyopia to optically shield the normal eye at near vision. At this time, check that the degree of near vision in the normal eye is suppressed enough and worse than the near visual acuity of amblyopic eye.

1.2.1.5 Assessment of Visual Acuity for visually handicapped

It is based on the reading and writing ability, and it is the evidence data to choose the public school, the school for amblyopia, or the school for blindness.

1.2.2 Method

Using a near vision chart, measure visual acuity at the distance of 30 cm. The bright indoor level is enough to be tested, and the illuminance should be 400–800 lux. If the largest target cannot be read, the test distance should be shorter. For example, if a target of 0.1 is read at 15 cm, the visual acuity becomes 0.1 × 15/30 = 0.05, which is not a near visual acuity of the original meaning but a visual acuity indicating at least how many

Table 1.3 The comparison of near visual acuity

Decimal method	Fractional method	Jaeger method	Point method
1.0	20/20	J1	N3
0.8	20/25	J2	N4
0.5	20/40	J4	N6
0.2	20/100	J13	N14
0.1	20/200	J16	N30

characters can be read. At this time, the record should be written in 0.1 (15 cm). A large target of 0.1 or less should be prepared as the maximum target.

1.2.3 Interpretation

When reading 3/4 or 4/5 or more characters, it is regarded as a visual acuity (Table 1.3).

It is important to strictly set the test distance to 30 cm, and it is necessary to define the distance between the eyes and the target in a ruler or a thread. The chart made in Europe and United States should be careful because the test distance is set to 1/3 m (33 cm). Generally, the visual acuity chart printed on ordinary paper has a deterioration of contrast sensitivity due to discoloration due to years, so it is necessary to change it to a new one every 3 years. The standard should have a contrast sensitivity of 85% or more.

1.3 Contrast Sensitivity Test

An object does not have the same brightness. This change of brightness is expressed as contrast. Contrast sensitivity refers to how to distinguish objects with different contrasts from one another. For example, there is a strong contrast between the face and hair, but there is less contrast between the nose and mouth. The visual acuity is related to the sensitivity of the retina. The amount of light and the background play a more important role than the size of the object. That is, you can see stars in the middle of the night, but you cannot see them during the day.

Snellen acuity has 100% contrast sensitivity and is completely black on white paper. Visual acuity measures the ability of the eye to resolve the fine objects, but does not adequately represent the ability to see objects with low contrast. In visual abnormalities such as cerebral abnormalities, optic neuritis associated with multiple sclerosis, glaucoma, diabetic retinopathy, and amblyopia, visual acuity is close to normal, but contrast sensitivity decreases. For example, the VCTS, CSV-1000, Regan letter chart, Vistest picture test, and Pelli-Robson letter sensitivity chart are examples of devices that can test the spatial frequency.

1.3.1 Indication and Purpose

The purpose is to find out the causes of visual deterioration that cannot be found in visual acuity test. When the contrast sensitivity of a normal person is measured, the contrast becomes higher as the spatial frequency increases, highest as the spatial frequency reaches the middle, and lower as the spatial frequency increases again. This spatial frequency is established under the optical system of the eye, the intraretinal processing system, the neurotransmission system, and the information processing system of the visual cortex, so the specific pattern of contrast sensitivity represents the area where the defect happened. For example, a decrease in the contrast sensitivity in the high frequency means a decrease in the visual acuity itself, and a decrease in the maximum height means a decrease in the retinal inhibitory effect. If the visual acuity and fundus examination are both normal and the contrast sensitivity of low frequency is decreased, a lesion that gives pressure on visual pathway such as optic neuritis, multiple sclerosis, or Parkinson's disease can be considered. However, spatial frequency does not have diagnostic value to accurately determine the area of the defect.

1.3.2 Method

The VCTS has a distance (3 m) and near test charts which have approximately 1.5° size of the circle with 8 horizontally, 5 vertically, and 5 blank vertical targets and a total of 45 targets. The target is arranged such that the contrast is

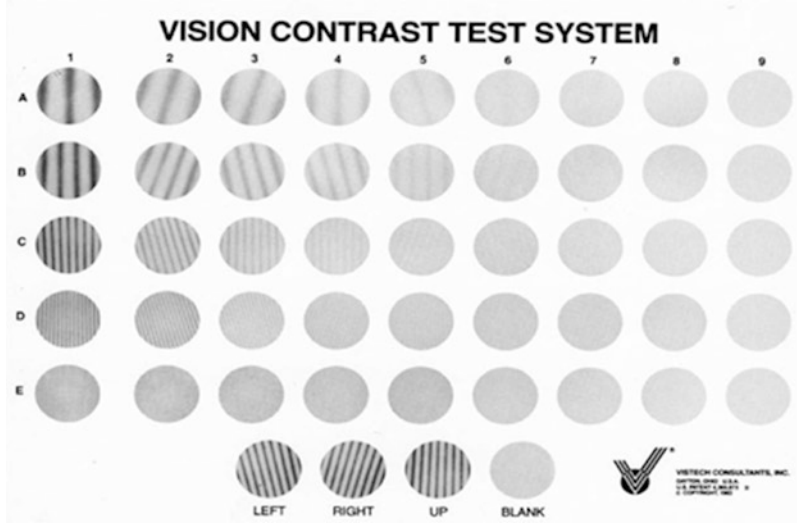


Fig. 1.4 VCTS chart

decreased from left to right or the spatial frequency is increased from the top to the bottom.

High-contrast examples are shown for the purpose of indicating that there are three kinds of stripes with vertical, 10° right angled and 10° left angled (Fig. 1.4).

There is a set containing one check sheet for each of distant and near and a set containing three sheets for each. In the 3-sheet set, the arrangement of the patterns that can be placed on the 40 marks of each test chart is changed so that the patient cannot memorize the direction of the target. Show the patient a sample of the mark on the bottom of the checklist, and make a full understanding what the check is. Begin the examination from the top most target with the smallest spatial frequency. First, ask the patient whether the direction of the stripe is vertical or whether it is tilted slightly to the left or right. If the answer is correct, ask the direction of the target with low contrast on the right side, and repeat this until the patient cannot answer. Perform this procedure for the next four groups. Write the contrast sensitivity at each spatial frequency on the recording paper (Fig. 1.5).

1.3.3 Interpretation

The normal value displayed on the attached paper is compared with the recorded result to determine whether the contrast sensitivity of low frequency area, the highest value area, or high frequency area is decreased.

1.4 Glare Test

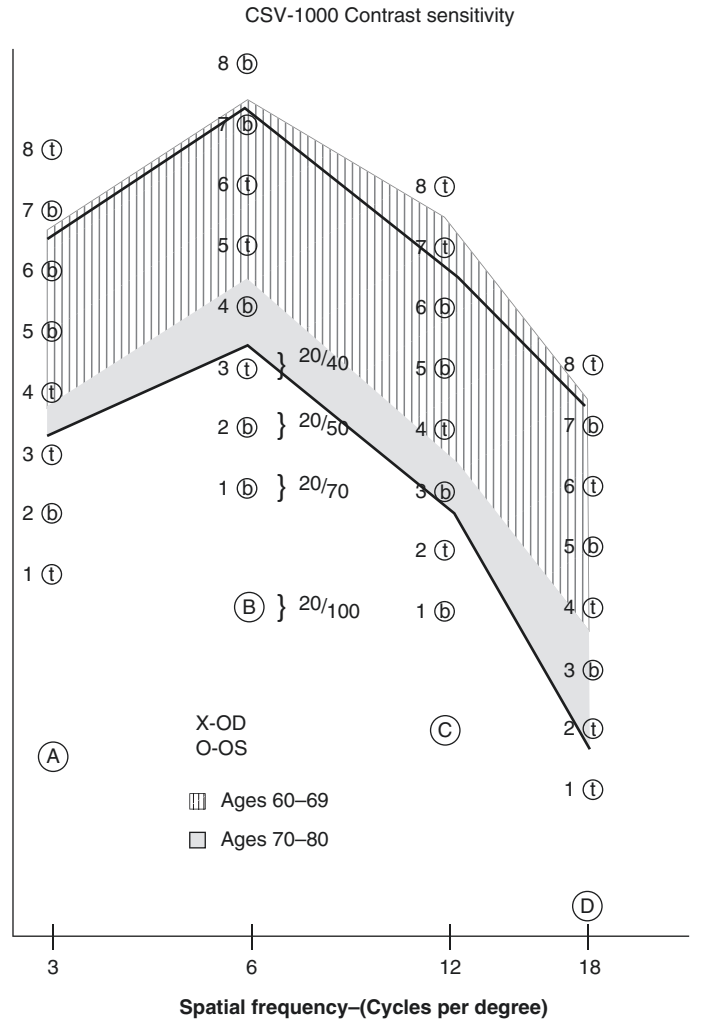
1.4.1 Indication

It is necessary to determine the surgical indication of a case with media opacity such as cataract, after cataract, or corneal opacity or to observe after the corneal refractive surgery.

1.4.2 Purpose

Glare is the decrease of contrast sensitivity on the retinal image due to scattering of light in the eye. When there is opacity, the light is sometimes scattered when the light passes, so the patient sometimes complains of photopia, and the visual acuity in the strong and bright light is worse than the visual acuity measured by the normal visual acuity test.

The glare test measures the degree of glare that cannot be checked by conventional visual acuity test, and it is the main purpose to determine the indication of cataract surgery. This is the example of the test using the Miller-Nadler glare tester.



Patient name _____ Age _____ Date _____

Functional acuity OD _____ OS _____

Standard acuity OD _____ OS _____

Comments _____

Fig. 1.5 VCTS recording paper

1.4.3 Method

The Miller-Nadler glare tester is a tabletop-shaped instrument that uses a projector to illuminate the slides of the charts attached to the background (Fig. 1.6). The target is a Landolt ring of 20/400 and is displayed in a 4 cm diameter circular background. It consists of 19 slides with a different contrast between the target and the background from 80% (No. 1 slide) to 2.5% (No. 19 slide). The target is displayed in the center of the square screen of the background light of 3200 lumens.

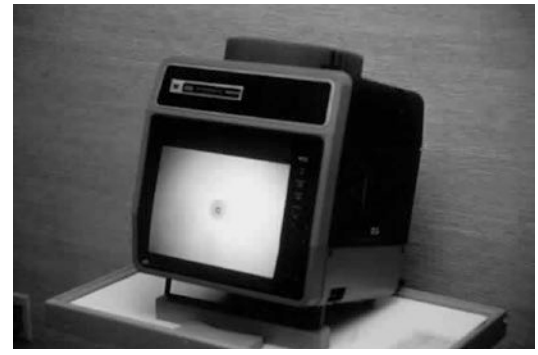


Fig. 1.6 Miller-Nadler glare tester

Fix the patient's head at a distance of 36 cm from the projection plane. After correcting the refractive error so that the patient can see well at this distance, the target slides attached to the background are projected onto the light source from the No. 1 slide. Repeat the above procedure by sequentially presenting slides with different contrast between the target and the background. Obtain a glare disorder from the contrast difference of the final slide that was readable.

1.4.4 Interpretation

The lower contrast slide (higher number slide) is readable, the less glare disorder is. The glare disorder is expressed by the contrast value (%). For example, if you read contrast value 80%, the glare disorder is expressed as 80%. If the screen illuminating the slide becomes dirty, the contrast of the target will change, which can affect the test results.

1.5 Pediatric Visual Acuity

1.5.1 Indication and Purpose

Pediatric patients can be tested with using Landolt ring from the age of 3 years old. In recent years, screenings have been conducted in kindergartens, so that visual development disorder in children can be detected in early stage.

The characteristics of visual acuity in children is better visual acuity because of using the Landolt ring instead of the character, the single object chart instead of parallel object chart, and the near distance instead of 5 m distance. There is also a problem that it is difficult to interpret the result only by a single test.

Children cannot express their thoughts unlike adults, so the cognitive ability of children can be tested through physical tests or electrocephalogram. There are a number of tests that can be used to determine the development of visual acuity in children.

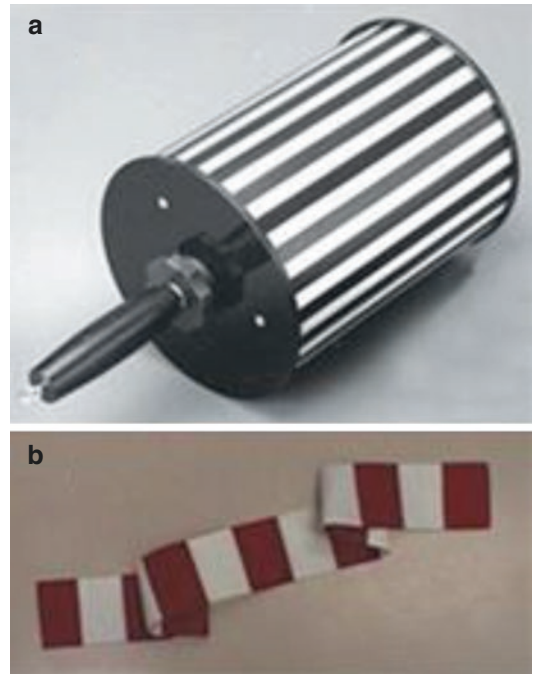


Fig. 1.7 The equipment of measuring optokinetic nystagmus (OKN). (**a**) OKN inducing shaking drum. (**b**) OKN inducing cloth pocket strip

1.5.2 Method

Under 3 years old, it is possible to evaluate the visual acuity through qualitative tests which include the reponse of the child, gaze, pursuit movement, eyelid reflex and optokinetic nystagmus (OKN), and quantitative tests which include OKN, visual evoked potential, preferential looking test, and grating acuity card. Landolt ring single object visual acuity test can be used for 3- to 7-year-old children, and Landolt ring parallel visual acuity test for children over 8 years old.

1.5.2.1 Response of Child

When a child is suspected to have a visual disturbance, attention should be paid the child's expression, attitude, or behavior. Check whether the child is looking the eyes or the head by moving the milk bottle or the red target of the toys. Although there is a device such as Dayton that uses nystagmus, OKN drum (Fig. 1.7a) or cloth pocket strip (Fig. 1.7b) is widely used. If

there is no response or no eye contact or no response, check the eyelid blinking motion or the light response by illuminating the pupil with a pen light or strong light coming from the side.

1.5.2.2 Optokinetic Nystagmus OKN

It is a qualitative test that records the phenomenon of nystagmus. This can record visual movement response even in children who are not sure to watch or respond. Rotate the belt with various frequency bands (stripes) to cause nystagmus, and record the highest frequency band as a visual acuity.

1.5.2.3 Visual Evoked Potential

It is a method to see the reaction of the electroencephalogram by the stimulus coming from the eye by putting the electrode on the back part of the head of the child, that is, the part where the visual cortex is located. The visual stimulus uses western chessboard patterns, stripes, or stereoscopic signs. When the pattern is seen, the brain wave is generated, and the size, thickness, or contrast of the pattern becomes smaller. When the child cannot see, the brain wave is not generated. Therefore, the visual acuity and stereoscopic vision of the child are indirectly measured (see Chapter Electrophysiologic Test).

1.5.2.4 Preferential Looking (PL) Test

In 1962, Frantz performed the first visual acuity test for child, which used child's interest in striped pictures. The device is a rear-projecting slide Awaya-Mohindra visual acuity test with two translucent circular windows with a diameter of 11° in the center of the screen, at a distance of 50 cm, projecting a stripe pattern and a uniform image from the back to the projector. The width of the stripe pattern varies from 30.0 to 0.25 mm, the illuminance is about 40 cd/m^2, and the contrast sensitivity is about 85–95%.

There are two methods, forced-choice and pointing. The forced-choice method shows a black-and-white stripe pattern and a grayish-white uniform color to the child. The examiner looks into the hole in the middle of the two circular targets. This test is simpler than OKN and VEP and is for infant aged between 2–3 months and younger than 1 year.

Fig. 1.8 Preference looking test using TAC

If the child is able to talk, the examiner first shows a striped pattern and then displays a pattern less pattern. Make a child point in the direction of the screen by pointing the finger on the screen.

If the child is pointing at the target, the examiner presents the target with the same width once again. If the target is wrong, return the target with bigger size. If the correct rate is over 75%, the target value is regarded as a child's PL visual acuity. If it is fully skilled, it takes about 5–10 minutes. Using the forced-choice method and pointing method, it is possible to measure the visual acuity from 2 to 3 months infant to 3-year-old child.

1.5.2.5 Grating Acuity Card

In principle, it is the same as the preferential looking test. It is simpler and it is possible to perform visual acuity test for premature infants and newborn babies. Teller acuity cards (TAC), which are available from Vistech, are commonly used as test cards (Fig. 1.8).

This shows the visual acuity card at a distance of 38 cm and judges which side the patient is looking at by eye movement. The narrowest stripe target is regarded as a visual acuity. After confirming whether the child is staring at the card, the examiner can move the

card about 15 cm from the center to the left or right to judge the child's eye movements. It takes approximately 5 minutes and the success rate is reported as 80% for experienced examiner.

Measure the visual acuity by converting the stripe spacing to visual angle.

1.5.2.6 Landolt Ring Vision Test

Because child from kindergarten to elementary school is hard to read the parallel visual acuity chart, especially in patient with amblyopia, it is recommended to use one object visual acuity chart. If you repeat the parallel visual acuity chart, the child may memorize all the visual acuity charts, so it is better to use the one object visual acuity chart.

At first, binocular visual acuity is measured and then measure one by one. The infant does not want to cover one eye, so measure the better one. At this time, when the eye is covered with an occluder or black glasses, the child may turn the eyes or head to look through the gap. So, it is better to patch one eye. Make a child watch a 0.1 target at a distance of 5 m. If the answer is not good at 5 m, reduce the distance and convert the visual acuity value. For child aged 3 years or older, make a child have a handle that mimics the Landolt ring, and know the open direction. When the age increases, make a child point or answer the open direction. If the answer is correct, change it to a smaller target, and record the visual acuity when answering more than three directions out of four directions. For a child who cannot answer at initial visit, practice should be done at home and examine at next visit. If the difference between single and parallel target is large, it is helpful to diagnose the amblyopic eye.

1.5.3 Interpretation

A 6-month-old infant has the same visual acuity as an adult with visual evoked potential test. The preferential looking test shows that visual acuity reaches 20/20 of the adult at age 2. The preferential looking test records the visual acuity when correct answer rate is 70% or more. If you do this way, it will take about 5–10 minutes to measure, and you will be less likely to miss the test. For Landolt visual acuity test, if three directions out of four directions are correct, it is regarded as a visual acuity.

Suggested Reading

Bailey IL, Lovie JE. New design principles for visual acuity letter charts. Am J Optom Physiol Opt. 1976;53(11):740–5.

Benjamin W. Borish's clinical refraction. 2nd ed. St. Louis: Elsevier; 2006.

Colenbrander A. Measuring vision and vision loss, Ch. 51. In: Duane's clinical ophthalmology, vol. 5. Philadelphia: Lippincott Williams & Wilkins; 2009.

Davidson DW. Visual acuity. In: Clinical procedures in optometry. Philadelphia: Lippincott Williams & Wilkins; 1991.

Elliott DB, Whitaker D. Clinical contrast sensitivity chart evaluation. Ophthalmic Physiol Opt. 1992;12(3):275–80.

Fannin TE, Grosvenor T. Clinical optics. 2nd ed. Boston: Butterworth; 2002.

Garcia GE. Handbook of refraction. 4th ed. Boston: Little, Brown and Company; 1989.

Keirl A, Christie C. Clinical optics and refraction: a guide for optometrists, contact lens opticians, and dispensing opticians. Edinburgh: Elsevier; 2007.

Macnaughton J. Low vision assessment. Edinburgh: Elsevier; 2005.

Verweyen P. Measuring vision in children. Community Eye Health. 2004;17(50):27–9.

Refraction and Glasses Exam

2

Ji-Eun Lee

It is an objective examination to check and correct the refractive error (Fig. 2.1).

2.1 Objective Refraction

2.1.1 Skiascopy, Retinoscopy, and Shadow Test

When a light projects to the patient's eye, the light reaching the retina reflects out of the eye. According to the refraction state of the eye, the reflected light is parallel in emmetropia, diverged in hyperopia, and converged in myopia.

2.1.1.1 Indication

Patients with refractive error, abnormal eye position, and asthenopia are candidates, and they should have retinal reflex.

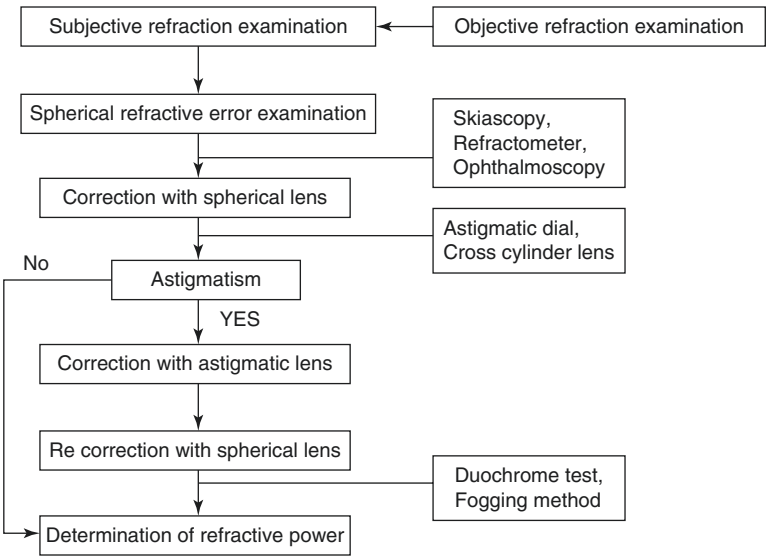


Fig. 2.1 The sequence of refraction examination

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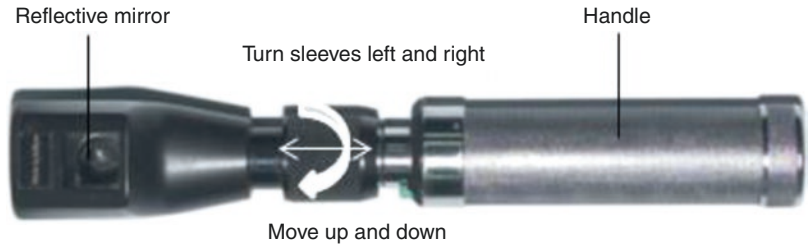


Fig. 2.2 Streak retinoscope

2.1.1.2 Method

There are a streak retinoscope, a spot retinoscope, and a specular retinoscope. The streak retinoscope is the most commonly used method.

The descriptions of two methods are as follows: one for refraction test to keep the patient's point of view at a long distance and the other for accommodation test to keep close at a near distance.

The light band from the streak retinoscope (Fig. 2.2) can be used by turning the sleeve up and down to adjust it to a light band of the parallel, convergence and divergence. It is also possible to turn the sleeves to horizontal and vertical strips by turning them left or right.

The following are the procedures using streak retinoscope.

Prepare a streak retinoscope and trial lenses in a semi-darkroom. The examiner can have a test distance of 50 cm, 67 cm, or 1 m with the patient, but it usually sits at a distance of 50 cm. The patient should be in the state of accommodation free by viewing the point at least 5 m away from the back of the examiner. Examine the patient's eye with the same eye as the examiner's eye. That is, when examining the patient's right eye, the examiner puts a retinoscope in his right eye and holds the lens with his left hand in front of the patient's right eye. While looking through hole of the streak retinoscope, move the sleeve upward or downward to make the light divergent, and turn the sleeve to the left or right to make the light strip vertical. This vertical light passes through the patient's pupil to the left and right by turning the retinoscope itself to the left and right. Observe the movement of the light shadows of the red reflexes reflected from the retina in the pupil. Inspect the refractive error of the horizontal meridian. Then, turn the sleeve of the retinoscope to the left or right to select the horizontal light band, and move the retinoscope itself up and down to observe the upward and downward movements of the light shadow to check the refraction of the vertical meridian. There are three kinds of movement of light shadow. If the moving direction of light shadows coincides with the insertion direction of the light band, it moves "with movement." If it moves in the opposite direction, it is called "against movement." If the focus coincides with the position of the examiner's eye, light shadow does not move, and this is called "neutralization" (Fig. 2.3).

If the light shadow is "with movement," it means myopia less than −2 diopter (D), emmetropia, or hyperopia. Put a weak "+" lens in front of patient's eye and observe the light shadow. Gradually increase the power of the "+" lens by +0.5D and find the "neutralization" point. The power of lens at the time of switching from "with movement" to "against movement" means the neutralization point. If the test distance is slightly increased, it is possible to confirm the neutralization, and it is also possible to make a fine adjustment of the dioptric power (Table 2.1).

In the case of "against movement," it means myopia of −2D or more. Start with a weak "−" lens, and gradually increase the power to find the neutralization point. The power of lens at the time of switching from "against movement" to "with movement" means the neutralization point.

In the case of "neutralization," the movement of the light shadow cannot be seen with the movement of the retinoscope, and it means myopia of −2D. If 2D is subtracted from the power of lens

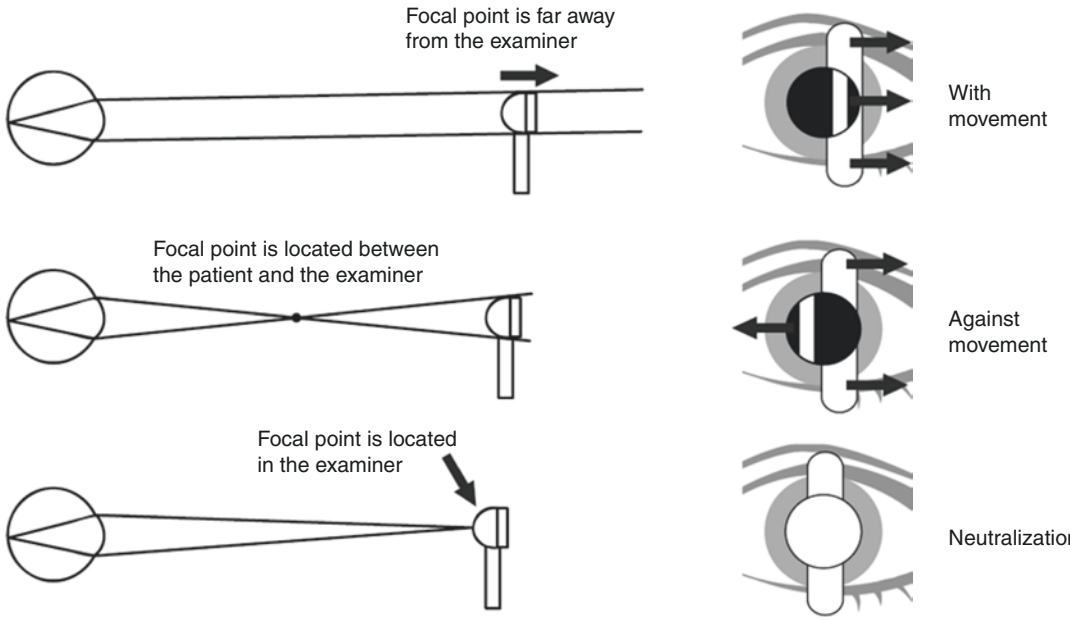


Fig. 2.3 Reflections from retinoscope

Table 2.1 Refraction according to motion of streak at 50 cm distance

Streak	Refraction
With movement	Hyperopia, emmetropia, myopia under 2D
Against movement	Myopia more than 2D
Neutralization	Myopia of 2D

at neutralization point, it becomes a refractive error. However, 2D is changed according to the test distance. If the test distance is 67 cm, 1.5D should be subtracted, and if it is 1 m, 1.0D should be subtracted. The test distance of 67 cm has less error. After finding the neutralization point in the horizontal direction, turn the sleeve, and change the light horizontally to find the neutralization point in the vertical direction with the same manner. If the neutralization point in the horizontal direction and in the vertical direction is different, it means that there is astigmatism so that the refractive indices in the two directions are calculated in the same manner as above. Astigmatism has two axes. The angle between the two axes is always 90°. When the axis between the light band of retinoscope and the light shadow of pupil does not coincide with each other, this is referred to as an off-axis, which means that there is oblique astigmatism. There are "with the rule astigmatism," "against the rule astigmatism," and "oblique astigmatism" (Fig. 2.4).

If the light band does not coincide with the astigmatic axis, the break is eliminated by rotating the sleeve and aligning the axes. The angle at this time becomes the main meridian, and the perpendicular meridian becomes another main meridian. It is easy to find the astigmatic axis by adjusting the light band as narrow as possible to the pupil. If it is not sure, moving the light band will be helpful to notice, which is called skew (Fig. 2.5).

When the light band coincides with the astigmatic axis, the width of the reflected light is the thinnest, and as the axis deviates, the width increases (Fig. 2.6).

When the light band coincides with the astigmatic axis, the reflection band shines most brightly, and as the axis shifts, it becomes darker. If the axis is not correct, the power is not also accurate, so there is a straddling test to confirm the axis. With wearing glasses, put the light band

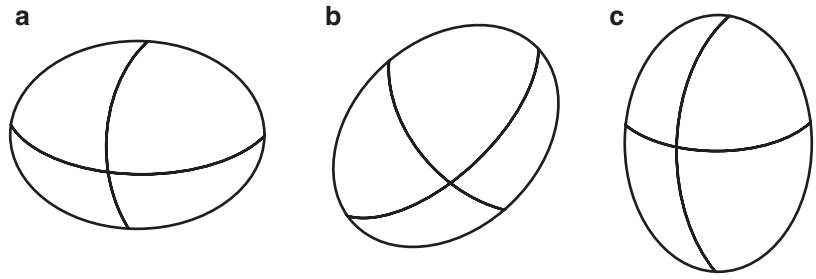


Fig. 2.4 Classification according to astigmatic axis. (**a**) With the rule astigmatism. (**b**) Oblique astigmatism. (**c**) Against the rule astigmatism

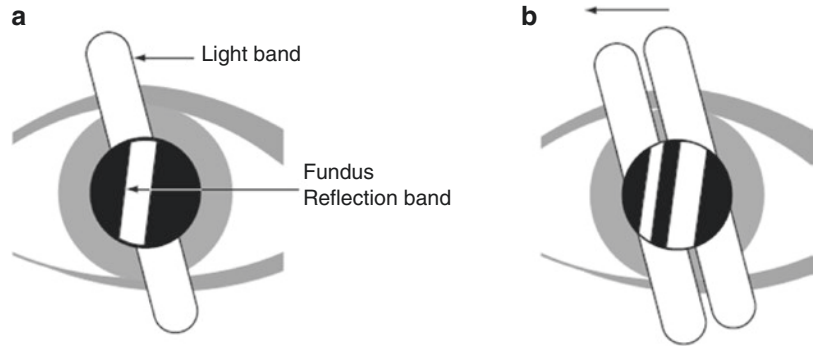


Fig. 2.5 Break and skew phenomenon. (**a**) Break phenomenon. (**b**) Skew phenomenon

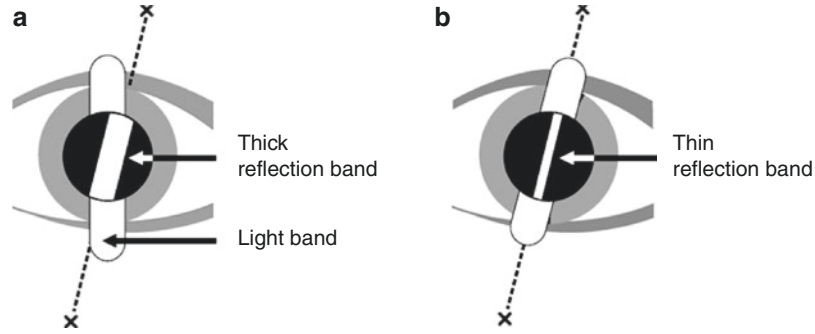


Fig. 2.6 Incorrect axis. (**a**) Incorrect axis. (**b**) Correct axis

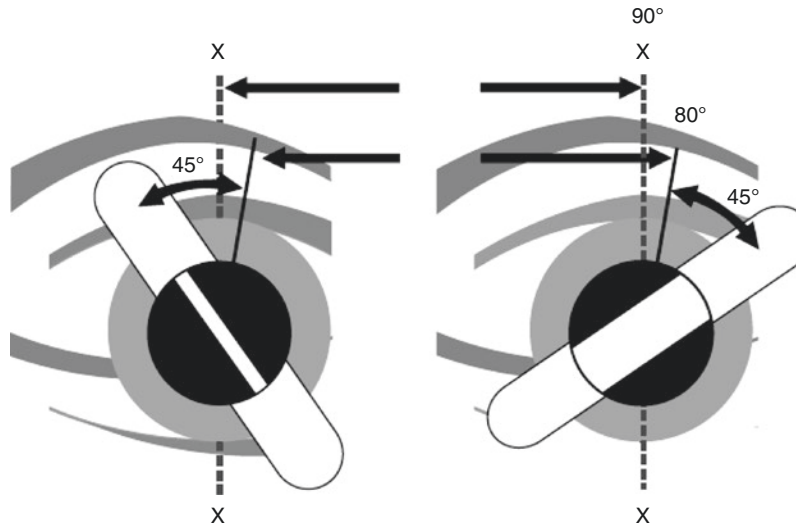
on the astigmatic axis, and turn it 45° to the left and right. At this time, the left and right sides of the reflection should be the same. If one side is narrower and brighter, move the axis 5–10° to the opposite side until the left and right sides are the same in the case of concave lens. Convex lenses should be reversed (Fig. 2.7).

If you think that the axis is perfect, move your body a little forward, and raise the sleeve so that the reflection becomes brighter. Move back the sleeve while pulling your body back, and compare the reflections of two axes. When using a concave lens, astigmatic power is too strong if the spherical axis (the axis that is perpendicular to the astigmatic axis) is first neutralized, and if astigmatic axis is first neutralized, astigmatic power is too weak.

2.1.1.3 Interpretation

For example, if there is with the movement with +4.0D and against the rule with +4.5D at 50 cm, neutralization will be +4.25D. The refractive error is calculated as +4.25 – 2 = +2.25D. In astigmatism, if there is neutralization at +1.0D in

Fig. 2.7 Straddling test



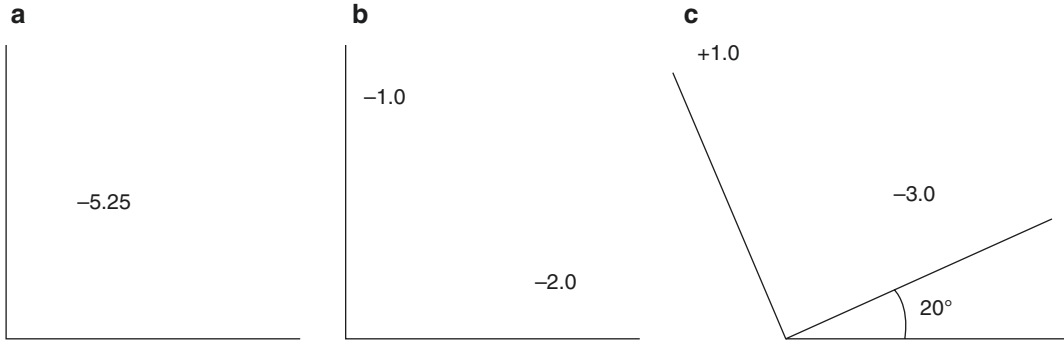


Fig. 2.8 Recording of refractive error. (**a**) No astigmatism. (**b**) Astigmatism. (**c**) Oblique astigmatism

the vertical meridian and 0D in the horizontal meridian, the refraction error will be −1.0D in vertical meridian and − 2.0D in horizontal meridian.

To find the neutralization point in a vertical meridian, you have to move the light horizontally up and down while moving it horizontally. To find the neutralization point in the horizontal meridian, you should move the light vertically, and move left and right.

If the 20° meridian is −1.0D and the 110° meridian is +3.0D, then record as shown in Fig. 4.9c, and write as +1.0D cyl 20° = −3.0D cyl 110° or +1.0D sph = −4.0 cyl 110° or −3.0D sph = +4.0D cyl 20°. The recording method shows the error of horizontal and vertical meridian as follows (Fig. 2.8).

Caution should be given when changing the divergent ray and the long convergent ray into a short convergent ray because with the movement and against the movement are switched. When the refractive power is to be obtained, the pupillary plane should be completely covered with a light band. Convergent light band does not completely cover the pupillary plane, so it is necessary to check them with divergent light band. When a short convergent light band is used in high myopia and a long convergence light band is used in high hyperopia, the brightness of the light band is increased, and it becomes easy to watch. In high myopia, short convergent ray changes from with the movement to against the movement, which makes it easier to distinguish the light shadow. There is also a way to check

Table 2.2 Types and characteristics of cycloplegics

Agents	Time to pupil enlargement	Time to reach the highest effect	Time duration	Residual time	Degree of cycloplegia
Atropine 1%	30 min ~ 1 h	12~24 h	24 h	10~18 days	+
Scopolamine 0.25%	30 min ~ 1 h	1 h	2 h	4~6 days	+
Homatropine 5%	30 min	1 h	1–2 h	36–48 h	+
Cyclopentolate 1%	20 min	20~45 min	30 min	6~8 h	++
Tropicamide 1%	20 min	20~35 min	15 min	2~6 h	+++

overcorrection of glasses by performing retinoscopy with wearing glasses.

2.1.1.4 Cycloplegic Refraction

In general, it is performed in hyperopic patients with excessive accommodation. Others included mental retardation, children with low concentration, children with residual hyperopia, and patients with malignancy. After applying cycloplegics, perform the retinoscopy. Atropine is the most powerful cycloplegics with long lasting effect. So cyclopentolate is commonly used. The types and characteristics of the cycloplegics are shown in Table 2.2.

2.1.2 Autorefractometry

It is a method to measure the refractive power of the eye by projecting a certain target on the fundus and adjusting the distance so that the target marked on the retina can be seen clearly, which is similar to the principle of the ophthalmoscope. Although errors may occur when the patient looks inside the machine, the error can be reduced to a certain level by using various fog methods and automatic tracking devices. A portable autorefractor has also been developed and can be measured regardless of patient position.

2.1.2.1 Indication

This is usually the case when a sitting position is possible and the face can be fixed to the chin rest. If the pupil is small, if the patient absorbs the infrared light during measurement (pseudophakia), if the patient is not able to watch well, if there is severe nystagmus, if the cornea has irregular astigmatism, or if there is media opacity such as cataract, corneal opacity, or vitreous opacity, it may not be tested or may have inaccurate results. The measurable range differs from model to model, but the maximum is ±25D in spherical power and ±18D in cylindrical power.

2.1.2.2 Purpose

It was developed for the purpose of measuring refraction in a short time without the need for skill. The spherical power and cylindrical power and axis can be measured quickly and printed in numerical value.

2.1.2.3 Method

Place the patient in front of the autorefractometer, move the chin rest up and down to be a comfortable position, and raise the chin on the chin rest. Keep the forehead fixed so that the head does not move while examining. The examiner moves the adjustment knob to the front, back, left, and right so that the focus is focused on the center of the patient's pupil. Take care not to blink the eyes. If the eyelids or eyelash blocks, pull the eyelids up, taking care not to press the eyes. Measure by pressing the button. If the pupil is small, it may be possible to measure if it is dark. Measure several times to obtain representative value. Young patient with high accommodation, patient with abnormal eyeball position (especially esotropia), or monitor worker need cycloplegics. Multiple measurements and representative measurements are output.

2.1.2.4 Interpretation

If there is no significant difference between the measurements and the astigmatic axis is stable, it is judged that the measurement is

performed correctly. The reason why the reliability is low and unstable result is obtained is as follows. In case that observation is not maintained at the measurement, the pupillary center is deviated from the center, or accommodation relaxation is insufficient. When the centers of measurement and pupil are deviated, the power of cylindrical lens tends to become strong and that of the spherical lens tends to be weak. As a representative value, it is preferable to select a hyperopic value in spherical lens and a lower value in cylindrical lens.

2.1.3 Keratometry

Most of the autorefractor measures refractive as well as keratometric value. This device also uses a non-visible infrared wavelength reflector and detector, which is convenient because it reduces the patient's glare which happens when using a manual keratometer. It is divided into automatic and manual keratometry.

2.1.3.1 Autokeratometry

It is for patients who can place the chin on the chin rest in a sitting or standing position, especially before and after cataract surgery, astigmatism correction surgery, refractive surgery, and contact lens prescription and in corneal abnormalities or suspected corneal astigmatism. It is performed to evaluate the effect of corneal astigmatic power and axis on corneal abnormality, cataract surgery, astigmatism correction surgery, or refractive surgery. Place the patient in front of the autokeratometer, and raise the chin on the chin rest. Keep the forehead fixed so that the head does not move while examining. The examiner performs the test after the focus of autokeratometer is focused on the pupillary center (Fig. 2.9).

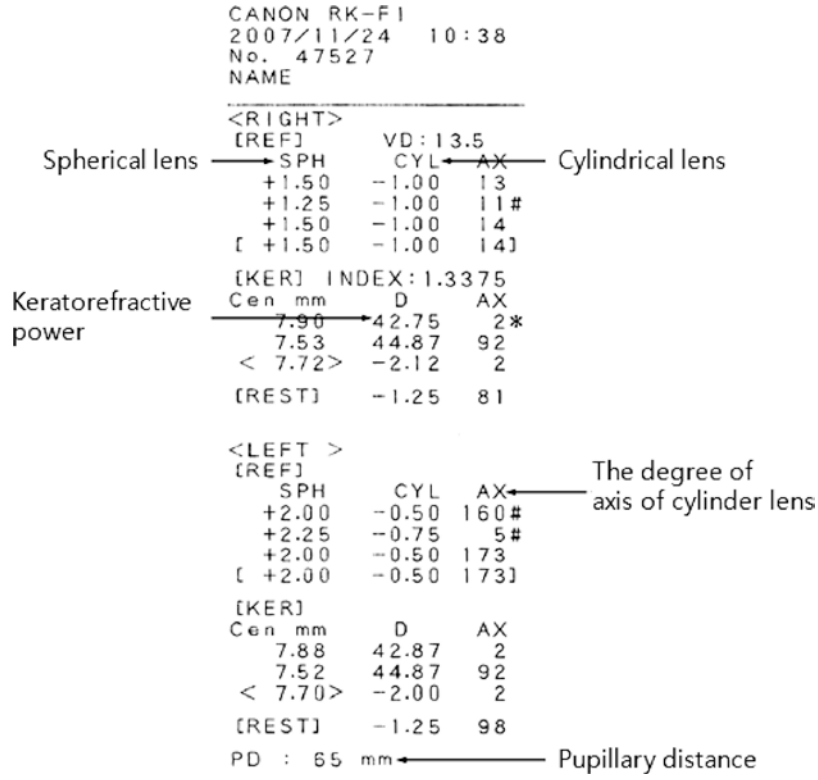


Fig. 2.9 Record of autorefractometer

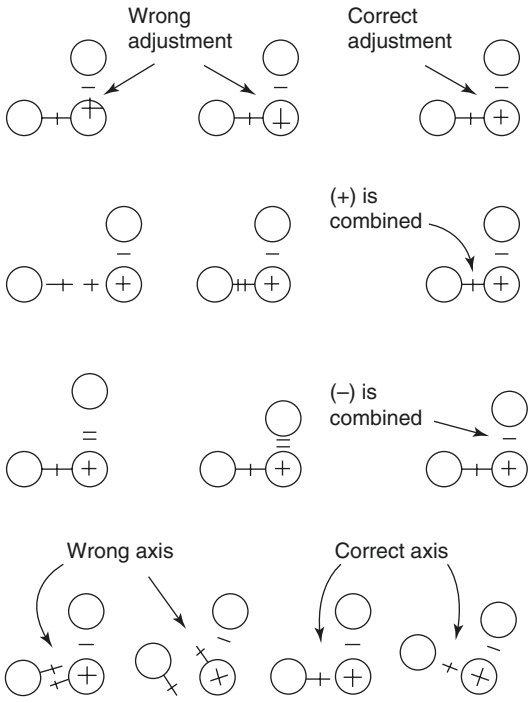


Fig. 2.10 Manual refractometer method

2.1.3.2 Manual Keratometer

Place the patient in front of the manual keratometry in the dark or semi-darkroom, and fix the head with the chin rest and the forehead rest. After covering one eye, adjust the reflector to be reflected on the patient's cornea through the ophthalmoscope. Turn the focus screw forward or backward so that the three circles are clearly visible. At this time, make sure that the right lower circle is located in the center of the cornea and the "+" mark appears in the center of the right lower circle (Fig. 2.10a). Turn the knob (Fig. 2.10b) so that the right "+" mark of left lower circle is overlapped with left "+" mark of right lower circle. Turn the vertical adjustment knob (Fig. 2.10c) so that the "−" mark of the bottom of the upper circle and the "−" mark of the top of the lower right circle are overlapped. If the "+" marks of the lower circles are not in the same position, it means that there is astigmatism (Fig. 2.10d). The value of horizontal, vertical, and cylindrical axis is read and written, and the refractive power of the entire cornea marked with D can be converted into the radius of curvature by the conversion table.

Normally, the refractive power of anterior cornea is 43D, and the radius of curvature is about 7.8 mm. Corneal scars and corneal irregular astigmatism are suspected when the concentric circles are not completely or partially visible. When there is a difference between the horizontal and vertical meridian, the difference is the degree of astigmatism. If the value of the horizontal or vertical line is less than 36D or 9.38 mm or 52D or 6.49 mm or more, it cannot be measured and indicates pathological refractive error.

2.1.4 Photorefraction

2.1.4.1 Indication

It is useful for infants or children and the patients who are not able to perform subjective refraction test because of poor coordination or lack of attention. Especially, it is useful for group screening of infants and children.

2.1.4.2 Purpose

The reflected light from the cornea and fundus can be photographed to measure refractive error and the presence of strabismus.

2.1.4.3 Method

It is a method using a camera equipped with a light source. When a patient's face is photographed by attaching a light source slightly lower than the lens of the camera, the patient's pupil becomes red due to reflex from the fundus. Here's how to use MTI photoscreener: use Polaroid monochrome film, and shoot at a distance of 1 m with an eccentricity of 1.2 mm between the lens entrance and the light source. At this time, the examiner makes an X mark exactly 1.25 inches above the center of the pupil. Red light and sound generator are used to make a patient pay attention. In order to measure the astigmatism, the light source is rotated 90° vertically and horizontally, and the picture is taken in two directions to print on one film.

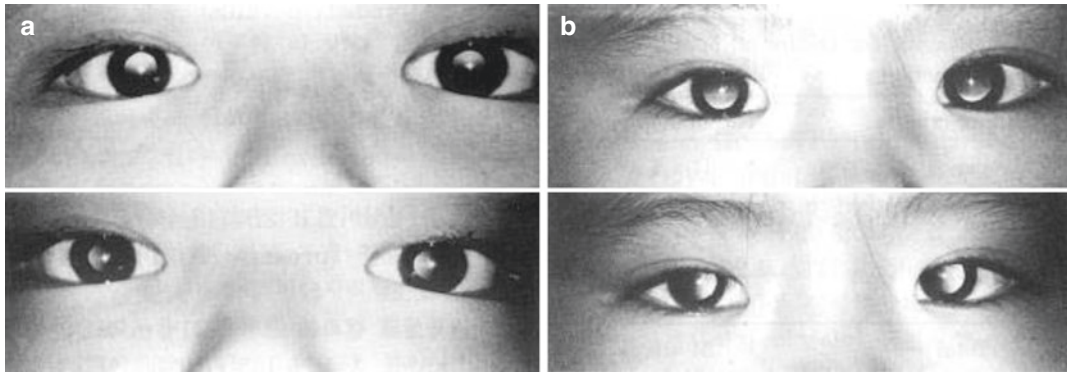


Fig. 2.11 Photo refraction method. (**a**) Myopia: Half-moon reflections appear at the top in the upper picture and at the left in the lower picture. (**b**) Primitive: Half-moon reflections appear on the bottom in the upper picture, on the right in the lower picture

2.1.4.4 Interpretation

In Polaroid photographs, there are two photographs, with a vertical axis picture at the top and a horizontal axis picture at the bottom. If the patient is emmetropic, the fundus reflex appears to have a similar brightness as a whole. If the patient is myopic, fundus reflex with half-moon shape appears on the upper side in the upper picture and on the left side in the lower picture and vice versa. If the light source is mounted on the top of the camera, half-moon reflex is observed at the opposite location (Fig. 2.11).

2.1.5 Dynamic Retinoscopy

2.1.5.1 Indciation and Purpose

Patients with refractive error or accommodative disorder can be candidate. This is for measuring the accommodative lag at a near distance in the binocular state, that is, the distance gap between the near target and patient's near target.

2.1.5.2 Method

A typical Nott method is as follows. Have the patient watch the near target at 40 cm after correcting far vision. The examiner should perform retinoscopy from the slightly outward and upward position, being careful not to cover the patient's visual axis. Determine the neutralization point while moving backward or forward. When performing this test, the patient should use bright and clear targets so that they can watch the near vision.

2.1.5.3 Interpretation

The dioptric value at the near target point is subtracted from the dioptric value at the neutralization point, which is the accommodative lag. If the neutralization point is further from the patient than near target point, the value will be "+" and vice versa. The normal value is +0.25 ~ +0.75. If a greater positive value is obtained, it shows insufficient accommodation such as esotropia or accommodative insufficiency, and if the value is lower than normal or -, it indicates excessive accommodation such as exotropia or accommodative spasm.

2.1.6 Ophthalmoscopy

The degree of refractive error can be found. The emmetropic examiner focuses the patient's retina through the lens by rotating the lens disc of ophthalmoscope. The power of lens indicates the patient's refractive error. The green number of the lens shows + lens, and the red number shows − lens. If both the examiner and the patient are emmetropia, they will look better when the lens disc is at 0, but it is usually better at −2 to –3D because of some accommodation (see Chap. 15).

2.1.7 Visual Evoked Potential (VEP)

In the case of a checkboard pattern, when the focus is on the retina, visual evoked potential waves become maximal. If the best correction trial lens is inserted in front of the eye, the maximal wave is generated, which is used to determine the refractive error (see Chap. 19).

2.2 Subjective Refraction

It is used to correct the glasses prescription which is obtained from objective refraction.

2.2.1 Astigmatism Examination

2.2.1.1 Cross Cylinder Method

Cross cylinder lens is composed of a – cylinder lens on one meridian and + cylinder meridian on the other meridian. The absolute dioptric values of two meridians are the same, and the axes are 90° from each other. Usually, 0.5D is used. When using a cross cylinder lens, a circle of least confusion should be placed on the retina, corrected with spherical and cylindrical lenses.

This test can confirm the dioptric power and axis of astigmatism. Calculate the spherical equivalent which is spherical lens power plus 1/2 cylindrical lens power and can obtain the best visual acuity. In this case, the circle of least confusion is placed on the retina. Check the astigmatic axis by comparing the visual acuity after placing the "–" axis of cross cylinder lens at 45° or 135° in front of the cylinder lens. If the latter is better than the former, in the case of "–" cylinder lens, the axis of the cylinder lens is rotated 5° to the "–" axis of the cross cylinder lens when cross cylinder lens is positioned at the side where better visual acuity was obtained, and then the visual acuity at 45° or 135° is compared over and over until the same visual acuity is achieved (Fig. 2.12).

Check the astigmatic power by comparing the visual acuity when the "–" axis of the cross cylinder lens is overlapped on cylinder lens with the

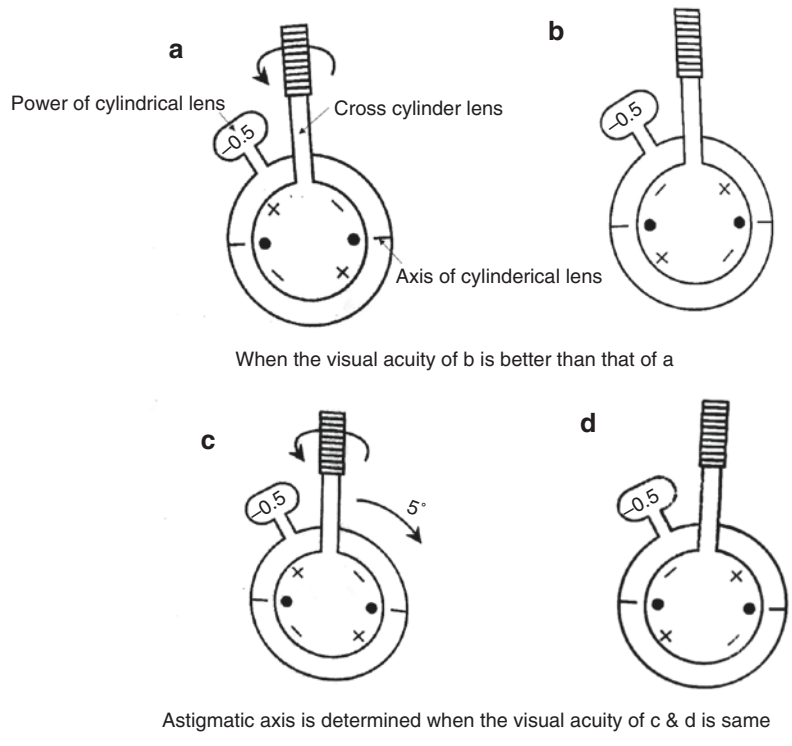


Fig. 2.12 Determination of astigmatism axis using a cross cylinder lens. Place the "-" axis of cross cylinder lens at 45°(**a**) or 135°(**b**) in front of the -0.5 cylinder lens. When the visual acuity of **b** is better than that of **a**, the axis of the cylinder lens is rotated 5° to the right (to the "-" axis of the cross cylinder lens when cross cylinder lens is positioned at the side where better visual acuity was obtained). Astigmatic axis is rotated over and over and determined when the visual acuity of **c** and **d** is same

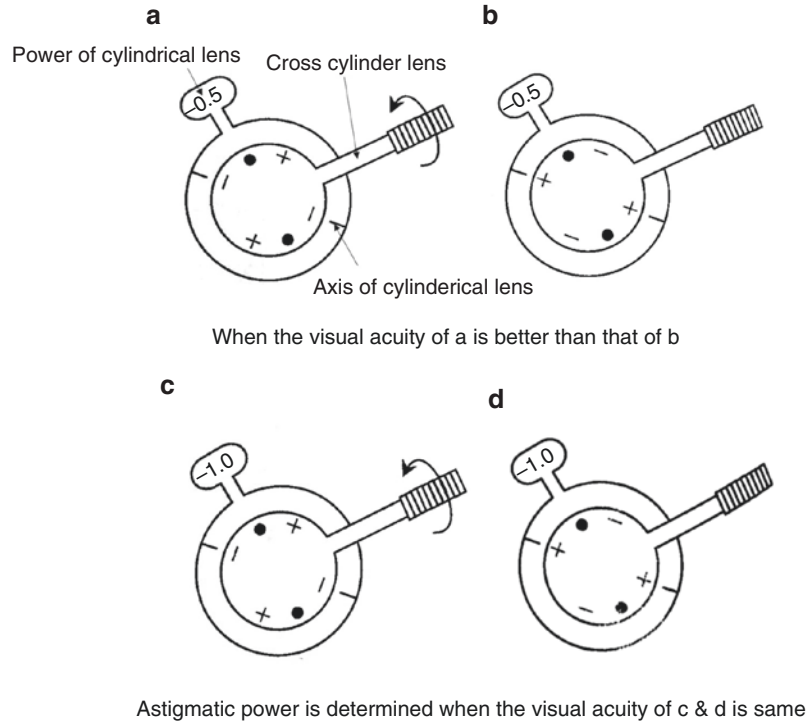


Fig. 2.13 Determination of astigmatism power using a cross cylinder lens. Overlap the "-" (**a**) or "+"(**b**) axis of the cross cylinder lens on the axis of -0.5 cylinder lens. When the visual acuity of **a** is better than that of **b**, increase the astigmatic power to -1.0 cylinder lens and the repeat until the same visual acuity is achieved. Astigmatic power is determined when the visual acuity of **c** and **d** is same

visual acuity when the "+" axis is overlapped. If the former is better the latter, in the case of "−" cylinder lens, increase the astigmatic power, and then repeat until the same visual acuity is achieved (Fig. 2.13).

Wear the cylinder lens, and measure the visual acuity until the best visual acuity is achieved with wearing the lowest "−" spherical lens or the highest "+" spherical lens to determine the final spherical lens power.

2.2.1.2 Astigmatic Dial

It is used to check the presence and degree of astigmatism. With wearing spherical equivalent lens (spherical lens power +1/2 of cylinder lens power), add +1.0D (fogging method) which makes compound myopic astigmatism. There is no astigmatism if there is no difference in all directions. If there is a difference in the contrast of the lines in the astigmatism dial, place the "−" cylinder lens at 90° to the direction that it is thick. Slowly increase the power of cylinder lens until lines in all direction have same contrast (Fig. 2.14).

Make a final spherical lens with fine adjustment. That is, check the highest "+" lens power or the lowest "−" lens power having the best visual acuity after wearing the spherical and cylinder lens which are determined in the previous step.

2.2.2 Reassessment Test

2.2.2.1 Red-Green Test and Duochrome Test

The principle is that chromatic aberration causes light to focus on different retinal plane depending on the refractive status. In emmetropia, long wavelengths of red light are focused slightly behind the retina, and short wavelengths of green light are slightly before the retina (Fig. 2.15). Therefore, the red and green marks look similar in emmetropia, but in the case of hyperopia, the focal plane is placed behind the retina, so that the green mark looks brighter, and in the case of myopia, the focal plane is placed before the retina, so that red mark looks brighter.

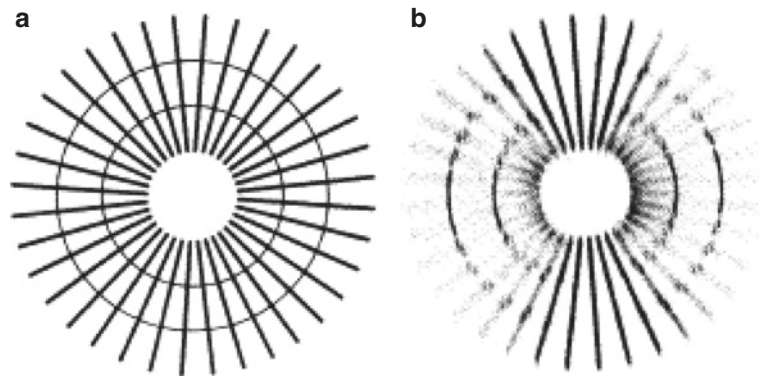


Fig. 2.14 Astigmatic dial. (**a**) Astigmatic dial. (**b**) In this case, the axis of astigmatism should be horizontal

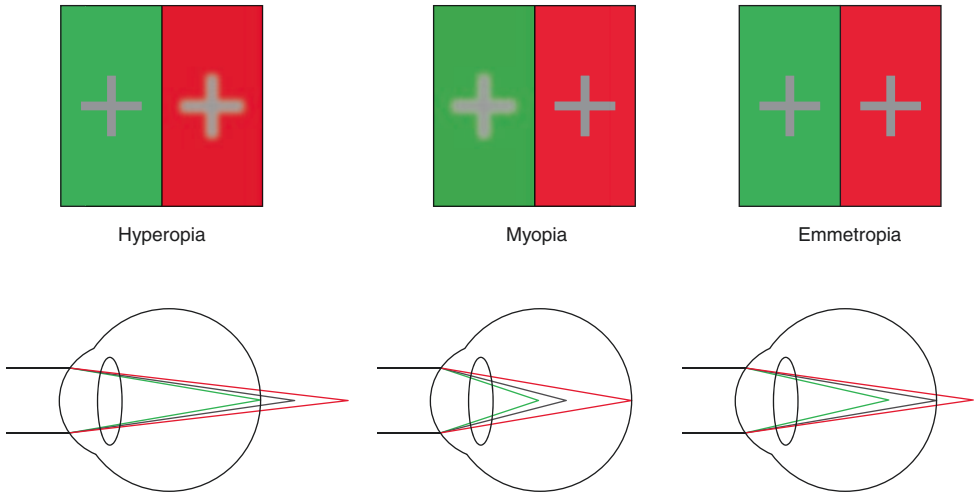


Fig. 2.15 Principle of red-green test

The final spherical lens can be adjusted up to 1/8D. At first, examine at 5 m distance with wearing final corrected lens. Make a look at the target with a black "+" sign on the red or green background. If both eyes are clearly visible, there is no astigmatism. If the red light looks clearer, it means myopic state which means undercorrection of myopia or overcorrection of hyperopia and if the green light looks clearer, vice versa.

2.2.2.2 Fogging Method

A subjective refraction test should be measured without accommodation. The fog method can reduce the accommodation by using a convex lens which does not make the image clear even when the patient accommodates. In this state, regulation is eliminated in principle. No accommodation occurs in fogging method.

The objects are not limited to children but VDT workers over the age of 30 years. It is helpful to avoid overcorrection of myopia because of relaxation of accommodation.

Both eyes wear the final spherical lenses with adding +3.0D lenses for 20–40 min.

Cover one eye, and make 0.5D decrements from the previous +3.0D on the other eye. At this time, 0.5D decrement lens is inserted, and then the existing lens is removed. When the visual acuity becomes 0.5–0.7, make 0.25D decrements until the visual acuity becomes 1.0. Check the lowest "−" lens or the highest "+" lens at which the best visual acuity is obtained. Calculate the spherical lens power as follows: the power obtained for the best visual acuity plus the power of 1/2 of the astigmatism plus +1.0D (fogging method). With wearing this lens, the visual acuity

becomes 0.5 which is appropriate to perform the astigmatic dial test. After wearing the spherical lens determined above, have the astigmatic dial be seen. If there is a difference in the contrast of the lines in the astigmatic dial, place the "−" cylinder lens at 90° from the direction to be thick. The axis of cylinder lens determines the axis of astigmatism. Until the lines become thick in all directions, increase the cylinder lens power. This cylinder lens power determines the power of astigmatism. With wearing the cylinder lens, check spherical lens again. Find the lens of the lowest "−" lens power or the highest "+" lens power at which the best visual acuity is obtained. This spherical lens determines the final spherical lens power.

The other eye is tested with the same manner. Check if the patient is comfortable with final lens. It is recommended to wear glasses for 15–20 min to determine the comfortableness. Fine adjustment can be performed and then the glasses are prescribed.

2.3 Prescription of Glasses

2.3.1 Precautions for Glasses Prescription

Patients should be prescribed according to their needs. Full correction is recommended for children and patients with strabismus. If there is no strabismus, hyperopia should be 1/3–1/2 undercorrected. Do not make much change compared to the previous glasses. If the astigmatic axis continues to be uncomfortable, set it to 90° or 180°. If it is not effective, adjust it with spherical aberration. Undercorrection is better than overcorrection.

2.3.2 Reading Glasses Prescription

Calculate the accommodative power by knowing the near point of accommodation after correcting to be an emmetropia. For example, if you can see a target of 1.0 at 33 cm in front of you, the accommodative power is 3D (1/0.33 = 3).

When the accommodative power is decided, leave 1/3 or 1/2 of them, and use the rest of them for reading glasses. For example, if the patient with accommodative power of 2D is reading at 40 cm, 2.5D is needed for accommodation. The patient's accommodative power is 2.0D, so leave 1D which is 1/2 of patient's accommodative power and prescribe 1.5D for reading glasses. Wear the prescribed lens, measure the near visual acuity, and adjust the lens power. It is better not to prescribe too strong because near vision does not have to be 1.0. Reading glasses less than 0.75D are not usually prescribed. It is a principle to prescribe a reading glass according to the individual patient.

2.3.3 Record of Glasses Prescription

Record the patient's name, age, sex, and date of the test. Record spherical lens, cylindrical lens, axis, and pupillary distance, and specify the near or far use (Fig. 2.16). Prescribe prism for phoria, strabismus, or convergence abnormality.

2.3.4 Lens Replacement

Cylindrical lenses can be prescribed as "+" or "−" and can easily be changed with each other. At first, combine the cylindrical and spherical lens power. Next, change the mark of cylindrical lens, and then add 90° to the astigmatic axis. For example, +2.5D sph = +1.5D cyl 90° is substituted by +4.0D sph = −1.5D cyl 180°, and −2.0D sph = +1.0D cyl 90° is replaced by −1.0D sph = −1.0D cyl 180°. In addition, +1.0D sph = −1.0D cyl 45° is substituted by plano = +1.0D cyl 135°, and plano = −1.5D cyl 120° is replaced by −1.5D sph = +1.5D cyl 30°.

2.3.5 Pupillary Distance

It is necessary to measure the pupillary distance not only for prescribing glasses but also for measuring angle of strabismus. Glasses that do not

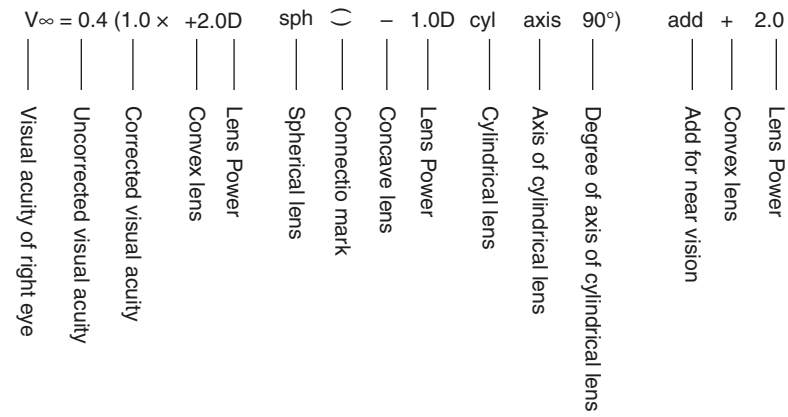


Fig. 2.16 Recording of glasses prescription

Prescription Glasses

		SPH	CYL	AXIS	PRISM BASE	PD
FAR	Rt.	D	D	°	Δ	
	Lt.	D	D	°	Δ	mm
NEAR	ADD					
	Rt.	D	D	°	Δ	
	Lt.	D	D	°	Δ	mm

measure the pupillary distance accurately will exhibit a prism effect.

2.3.5.1 For Far Vision

In the darkroom, the examiner sits in a position slightly lower than the front of the patient, 60 cm away from the patient, and holds the ruler in the left hand and places it horizontally under the line connecting the patient's pupillary center. The examiner closes the right eye and aligns scale of ruler 0 on the temporal boundary of the patient's right pupil, having the patient watch the examiner's left eye. The examiner closes the left eye and performs the same way. Measure the distance to the nasal boundary of the patient's left pupil (Fig. 2.17a). In the same way, the distance between corneal margin and pupillary reflex can be also used.

2.3.5.2 For Near Vision

Measure the pupillary distance at 33 cm which is usually used for near work, with examiner's one eye. The examiner's eyes are placed in the center of the patient's eyes, and the ruler is placed on the lower eyelid 12 mm below the apex of the patient's cornea. The patient then takes a look at the examiner's one eye, and the examiner measures the pupillary distance (Fig. 2.17b). If there is a high refractive error, record the distance between pupillary reflexes at 33 cm to eliminate the prism effect.

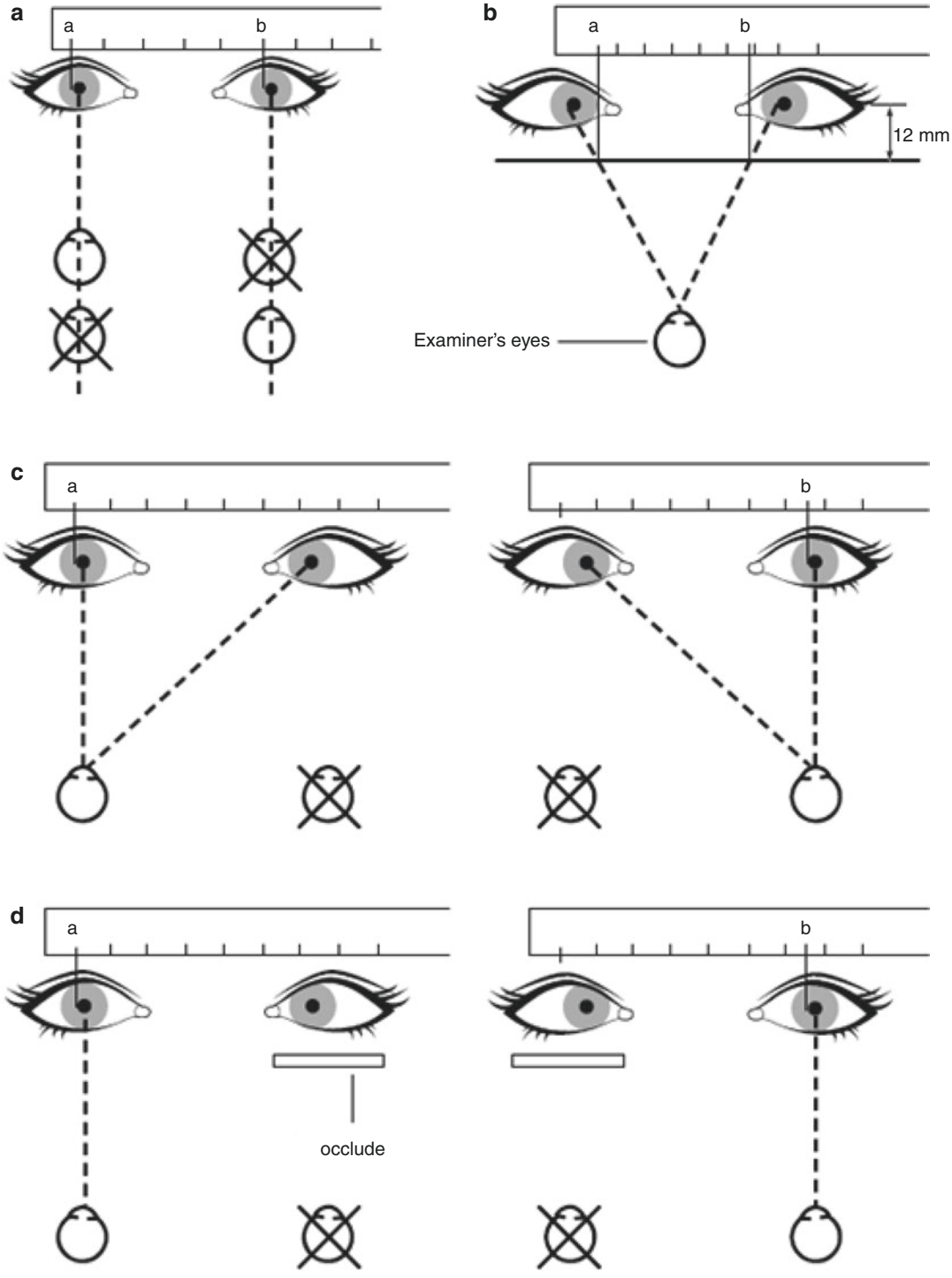


Fig. 2.17 Pupillary distance measurement. (**a**) In the case of distant gaze. (**b**) In the case of near gaze. (**c**) In the case of child. (**d**) In the case of strabismus (distance between a and b: pupillary distance)

2.3.5.3 For Children

This method is used for children with unstable visual line. The examiner faces the patient in front and places the ruler on the upper or lower eyelid. The examiner closes the right eye and aligns the scale of ruler 0 on the temporal boundary of the patient's right pupil, having the patient watch the examiner's left eye. The examiner closes the left eye and performs the same way. Measure the distance to the nasal boundary of the patient's left pupil.

2.3.5.4 For Patients with Strabismus

The examiner faces the patient in front and places the ruler on the patient's upper or lower eyelid. Cover the patient's left eye, have the patient's right eye watch the examiner's left eye, and read the scale of ruler with examiner's left eye. At this time, examiner closes the right eye. Cover the patient's right eye, have the patient's left eye watch the examiner's right eye, and read the scale of ruler with examiner's right eye. At this time, examiner also closes the left eye (Fig. 2.17c).

2.4 Glasses Test

To confirm the glasses have appropriate power or the glasses are properly made as prescribed, the power of the lens, the optical center, the principal meridian direction, and the prism power and the base direction are measured. There are analog and digital systems. Analog systems include telescope type and projection type. Digital type is display-only digital type or computer-integrated type (Fig. 2.18).

The analog method of telescope type lens meter is as follows:

Turn on the light source of the lensometer (Fig. 2.18a), and focus on the "+" mark while looking at the eyepiece. Put the glasses on the lensometer, and fix them, and then turn the screw to focus the circle with a yellow dot. Move the center of yellow dot vertically and horizontally to match the intersection of the "+" mark which is the center of the field of view. Focus the yellow point again and read the scale. When focusing, always turn the steering wheel slowly from the positive (+) side to the minus (−) side not to

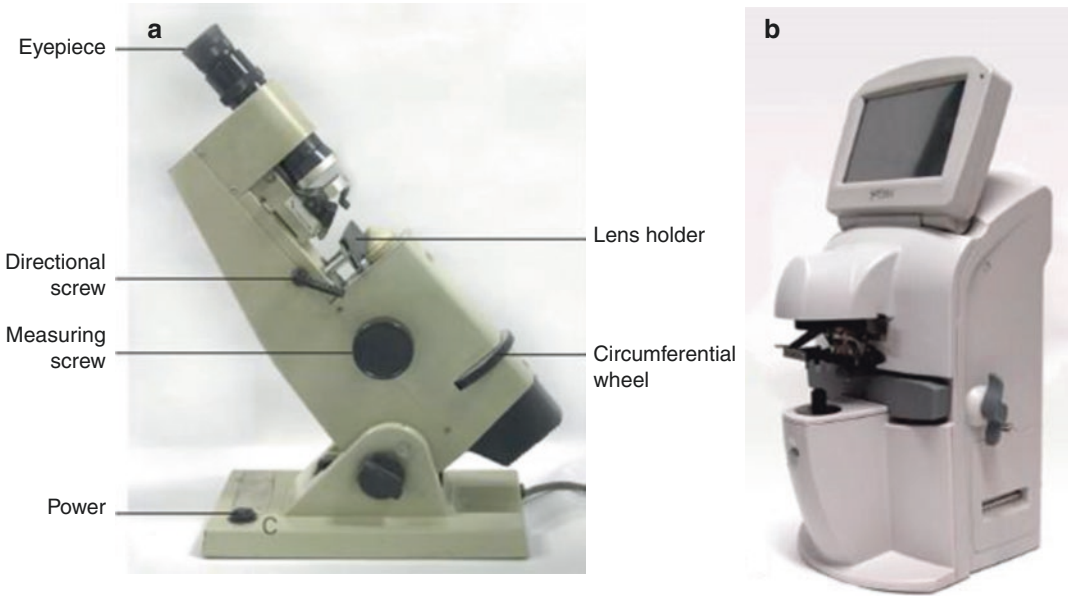


Fig. 2.18 Lensometer. (**a**) Analog lensometer. (**b**) Digital lensometer

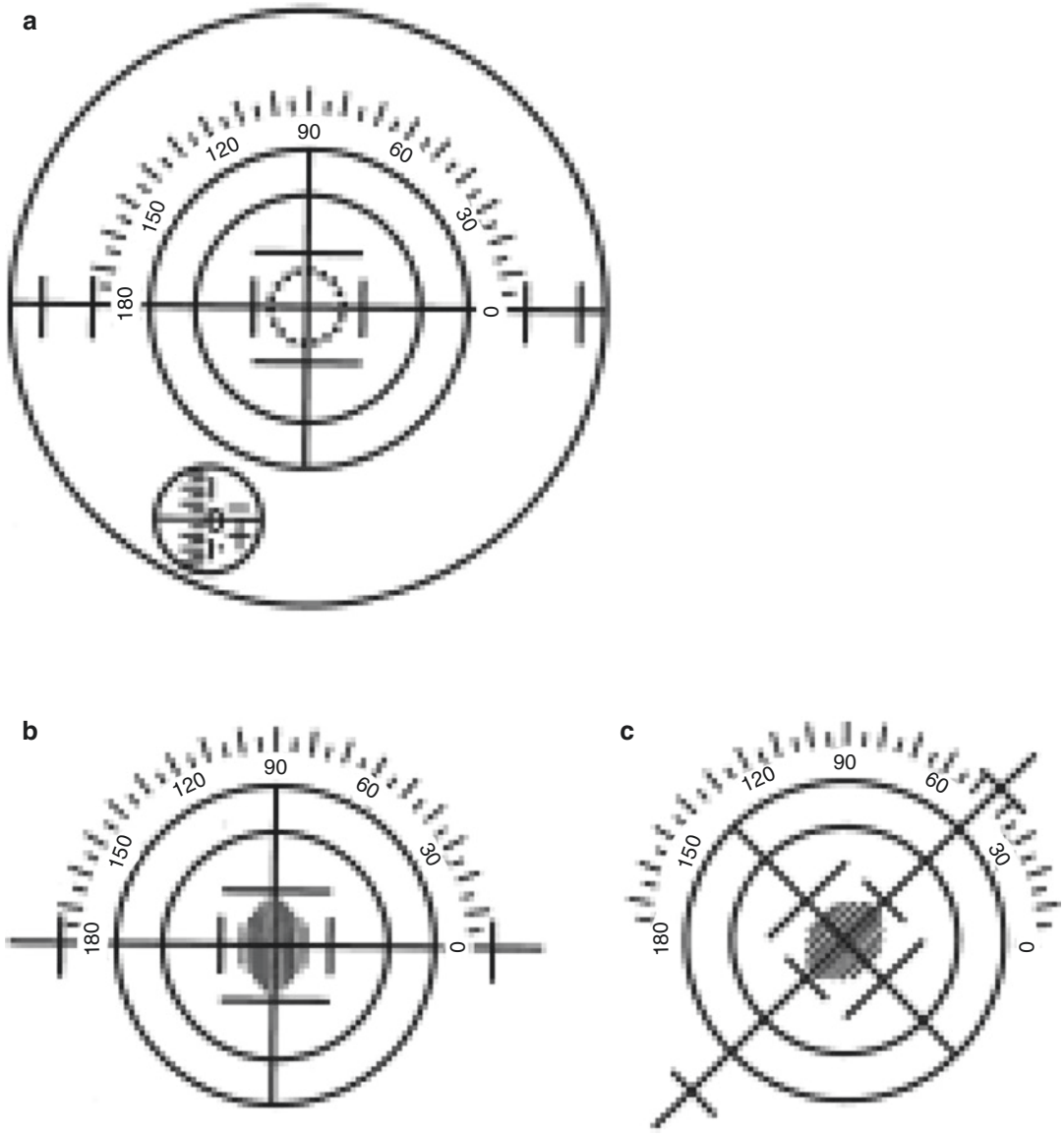


Fig. 2.19 Viewing the lensometer. (**a**) With no astigmatism. (**b**, **c**) With astigmatism

induce the examiner's accommodation. If you pass too much to the minus side, do not turn back to the plus side slowly, but return to the plus side quickly, and start slowly again from the beginning. The dioptric power at this time is the refractive value (Fig. 2.19a). In the case of projection type, results can be stable since the examiner's accommodation is not involved. If the circle of yellow point does not become an accurate circle, it means that there is astigmatism (Fig. 2.19b). By moving the rotary screw, the long line of the "+" mark coincides with the direction of the circle of yellow point. Record the power and the angle in this direction (Fig. 2.19c). Turn the screw again to focus in the direction perpendicular to the direction in which the yellow point flows, and read the power at this time. Move the pointing device at the center of the optical axis to mark the optical axis of the lens. The glasses of the other eye are also performed in the same

manner, and the distance between the centers of two optical axes will be pupillary distance. In the case of astigmatism, the numerical value obtained by subtracting the smaller from the bigger is the power of cylinder lens, and the numerical value of the smaller is the power of spherical lens. The axis is an angle in a direction in which the line having the larger absolute value flows.

Suggested Reading

Artal P. Handbook of visual optics: instrumentation and vision correction. Boca Raton: CRC Press; 2017.

Brown B. The low vision handbook for eyecare professionals. Thorofare: Slack; 2007.

Cole RG, Rosenthal BP. Remediation and management of low vision. St. Louis: Mosby; 1996.

Faye EE. Clinical low vision. Boston: Little Brown & Company; 2000a.

Faye EE. The lighthouse ophthalmology resident training manual: a new look at low vision care. New York: Lighthouse International; 2000b.

Freeman PB, Jose RT. The art and practice of low vision. Oxford: Butterworth-Heinemann; 1997.

Jonathan Jackson A, Wolffsohn JS. Low vision manual. Edimburg: Butterworth Heinemann/Elsevier; 2007.

Jose RT. Understanding low vision. New York: American Foundation for the Blind; 1983.

Lueck AH. Functional vision: a practitioner's guide to evaluation and intervention. New York: AFB; 2004.

Rosenthal BP, Cole RG. Functional assessment of low vision. St. Louis: Mosby; 1996.

Accommodation and Convergence

3

Jae Ho Jung

3.1 Near Point of Accommodation

The accommodation is a reflex action of the eye, in response to focusing on a near target, then looking at a distance target (and vice versa), comprising coordinated changes in vergence, crystal lens shape and pupil size. The accommodation amplitude meane the difference of refractive error between looking at near target and at distance target. Far point of accommodation (FPA) refers to the farthest distance that a man can see something without accommodation, and the near point of accommodation (NPA) is the closest distance that can be clearly seen when the accommodation is maximized.

Range of accommodation refers the distance between the FPA and the NPA. These measurements can be helpful in situations where accommodation abnormalities are suspected such as presbyopia, hypermetropia, amblyopia, and strabismus.

3.1.1 Method (Fig. 3.1)

- Under correcting the refractive error, based on looking a distance target, place the rule on the patient's noze.
- Target slowly approaching the from a distance to patient's nose. The near point accommodation rule is the point closest to the nose where convergence and binocular single vision can

Fig. 3.1 Accommodative rules. (**a**) The RF rule. (**b**) The Krimsky-Prince Rule. (**c**) The Berens Rule.

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no longer be maintained as an object approaches. Examiner select the target (usually 20/40 target) that the patient can see clearly at 0.4 meter, and fix it. This test started with monocularly and then binocularly condition. Binocular condition show the convergence influences on accommodation.

- NPA is represented as centimeters.
- In case if the NPA is too far and so cannot be measured within a distance of the near point measuring system, NPA is checked with a convex lens so that the nearest point moves 20–30 cm forward. That is, if the NPA is measured wearing the a diopter lens is *at b* m with a diopter convex lens, the NPA is $b/(1 - a \times b)$ cm.
- For young adult with normal vision, the near point is about 25 cm, and the far point is between 25 cm and infinity.

3.2 Amplitude of Accommodation

The difference between the dioptic power needed to focu at near point and far point is called amplitude of accommodation. *This power is measured in units called diopters (D) and is calculated by dividing the NPA in centimeters into 100. If a patient with an NPA of 25 cm has an accommodative amplitude of 100/25=4 D). Specifically, amplitude of accommodation can be calculated using following method.* $A = 1/p - 1/r$, A diopter = amplitude of accommodation, p meter = NPA, and r = FPA. Also, $A = P - R$, P = refractive error of NPA, and R = refractive error of FPA. In the emmetropic eye, r is infinite, so $A = 1/p$, that is, the amplitude of accommodation is the reciprocal number of the NPA.

$A = 1/0.1–2 = 8$D in −2D myopic eye with 10 cm of NPA, and $A = 1/0.25 - (-2) = 6$D in +2D hypermetropic eye with 25 cm of NPA.

Since the FPA is in the back of the retina in the hyperopic, so '-' sign attach. The amplitude of accommodation decreases with age. The average amplitude of accommodation according to age is shown in Table 3.1.

Table 3.1 The average amplitude of accommodation according to age

Age	Accommodation amplitude (D)	NPA of emmetropic eye (cm)
10	14	7.1
20	10	10
30	7	14.3
40	4.5	22.2
45	3.5	28.5
50	2.5	40
55	1.75	57
60	1	100
65	0.5	200
70	0.25	400
75	0	∞

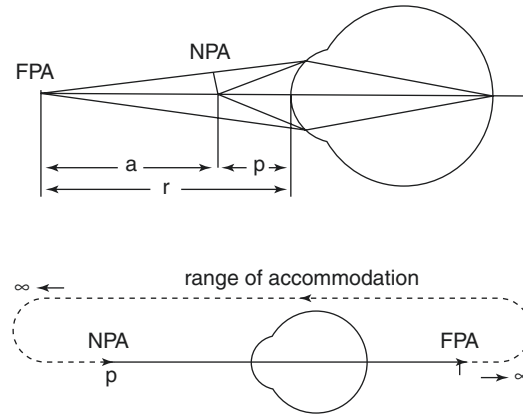

Fig. 3.2 Range of accommodation

The range of accommodation is the distance bewteen the furtherest point an target of a certain size is in clear sight and the nearest point at which the eye can maintain that celar vision. The range of accommodation indicates the adjustable range of accommodation, which is the range between the NPA and FPA, is meaningful only in myopia (Fig. 3.2). For example, when we calculate the range of accommodation in emmetropia, −2D myopia and +2D hypermetropia with 10D of amplitude of accommodation, $10 = 1/p - 1/r$ in case of emmetropia where r is infinity, p is 0.1, and the NPA is 10 cm. Therefore, the range of accommodation is from 10 cm to infinity. In case of −2D myopia, $10 = 1/p - 1/r$; r is 1/2, that is, 50 cm; and $p = 0.125$. Thus, the range of accommodation is 12.5–50 cm, and only within this distance a clear image is formed in the retina.

However, In hypermetropia, $10 = 1/p - 1/r$ and p is 1/2, that is, 50 cm, so $r = -0.125$. The control range is from 50 cm before the eye to 12.5 cm behind the eye.

The method of measuring the amplitude of accommodation is to measure the distance between the NPA and FPA as described above, but the method used in the clinic is as follows.

3.2.1 Near Point Method

While refractive error is fully corrected, the reciprocal number of the distance measured in meters in terms of distance from the point of blurring to the nearest eye until the letter or target is blurred The reciprocal number of the distance of the point to appear blurred when you bring your eye closer to the letters or targets until they appear blurred in the unit of meter is amplitude of accommodation, of which the unit is diopter.

3.2.2 Rule Method with Distance Correction

Use the rule with the diopter and the "+" lens to adjust the NPA to within the range of the rule. For example, while refractive error is fully corrected, if the NPA is 0.5 m with a +1.0D lens, the amplitude of accommodation becomes 1D.

3.2.3 Rule Method Without Distance Correction

In myopia patients who do not know the refractive error, the difference between the diopters of NPA and FPA.

3.2.4 Spherical Lens Method

The amplitude of accommodation is the difference between the lowest value and the highest value of the spherical lens to obtain clear visual acuity to the near target. First, increase the power of the "+" lens until the target appear blurred, and add the "−" lens again to increase the power until the target is blurred again so that the sum of the maximum number of "+" lenses and the number of "−" lenses can be the amplitude of accommodation. Since accommodative convergence may work, it should be tested in monocular environment.

3.2.5 Binocular Amplitude of Accommodation

Generally, amplitude of accommodation is larger in binocular condition than in monocular condition. Because, convergence works in accommodation.

3.3 Near Point of Convergence

Convergence is a vergence adduction movement that increase the visual angle to permit single binocular vision during near viewing. Convergence can be voluntary but need not be no near stimulus need be present to elicit vergence. It is also reflexive and a co-movement in the near response. Convergence may be divided in four groups: tonic convergence, fusional convergence, accommodative convergence, and proximal convergence. The convergence appears as synkinetic changes with pupil contraction and accommodation. The near point of convergence (NPC) is the distance between the eye and the object when the convergence is maximized. It is normally located at the same position as the nose and is similar to the interpupillary distance (PD).

3.3.1 Method

- Use an accommodative target (single 20/30 letter) place in 33 cm in front of nose and keep an eye on binocular condition. When the target is approached slowly toward the nose until fusion is no longer maintained, or the eyes abducted are measured. We should ask the patient to try to make the target one, so that the nearest distance can be near point of convergence.

- It can also be judged when the diplopia is manifested, the corneal reflex is deviated from the cornea center, and miosis of near reflex disappears.

3.3.2 Judgment

The normal range is usually 5~10 cm and is not related to age. If it is more than 10 cm, it means convergence insufficiency. If it is not more than 40–50 cm or convergence is not observed, it means convergence paralysis.

In normal subjects, there was no significant difference in the measurement results when using the accommodative target, the optical chart, or the optical chart with the red filter. However, when there was a problem in convergence, the NPC can be determined more objectively, using red glass over one eye and moving a light forward until the patient experience diplopia.

3.4 Fusional Convergence

Fusional convergence is a voluntary movement of the two eyes to obtain a binocular single vision. The fusional convergence amplitude is measured by the maxinal response to stimulation when patient may cease to converge further and may recognize diplopia, at the moment the examiner can see the patient's eye break from the point of maximal convergence; this is called the fusion break point; the examiner then reduce the retinal image disparity by reducing the prism power until fusion is restored and the target is seen clearly; this is the fusion restoration point.

3.4.1 Major Amblyoscope

Measurement should be done in no accommodative condition by wearing a fully corrected lens. First, the ocular deviation (subjective deviation) is investigated using the simultaneous pattern (heterogeneous pattern), and then the pattern is replaced with the pattern for fusion (homogeneous pattern). In the position of subjective ocular deviation, move the barrel slowly until the fusions are broken so that they begin to appear as two at the position of the eye convergence and divergence. The convergence amplitude is the range between limit point of the convergence and divergence.

3.4.2 Rotating Prism

Place the rotating prism based out, and set the scale to zero. The patient looks at a 5 m distance target and gradually increases the prism number from zero. But it is possible to return to the single binocular vision by convergence soon when diplopia occurs. The upper limit of the prism power when the patients are aware of the diplopia is referred to relative fusional convergence near point. In the same way, when the rotating prism based in, the relative divergence occurred, and the amplitude of the prism when the patients aware the diplopia is referred to relative fusional divergence far point. The range of relative fusional convergence near point and relative fusional divergence far point is the fusion amplitude.

3.4.3 Judgment

Fusioanl vergence is classified according to the plae of eye movement. Fusional convergence eliminates bitemporal retinal disparity and controls an exophoria. The normal value of the fusion amplitude is −5° to +15° ("−" means divergence, and "+" means convergence). When using a rotating prism, the normal value is −10 △ to +30 △ ("−" means divergence, and "+" means convergence). When using the Bagolini linear lens, it is judged based on the standard of rotating prism method.

3.5 Accommodation Convergence/ Accommodation (AC/A) Ratio

Accommodative convergnece is the amount of convergence elicited for a given amount of accommodation. The relationship between accommodation and convergence is prism diopters (PD) to accommodation in diopters: the AC/A ratio increase with age. Just as convergence can be

stimulated by accommodation, so accommodation can be stimulated by convergence. The ratio of convergence accommodation in diopters to convergence in PD is called CA/C ratio.

3.5.1 Method

3.5.1.1 Lens Gradient Method

It is a method to stimulate the accommodation by keeping the fixing distance constant and changing the power of plus or minus lenses. An accommodative target must be used and the working distance is held constant. Plus or minus lenses are used to vary the accommodative requirment, and the difference between the ocular alignment with and without the lens, divided by the power of the lens, is the AC/A ratio.

For example, patient's ocular alignment is measured with the patient viewing the accommodative target at a specific distance such as 33 cm, and the patient is found to have an esotropia of 15 PD. A plus 3 D spherical lens is placed over each eye, and ocular alignment is again measured with the patient viewing the same target at the same distance. The patient is now found to have an esophoria of 0 PD. The difference between the ocular alignment with and without the lens, divided by the power of the lens, is the AC/A ratio and is (15-0)/3 (D)= 5. This means that when 3 diopter of accommodation was reduced in this patient by placing a 3 D spherical lens in front of the eyes, the patient's convergence, measured at the same distance from the eyes, decreased from 15 to 0 PD. AC/A ratio of this patient is 5, patient has high AC/A ratio. In another patient viewing the clear target at 5 m, and a change in deviation from an exophoria of 2 PD to an esophoria of 10 PD when minus 3 D spherical lens. The AC/A ratio then would be (10−(−2))/3 (D) = 4. Lens gradient method has no difference between test distance, examiner can use 33 cm distance with plus lens and 5 m distance with minus lens.

3.5.1.2 Heterophoria Method and Geographic Method

This method uses the distance-near relationship to determine the AC/A ratio. Instead of measuring ocular alignment at near with and without a specific power lens, ocular alignment is measured at distance and near, and the difference in alignment in PD between distance and near viewing is divided by the fixation distance used for near viewing as expressed in diopters. Ocular deviation should be checked in condition of fully corrected refractive errors fixing 5 m target by prism and alternative cover test. Next, move the target to 33 cm, and measure the ocular deviation by the same method. If deviation at distance = 1Δ, deviation at near = 2Δ, and PD = interpupillary distance in centimeter and the reciprocal number of the near distance in diopter (33 cm is 3D), AC/*A* ratio = PD + (Δ 2 – Δ1)/D. Marking "+" in esotropia and "−" in exotropia. For example, interpupillary distance is 6.0 cm, ocular deviation at near is 8△ of esotropia, and ocular deviation in distance is 2△ of exotropia, the AC/*A* ratio = 6.0 + (−8−(−2))/3 = 4. This method can be overestimated due to the near convergence and depends on the interpupillary distance. The AC/*A* ratio of the normal person obtained by this method is within PD ± 0.3.

3.5.1.3 Near-Distance Comparison Method

It is most often used in a simple way. A high AC/A ratio can be presumed when the angle of deviation is 10△ or more at a near distance than the far distance, and the ratio is measured by the method mentioned above.

3.5.1.4 Fixation Disparity Method

In this method, the AC/*A* ratio is measured indirectly by using the change of the fixation disparity caused by the convergence induced by prism and the change of the accommodation caused by the spherical lens. This method is not used generally in clinical practice.

3.5.2 Results

The normal AC/A ratio is between 2 and 5, regardless of the method of testing that is used. It should be noted, however, that the

AC/A ratio varies from person to person and from day to day or hour to hour in a given individual depending on that person's level of fatigue or alertness. In addition, the AC/A ratio rises sharply after the age of 40 as accommodation begins to be lost but convergence remains stable. Nevertheless, values above 5 usually indicate an excess of convergence per unit of accommodation, whereas values below 2 suggest convergence insufficiency. An elevated AC/A ratio in a cooperative child is a risk factor for the rapid onset of myopia, or is risk for bifocal lens to treat accommodative esotropia.

3.6 Convergence accommodation/ accommodation ratio (CA/A ratio)

The CA/A ratio, needs the patient experience no blur during the test. This can be accomplished by the use of a pin hole device, performing the test in dim illumination, or using a Gaussian target. In this test, accommodation is measured as convergence is produced using progressively stronger base-out prisms. Unlike accommodation, convergence does not decline significantly with age. Thus, just as the AC/A ratio increases with age, the CA/C ratio decreases with age. Recent study suggest that CA/A ratio may work in control intermittent exotropia. Measruing CA/A raio may also important issue in strabismus patient.

Suggested Reading

Alpern M, Kincaid WM, Lubeck MJ. Vergence and accommodation: III. Proposed definitions of the AC/A ratios. Am J Ophthalmol. 1959;48(1):141–8.

Fincham EF, Walton J. The reciprocal actions of accommodation and convergence. J Physiol. 1957;137(3):488–508.

Ittelson WH, Ames A Jr. Accommodation, convergence, and their relation to apparent distance. J Psychol. 1950;30(1):43–62.

Von Noorden GK. Binocular Vision and Ocular Motility: Theory and Management of Strabismus. Mosby, 2002.

Color Vision

4

Jong-Ho Park

Color vision is a function of the retinal cone cell, which is the ability to distinguish the color of the object according to the wavelength difference among the visible light. In other words, the perception of color is a sensory phenomenon, not a physical phenomenon. Color vision abnormalities can be innate or acquired.

Every color that a normal person sees is represented by a mixture of three monochromatic lights (red, green, blue). The incomplete function of one of the three types of cone cells is called a trichromacy. And the incomplete function of two of the three types of cone cells is called a dichromacy. In reality, however, it is difficult to distinguish between color weakness and color blindness, so this classification has not been used well in recent years. Depending on severity, it is classified as mild, moderate, or high degrees, or it can be classified the protan, deutan, and tritan according to the cone cells with abnormalities (Table 4.1). The monochromat is total color blindness, and the object looks like a black-and-white photograph. In Koreans, 4.2–5.9% of men and 4% of women have congenital color vision defects.

During the test, daylight with cloud is considered as standardized luminance of examination condition. It is recommended to use standardized illumination for the examination because it is greatly influenced by latitude difference, time difference, and cloud thickness. Various color vision tests have been developed for detection of color vision abnormalities. There are two types of inspection: a method using the color of the object and a method using the color light. Correction of the refractive error is necessary, and elderly person wears magnifying eyeglasses to match inspection distance.

4.1 Selection of Color Vision Test

The pseudoisochromatic plate (PIP) or Lantern test is used in the screening test to detect cases of suspected color vision abnormality, but there is a limit. In other words, it turn out false even if it's

Table 4.1 Classification of color vision defects

	Protan	Deutan	Tritan
Anomalous trichromat	Protanomaly	Deuteranomaly	Tritanomaly
Dichromat	Protanopia	Deuteranopia	Tritanopia
Monochromat	Cone monochromatism, rod monochromatism		

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normal, and a person with color vision abnormality can get the right answer. It should be avoided to judge the degree of color abnormality as color weakness and color blindness. Be careful not to judge protan and deutan reversely. The anomaloscope is used to confirm the diagnosis. This test should be used in careers such as aircraft crew and policeman.

The degree of congenital color vision abnormality is checked with the Farnsworth dichotomous test panel D-15. However, this test cannot be used to determine the presence or absence of color vision abnormality. Discrimination tests such as the panel D-15 and the Farnsworth-Munsell 100 hue test are used for the detection of the degree of color discrimination ability and the confusion axis over the acquired color abnormality.

4.2 Screening Test

4.2.1 Pseudoisochromatic Plate

All diseases are subject to inspection, and this test is used to detect, classify, and qualify color blindness. It is easy to be confused by the dyschromatopsia because the letters and numbers are drawn in the background of the rounded dots of various colors in similar shape. It is widely used in group test because it quickly and easily finds the color abnormality. Ishihara and Hahn's pseudoisochromatic plate tests are effective in identifying normal and congenital color blindness, but it is not sufficient to determine classification and degree. The HRR pseudoisochromatic plate test consists of three simple geometric forms instead of numbers to determine the type and degree of the disordered person. It is possible to divide the degree by the degree of severity of color abnormality, and it can also distinguish tetartanopsia. However, it is not accurate to find out the red and green color abnormalities. It is desirable to inspect with the preexisting pseudoisochromatic plate test.

4.2.1.1 Methods

The illumination in pseudoisochromatic plate test uses natural light from the northward window or a fluorescent lamp for inspection to have a brightness of about 200 lux. At a distance of 75 cm, one plate should be presented perpendicular to the line of sight, and the inspection shall be carried out in accordance with the test rule. Test time is within 3 seconds per page. If the color vision is normal, it takes less than a second, but if run out of time, a slight error is suspected even if you get the correct answer. The normal person reads as 8, but a examinee who is a red-green color blindness reads as 3. (Fig. 4.1).

4.2.2 Ishihara Test Charts

It consists of 25 plates in total. Only the presence or absence of color blindness should be examined, and classification and degree judgment should not be made. Plates 1 through 21 are checked; the detection plate is used to determine the presence or absence of color abnormality. Plates 22 through 25 consist of two digits. It is easier for the patient with protan to read to the right digit between the

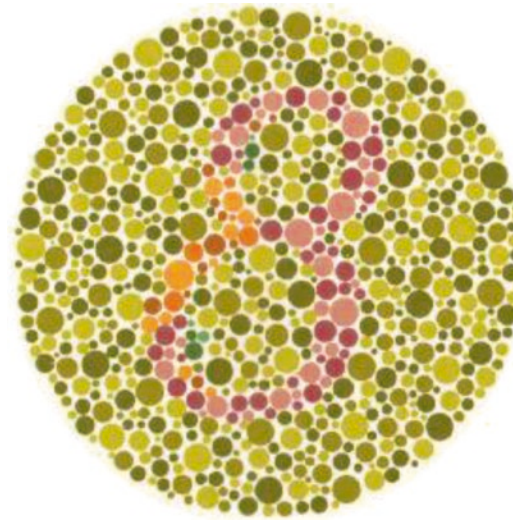

Fig. 4.1 Pseudoisochromatic plate test

two-digit numbers. However, it is easier for the patient with deutan to read to the left digit between the two-digit numbers. More than 6 wrong answers out of 14 plates are considered as abnormal, more than 3–5 wrong answers are considered suspected color vision abnormality, and less than 2 wrong answers are normal.

4.2.3 Hahn's Pseudoisochromatic Plate Test

It consists of total 21 plates that 12 plates of part 1 (detection of color abnormality) and 9 plates of part 2 (degree classification of color abnormality).

If a tester reads Arabic number in about 3 seconds or draws the curve straight in about 10 seconds, then it is considered to be normal. Plates 1–12 are used to judge the presence or absence of color abnormality. The classification and degree classification method of the color blindness is determined by examining using the plate 13–18 indicated by numerals and the plate 19–21 indicated by curves.

4.2.4 Hardy-Rand-Rittler (HRR) Color Test

It consists of 24 plates. Patients are asked to differentiate between the three patterns of circles, scissors, and triangles.

- Plates 1–4 identify color blindness.
- Plates 5–10 distinguish between the first and second (red-green) and third (blue-yellow) color blindness defects.
- Plates 11–20 qualify the first and second (red-green) color defects with mild, moderate, and high degrees.
- Plates 21–24 qualify the third (blue-violet) color-blind person with mild, moderate, and high degrees.

4.3 Lantern Test (Fig. 4.2)

It was developed in the US Navy to screen soldiers for color blindness. This has been widely used as an aptitude test to identify the identification ability of traffic lights for railways, ships,

Fig. 4.2 Farnsworth Lantern

and aviation employees. This test detects congenital color vision abnormalities sensitively, so this test is aimed at those who are detected in group screening and those who are suspected of having color vision abnormalities. Since this test uses color light, it can examine the condition of color vision more than one way. This test is highly reproducible because of low individual variation by the patient and the examiner, and it also detects slight color defects.

4.3.1 Methods

The tester consists of a main body and an operating plate. Two holes are arranged vertically in a cover like a cylinder in front of the body. The combination of color light is presented as nine kinds of red-red, green-green, yellow-yellow, red-green, green-red, green-yellow, yellow-green, red-yellow, and yellow-red. It is carried out in a semi-dark room. It illuminates for 2 seconds each at 3–5 m inspection distance and extinguishes for 2 seconds and displays nine kinds continuously. Let the examinee answer the name of the color given at that time. Patient's answer is written as: R for red, G for green, and Y for yellow. If all nine answers are correct, end the test. If there is a wrong answer, check again, and the number of incorrect answers will be the score. If red-green color is incorrect, 2 points is scored. If yellow color test is incorrect, 1 point is scored.

Judgment is classified into pass and fail. The test result is considered as pass in the following conditions: if the total number of points is scored 6 or less, or the number of incorrect answers is 3 or less for more than 2 times, and yellow color test alone is incorrect and mistaken, red and green tests are always correct, or patient recognizes the color correctly that was incorrect when the test distance is shortened. In addition to the inherent congenital abnormalities of color vision, it can also be used as a simple visual function test. In acquired achromatism, even if the visual acuity is about 0.01, a examinee is often recognized correctly.

4.4 Discrimination Test

4.4.1 Panel D-15 Test (Fig. 4.3)

This test is aimed at patients who have been judged as a color vision abnormality by false coincidence test. The degree of color blindness is divided into high (functional color blindness) or less than moderate. It is effective for the determination of the highly anomal type having the congenital color abnormality including the third color anomaly, but there is a limit in that a weak color tone abnormality is not detected. This test is not a test to determine whether it is normal or abnormal. It is also useful for various eye diseases that cause acquired color vision abnormalities other than congenital abnormalities, and this is helpful in the observation of choroidal retinopathy, optic nerve disease, etc. It is advisable to perform this test if there is congenital color vision deficiency.

4.4.1.1 Method

At the left end of the long box, the color of the reference color is fixed. There are 15 different color schemes; each color has a number on the back of it. And then take out 15 color plates and mix them in order. Ask the patient to find a color tint most similar to the reference color tint, and arrange the color tint next to the reference color

Fig. 4.3 Panel D-15 test

tint. And repeat the test in the same way. Inspection time should be 1–2 minutes, 5 minutes, or less.

Judgment of test consists of pass and fail.

- Pass, mild abnormal findings

After closing the box, turn it over, and read the number of the color plate arranged toward the bottom. Connect the lines according to the numbers arranged in the picture on the recording paper. When arranged according to the total number, a circle with no error is drawn, which includes normal and mild color abnormality (Fig. 4.4a). If there is a change in the number after the line, a crossing line is partially drawn, which is called a minor error and is regarded as a pass (Fig. 4.4b, c). Therefore, it does not check the color discrimination ability of 15 colors. If there is one crossing line, it is one error, and the judgment is passed. Normally, color numbers 7–15 go straight from right to left and from 15 to 8 are arranged upside down.

- Fail, severe abnormality

The occurrence of two or more transverse lines crossing circles in a sequence is considered

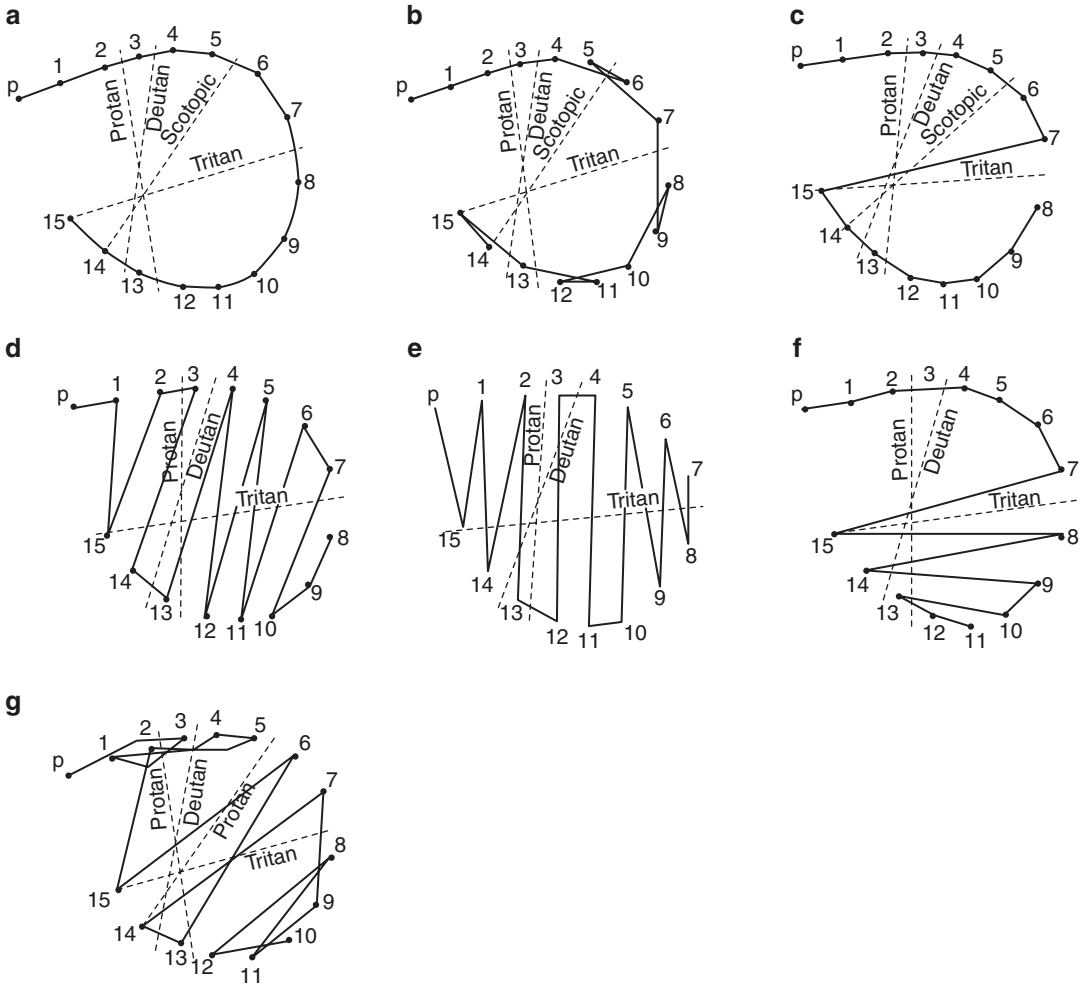

Fig. 4.4 Result of panel D-15 test. (**a**) Normal (**b**) Minor error (**c**) One error (**d**) Protan (**e**) Deutan (**f**) Tritan (**g**) Rod monochromatism

as fail and is judged to be a high degree of color vision abnormality. When the line of intersection coincides with the axis of the protan, deutan, and tritan, which are the leader lines printed on the recording paper, they are diagnosed as abnormalities of the first, second, and third color vision abnormality (Fig. 4.4d–f). If there is ambiguity or one crossing line, reexamination is carried out. The three-color hue passes the most of them, but some fail, which means a severe abnormality. The two-color hue and three-color hue altitudes are combined and classified as severe color abnormality. Rod monochromatism represents the scotopic axis, the intermediate deutan axis, and the tritan axis (Fig. 4.4g). In the case of acquired color abnormality, the blue line abnormality appears as a transverse line parallel to the tritan axis.

4.4.2 Farnsworth-Munsell 100-Hue Test

It is aimed to measure the degree of color discrimination ability and the nature of color confusion by dividing 85 groups of different colors into four groups. It is often used to detect minor anomalies in acquired color vision defects rather than congenital color vision defects and to determine the course and treatment effects.

4.4.2.1 Method

Eighty-five colors with almost similar color difference visually in 100 colors of brightness level 5 and chroma level 5 are numbered from 1 to 85 on the back of the color plate and divided into 4 wooden boxes. Two standard color plates are fixed to the ends of each wooden box, and all 8 colors are fixed colors, so they are made up of 93 colors (Fig. 4.5).

In the first box, 84 and 22 color patches are fixed on both ends, and there are 85 to 21 movement color patches between them. In the second box, 21 and 43 are fixed, and there are 22 to 42 moving colors. In the third box, 42 and 64 are fixed, and there are 43 to 63 moving colors. In the fourth box, 63 and 85 are fixed, and there are 64 to 84 moving color patches, each of which removes the moving color separately. From the first box, pick the color of the most similar color based on the fixed color of both ends, and place it beside the fixed color. Next, select the color plate that is closest to the color plate you placed, and arrange it next to it. Repeat these operations to arrange all 22 color schemes in color order. The above process is also carried out in the second, third, and fourth wooden boxes to arrange all of them, and the inspection is finished.

Close the lid of the box, and actually examine the number of the recording paper, fill in the number displayed after the arranged color display, and calculate the difference from the neighboring number. The recorded score is combined with the neighboring number again to calculate the deviation value (Fig. 4.6). This score is written on a radial chart, which is a recording plate, and connected by a line to judge the pattern. The total error score is the sum of the values obtained

Fig. 4.5 Farnsworth-Munsell 100-hue test

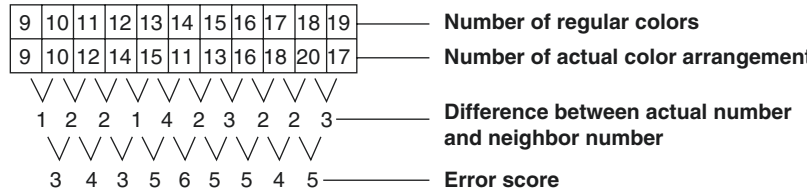

Fig. 4.6 A method of calculating the deviation value corresponding to each color according to the inspection result

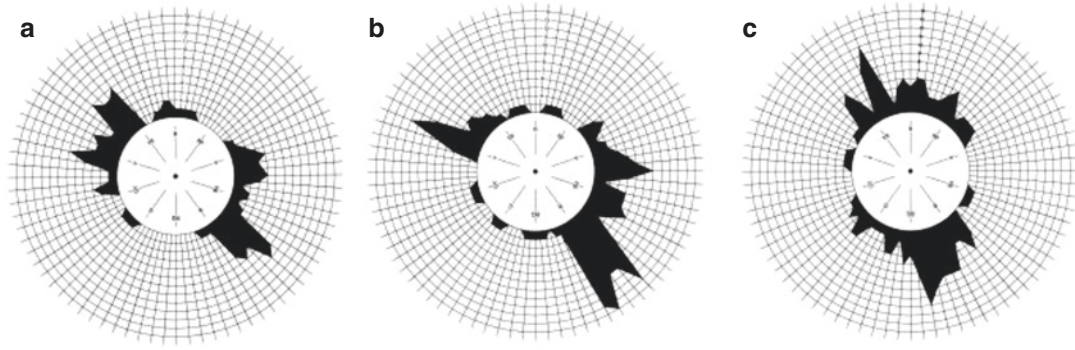

Fig. 4.7 Result of Farnsworth-Munsell 100-hue test. (**a**) Protan. (**b**) Deutan. (**c**) Tritan

by subtracting 2 from each deviation value. It is used as a reference value in evaluating the color discrimination ability and as a data in evaluating the disease progression in the acquired color vision abnormality. It is diagnosed as blue-yellow color abnormality, red-green color abnormality, and confusion of full color depending on the total score difference and the area (pole) with wrong answer on radial diagram. In protan, the scores are increased near 19 and 65. In deutan, the scores are increased near 15 and 59, and the scores are increased from 1 to 46 in the tritan (Fig. 4.7). However, since it is often difficult to judge the type, it is desirable to judge the type in a numerical form together with the total score difference. The normal range of the total score varies according to the age. The 20s have the smallest total score difference around 50–90, and the 50s have the total score difference around 160. It takes long to conduct and analyze the test, and it is difficult to judge the abnormality. Although there is a difficulty in group examination, it is possible to accurately evaluate the degree of color vision abnormality and to apply it to the follow-up of acquired achromatosis.

4.5 Color Matching Test

4.5.1 Nagel's Anomaloscope

It is based on principle that the color and brightness are recognized as the standard yellow light when the red light and the green light are properly mixed.

Basically, this test is used when it is necessary to judge whether the congenital protan or deutan or determine the degree of recognition of trichromacy or dichromacy. A case in which the presence or absence of color hue is not confirmed by another color hue test such as a pseudoisochromatic plate is also an object of inspection.

It is not a screening test and is used to confirm the type and degree of color abnormality.

Acquired color vision abnormality, the tritan (green-yellow) is not subject to be inspected basically.

4.5.1.1 Method

Under natural light conditions, the each eyes are examined separately not to interfere with color vision. Let the patient see the eyepiece and align

the optic axis of the patient with the visual axis of the patient to see if there is a circular visual field of the upper and lower semicircles. The lower semicircular light is yellow; rotating the monochrome screw changes the contrast. If the monochrome screw scale is 0, it is dark, and nothing is visible; raising the scale gradually brightens. The upper semicircular color light is green when the scale is 0 and red when the scale is 73 with rotating the color mixing screw. The scale of mixed two colors is between 0 and 73.

To obscure other eyes and to avoid color adaptation, let the patient see light adaptation plate just for 5–10 seconds.

The examiner turns the color mixing screw and adjusts the color mixing scale from 0 to 10 units. Then, the patient turns the monochrome screw to find the monochrome scale where color and brightness are the same (Fig. 4.8). When you find a place where the patient feels the same, record the monochrome scale value at the point. At this time, the mixed scale and the monochromatic scale are referred to as an equal point. If you cannot find the same point, record it as "not found."

Repeat the above test by raising the color mixing screws by 10 units. Since the equal range is extended as a result of a long examination, the presentation time should be within 3 seconds. At that time, let the patient watch the light adaptation plate for more than 5 seconds. The results obtained in this way are used for diagnosis in absolute equality. In the case of a color-blind person, first look at the circular field of view in the vicinity of the normal range of uniformity, and then calculate the uniform range by adjusting the color mixing screw and the monochrome screw according to the reaction.

The color vision abnormalities are classified into five types, protanomaly, protanopia, deuteranomaly, deuteranopia, and normal, according to the result of color mixing scale. When the color mixing screw scale is around 40 and the monochrome screw scale is around 15, it is judged as the normal neutral point where the color and brightness of the upper and lower semicircles synchronized each other. The range of neutral point is less than 5. For protan, color mixing scale is neutralized at the point smaller than normal neutral point. If the color mixing scale is neutralized at the point larger than normal neutral point, it is considered as deutan.

The protanopia is diagnosed when the color mixing screw scale is 40 and the monochrome screw scale is near 15; the color mixing screw scale is 0 and the monochrome screw scale is

Fig. 4.8 Nagel's anomaloscope

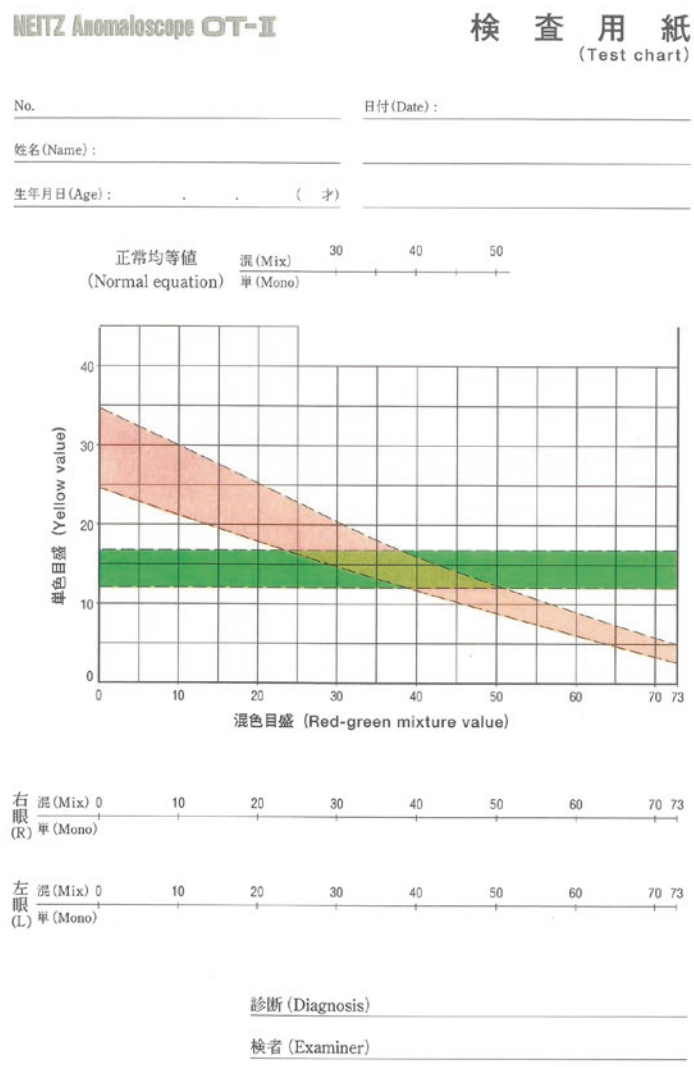

Fig. 4.9 Judgment of color abnormality in Nagel's anomaloscope. 1 + 5 + 2, protanopia; 2, protanomaly; 3, deuteranomaly; 3 + 5 + 4, deuteranopia; 5, normal

near 20; and the color mixing screw scale is 73 and the monochrome screw scale is near 4. In protanomaly, color mixing screw scale increases between 40 and 73, and corresponding monochrome screw scale decreases. The deuteranopia is diagnosed when the color mixing screw scale is between 0 and 73 and monochrome screw scale is near 15. The patient with deuteranomaly feels the same color and brightness of upper and lower semicircles when the color mixing screw scale is between 0 and 40 and monochrome screw scale is near 15. It is easy to determine the type of color abnormality by recording the neutral points and drawing the line between neighboring points on the recording paper as shown in Fig. 4.9. If the neutral point is in the range of red color in the recording paper, it is considered as protan. If the neutral point is in the range of green color, it is considered as deutan.

Suggested Reading

Baylor DA. Photoreceptor signals and vision. Invest Ophthalmol Vis Sci. 1987;28:34–49.

International Standard. ISO 8596 Ophthalmic optics, visual acuity testing, standard optotype and its presentation. 1994(E). p. 1–4.

Linksz A. The development of visual standards: Snellen, jaeger, and Giraud-Teulon. Bull N Y Acad Med. 1975;51:277–85.

Newell FW. History and interpretation. In: Ophthalmology principles and concepts. 8th ed. St. Louis: Mosby; 1996. p. 139–48.

5 Ocular Alignment and Movement Exam

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5.1 Measurement of Deviation

5.1.1 Qualitative Examination

The target is selected according to the purpose of the test. If it is necessary to test in accommodative environment, a small accommodating target should be used. And a large target or a light source may be used if the accommodation is to be eliminated. In the case of infants, a target that can induce the interest of the infant is used. Cover test can only be performed on patients who have enough visual acuity and concentration ability to look at the target. In addition, the results are inaccurate even when there is an abnormal retinal correspondence and extrafoveal fixation. The eye level of the examinee should be the same as the patient and be careful not to occlude the target by the examiner. Since the head position of the patient may affect the rest position, examination is required at the right head position.

5.1.1.1 Cover Test

Make the patient look at the target 30 cm and 6 m distance, and observe the eye movement covering the opposite eye.

If there is constant deviation, the deviation is shifted when the normal eye is covered. The direction of the deviation is opposite to the direction in which the eye moves (Fig. 5.1).

5.1.1.2 Cover-Uncover Test

Uncover the occluder and observe the movement of the covered eye.

It is possible to diagnose phoria and tropia, and it is possible to discriminate whether it is alternating or mono fixating. Uncovered eye is moving in case of phoria. In case of tropia, uncovered strabismic eye is not moving, but fixing eye is moving when uncovered after occluding.

5.1.1.3 Alternating Cover Test

Observe the movement of the eyes that were covered alternating the two eyes. It should be noted that the occluding time should be sufficient for 1.5–3 seconds, and the time to move the cover should be faster. In the case of phoria and tropia, there is eye movement when the occluder is moved to another eye. Phoria and tropia could not be distinguished.

5.1.2 Quantitative Examination

If the cover test indicated that there is abnormal ocular deviation, the amount of deviation should be measured.

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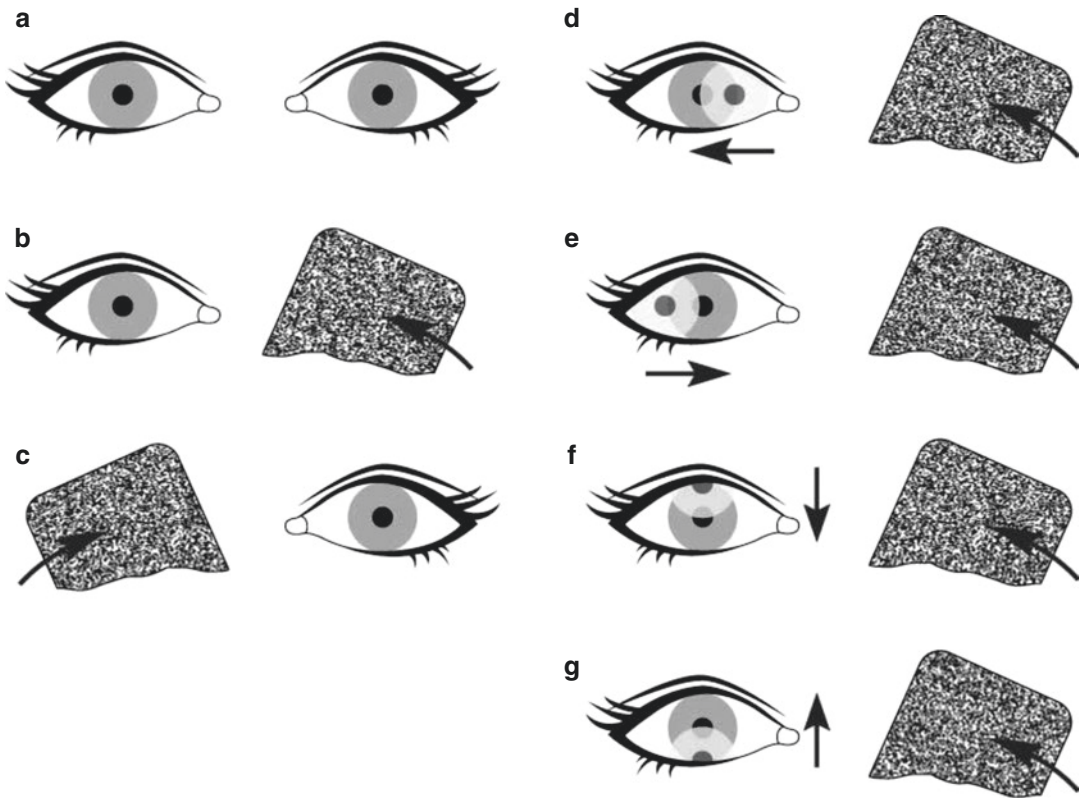


Fig. 5.1 Cover test. (**a**) The resting position. (**b**) There is no deviation in the right eye because the right eye's eye movement does not occur when the left eye is covered. (**c**) There is no deviation in the left eye because the left eye does not move when the right eye is covered. (**d**) When the left eye is covered, the right eye moves outward in esotropia. (**e**) When the left eye is covered, the right eye moves inward in exotropia. (**f**) When the left eye is covered, the right eye moves downward in hypertropia. (**g**) When the left eye is covered, the right eye moves upward in hypotropia

5.1.2.1 Prism and Cover Test

It is possible to measure the amount of deviation most accurately in various test distances and reliabilities in children and adults with good binocular function and cooperation.

Alternating Prism and Cover Test, APCT

Keep two eyes fixating the target, and place the prism in front of an eye, and cover the two eyes alternately; increase or decrease the prism diopters until the eyeballs do not move (Fig. 5.2).

The direction of the prism should be base-out in esodeviation, base-in in exodeviation, base-down in the hyperdeviation, and base-up in the hypodeviation. That is, the apex of the prism may be directed toward the side having the deviation. The total deviation can be known in the fusion-blocking state.

Simultaneous Prism and Cover Test, SPCT

Keep two eyes fixating the target, and observe the movement of the deviating eye, placing the prism at the deviating eye while the fixing eye is occluded. The prism diopters is increased or decreased until there is no movement. It can be used in the examination of the monofixation syndrome. There could be little or no deviation when using simultaneous prism cover test, in patients with relatively large deviation measured with alternating prism cover test. This means that the fixation disparity is present in the microtropia and monofixation syndrome. The latent deviation is difficult to measure.

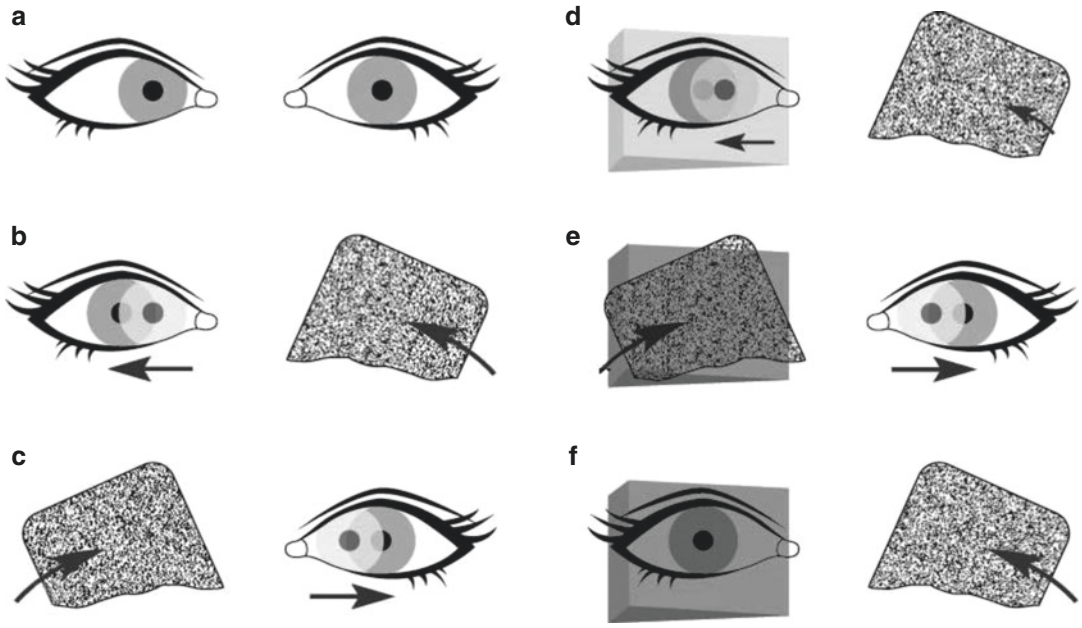
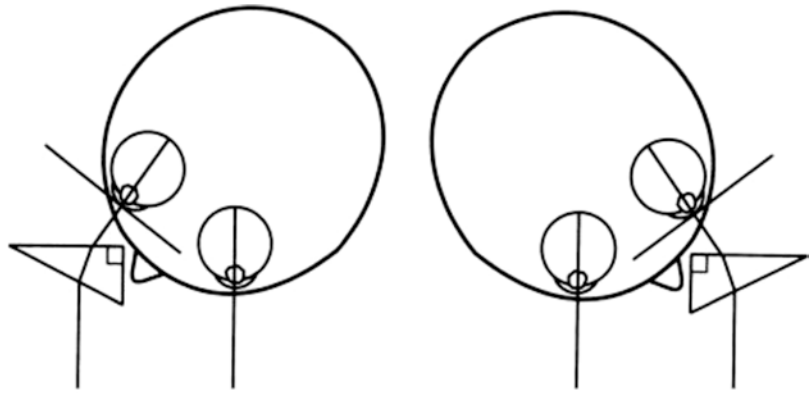


Fig. 5.2 Alternating prism and cover test. (**a**) Right esotropia. (**b**) When the left eye is covered, the right eye moves outward. (**c**) When the cover is trasferred to the right eye, the left eye moves outward. (**d**) Put the prism base-out in front of the right eye and cover the left eye; the right eye moves outward but less than in B. (**e**) Place the prism with the higher diopters on the right eye and cover. (**f**) Transfer of cover to the left eye and no eye movement occurs in the right eye. This prism diopter is consistent with ocular deviation

Fig. 5.3 Position of prism in eccentric gaze



Comments

Because prisms can cause variations depending on how they are placed, we need to know the manufacturer's standards. In the case of plastic prisms in general use, they should be placed in a minimum deviation position or a frontal plane position. When measuring from side gaze, make sure that the back of the prism is perpendicular to the viewing direction (Fig. 5.3).

When two prisms are overlapped in the same direction, it is not the same as the sum of two prisms. If two prisms are measured separately, the measured prism diopter must be corrected (Table 5.1).

In case of wearing glasses and measuring the angle of deviation, The angle may be less than the original deviation in the convex lens, and larger in the concave lens. In the naked eye, it is possible

Table 5.1 The actual angle of deviation when the prism is placed in both eyes individually in the horizontal direction

Prism in the left eye							Prism in the right eye					
	10	12	14	16	18	20	25	30	35	40	45	50
10	20	22	24	26	29	31	36	41	47	52	58	63
12	22	24	26	29	31	33	38	44	49	55	60	66
14	24	26	29	31	33	35	40	46	52	57	63	69
16	26	29	31	33	35	37	43	48	54	60	66	72
18	29	31	33	35	37	39	45	51	57	63	69	75
20	31	33	35	37	39	42	47	53	59	65	71	78
25	36	38	40	43	45	47	53	59	66	72	79	86
30	41	44	46	48	51	53	59	66	73	80	87	94
35	47	49	52	54	57	59	66	73	80	87	95	103
40	52	55	57	60	63	65	72	80	87	95	104	113
45	58	60	63	66	69	71	79	87	95	104	113	123
50	63	66	69	72	75	78	86	94	103	113	123	133

to observe eye movements in the horizontal direction 1–2 △, in cyclovertical direction 2 △.

5.1.2.2 Major Amblyoscope

It is used to examine sensory and motor abnormalities such as subjective and objective deviation measurements, fusion, retinal correspondence, suppression, stereopsis test, and training of binocular function in patients with suspicion of abnormal ocular deviation, binocular dysfunction, or abnormal eye movement disorder.

5.1.2.3 Corneal Reflex Test

Measurement of Angle Kappa

The corneal reflex is not located at the center of the cornea, and there is a slight difference individually, which is called the kappa angle. Therefore, correction of Kappa angle is necessary for analysis when performing amblyoscopy, Hirschberg test, and Krimsky test which measure the angle of deviation by corneal reflection method. Measure the angle formed by the two axes: visual axis and pupil axis.

- Objective method

Let the patient see the examiner's eye; place the patient's and the examiner's eye on the same axis. Position the light source coincident with the axis, and then observe whether the corneal reflex is in the center of the pupil. If the corneal reflex is not at the center of the pupil, keep patient fixing the target with target placing away from the position of the light source. The angle between the light source and the target when the corneal reflex is in the pupil center is the kappa angle (Fig. 5.4).

- Subjective method

Place the slide as shown in Fig. 5.5 on the amblyoscope, and let the patient fix the center of the slide (dog). If the corneal reflex is not at the center of the cornea, move the handle so that it is at the center of the cornea, and then ask for the symbol or picture. The position of this symbol or figure is the kappa angle.

When the corneal reflex point is located at the center of the pupil, the kappa angle is zero. The positive kappa angle refers to the case where the corneal reflex point is located inside the pupil. The negative kappa angle refers to the case where the corneal reflex point is located outside the pupil. The positive kappa angle below 5° is regarded as normal and cornea reflex point located at 0.5 mm on the nasal side in most people. Positive kappa angle seems to be exotropia, and negative kappa angle seems to be esotropia. If a large positive kappa angle and esotropia are present, or if a large negative kappa angle and exotropia are present, strabismus may not be seen or overlooked. If a patient has a large positive kappa angle, fundus examination should be performed to check for retinal abnormalities.

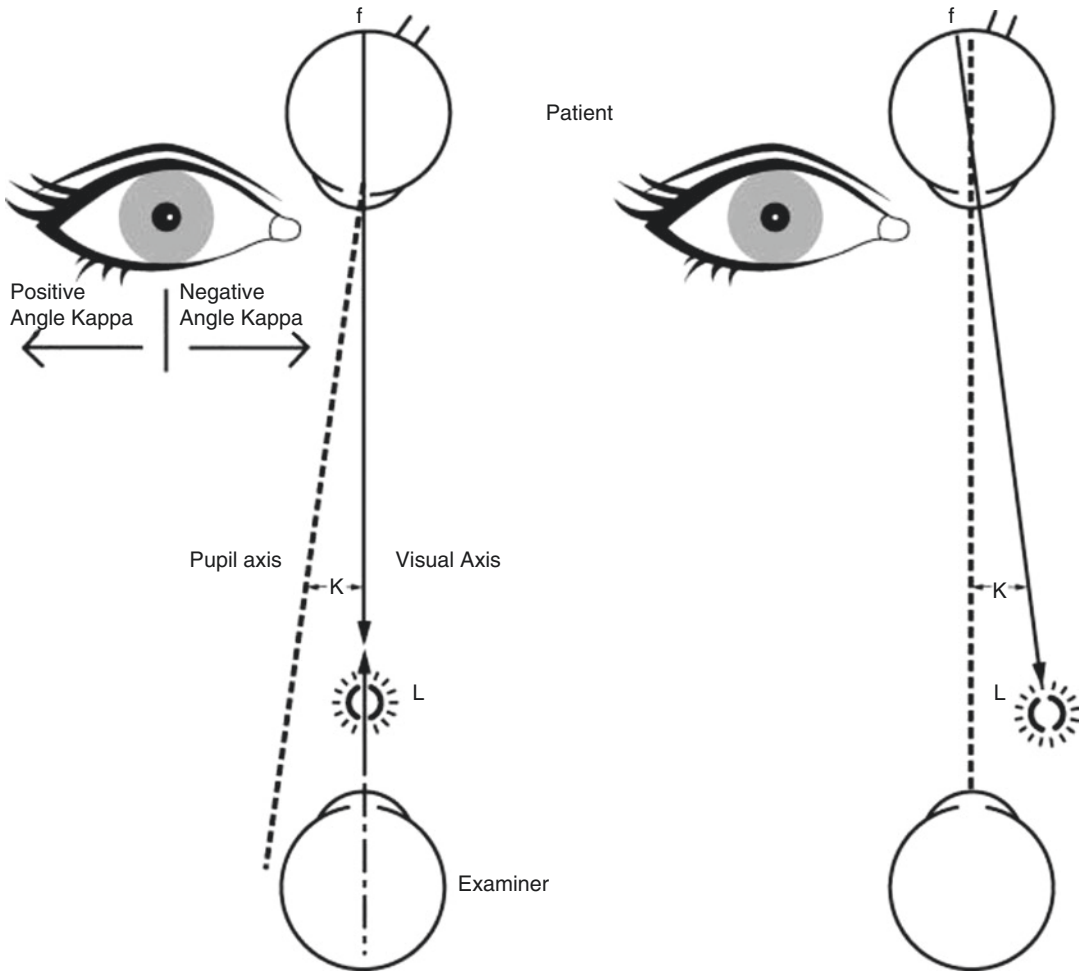


Fig. 5.4 Kappa angle. K Kappa angle, L light source, f fovea

Fig. 5.5 Amblyoscope slide for the measurement of Kappa angle

Hirschberg Test

It is used mainly for infant and mental retardation child who are difficult to cooperate, poor fixation due to low visual acuity, or for patients with eccentric fixation. In a dark room, make patient look at the light spot at a 33 cm or 6 m in front of the eye, and observe the location of the corneal reflex point.

If the corneal reflex point is in the pupil margin, 15° deviation (30△); if it is between the pupil edge and the limbus, 30° deviation (60△);

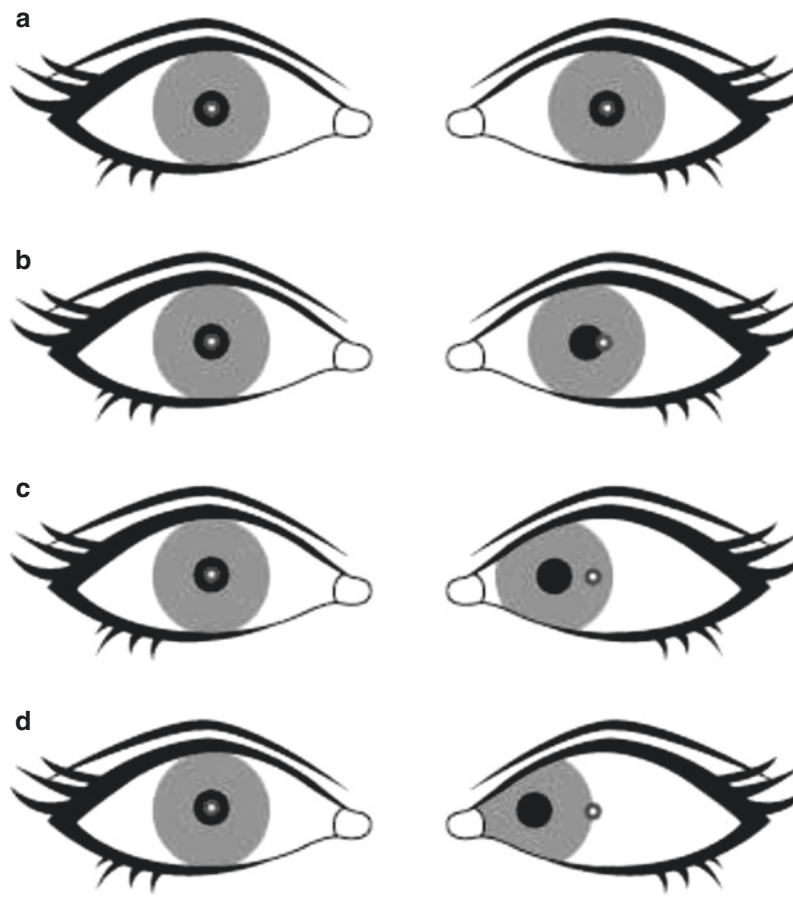


Fig. 5.6 Hirschberg test. (**a**) Normal. (**b**) Esotropia of 15°. (**c**) Esotropia of 30°. (**d**) Esotropia of 45°

and if it is in the corneal margin, 45° deviation (90△) is expected (Fig. 5.6).

The distance from the normal kappa angle should be measured, not the distance from the pupil center. It can not distinguish between phoria and tropia. If there is difference in deviation according to the fixing eye, incomitant strabismus, eccentric fixation, or macular dragging, accurate measurement is difficult in this method. Errors may occur if there is a difference in the corneal diameter of the infant or if the position of examiner changes.

Krimsky Test

It is used to measure manifested ocular deviation when it is difficult to perform the prism cover test because of poor visual acuity or poor cooperation. More accurate measurements can be obtained than Hirschberg test.

Let the patient fix the light spot. Looking the deviating eye, place the prism in front of the fixing eye (base-out in esodeviations and base-in in exodeviation). The prism is increased or decreased until the corneal reflex of the deviated eye is at the center of the cornea (Fig. 5.7).

The prism diopters when the corneal reflex comes to the center of the pupil are the deviation angle, and correction for the kappa angle is necessary. It is difficult to measure the angle of deviation when there are abnormal kappa angles, macular dragging, and eccentric fixation.

Photographic Method

In infant and young children, the angle of deviation can be measured using photographs. It consists of three horizontally arranged flashes and a camera with a small fixating light source. The pupil reflex from the first and fourth Purkinje

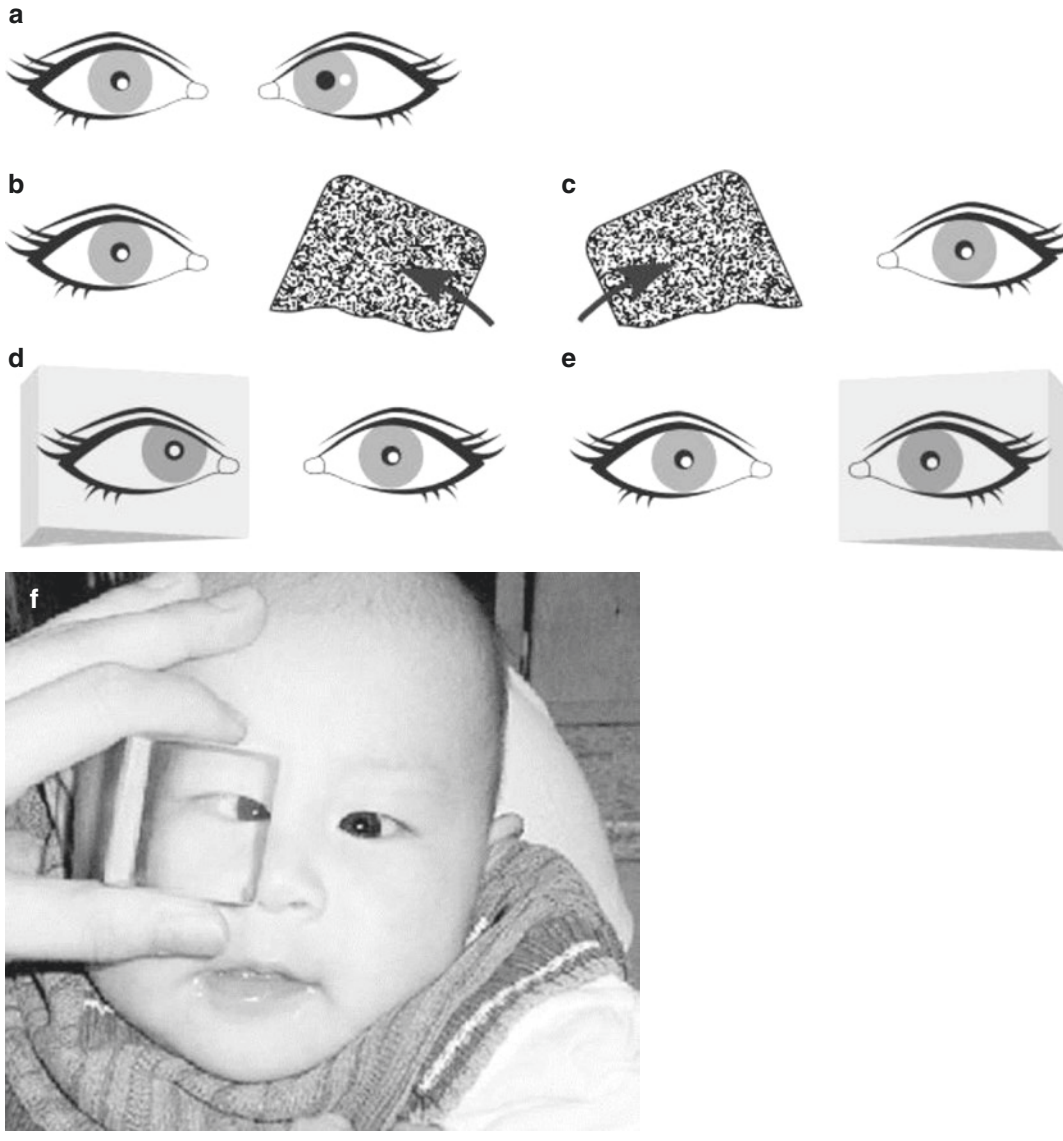


Fig. 5.7 Krimsky test. (**a**) The Hirschberg test in strabismic patient. Corneal reflexes are located on the nasal side of the pupil (+0.5 mm) in the right eye and on the temporal side of the pupil (−1.0 mm) in the left eye. Suspicion of left esotropia. (**b**) Kappa angle of the right eye. Corneal reflex in the right eye is present in the same position (+0.5 mm) as in binocular environment (**a**). (**c**) Kappa angle of the left eye. If right eye is covered, corneal reflex of the left eye is moved to the nasal side (+0.5 mm), and the left eye seems to be deviated. (**d**) Krimsky test. Place the base-out prism on the right eye which is the fixing eye. The corneal reflex which is located in the temporal side of the left eye (**a**), is observed at the nasal side, and is the same position as the kappa angle of the left eye. (**e**) Modified Krimsky test. Place the base-out prism in front of the deviated left eye. Corneal reflex at the temporal side (**a**) is moved to the nasal side and is located at the same position as the Kappa angle of the left eye. (**f**) Actual picture of a child

images of each light source is taken to determine the angle of deviation. Accuracy is about 2.0–4.5 △, which is more accurate than Hirschberg test; error can be made because of accommodation.

Brückner Test

It is used to diagnose strabismus in infants using the position of cornea reflex and the brightness of light reflected from the fundus. In the half-dark room without mydriasis, the pupil, the bright light of the direct ophthalmoscope, is illuminated at 1 m from the patient's two eyes. The position of the cornea reflection and the color of the light reflected from the fundus are observed through the ophthalmoscope. The difference in the brightness of binocular reflexes is important, and the fixing eyes are slightly darker than the strabismic eye.

It is useful for identifying children who could not cooperate or moderate strabismus. Asymptomatic fundus reflection could be observed until 10 months of normal development; there may be false positives in non-strabismic children. It should be noted that there may be differences in brightness due to anisometropia, pupil abnormality, retinal abnormality, or media opacity.

5.1.3 Subjective Tests

5.1.3.1 Red Glass Test

It is a test to determine the degree of strabismus and deviation by subjectively expressing the dual image of the foveal image in the fixing eye and parafoveal image of the deviating eye. It should be performed to the patients who can cooperate at least 4 years old. Red glasses are placed in front of one eye to separate the two eyes and darken to the extent that nothing other than faint red light is visible. Let the patient look at the small light source, and describe where the red light is relative to the white light. Position of the red light relative to the white light is related to the eyeball deviation.

The red glasses should be placed in front of the fixing eye generally since the red glasses make the sight dark, so it is better to look with better-looking eye. Maddox cross can be used together to measure the angle of deviation (Fig. 5.8).

5.1.3.2 Maddox Rod Test

Maddox rod is a red lens with a rod of circumferential lens in parallel. When the light source is viewed through the lens, a red line appears in the vertical direction of the rod. Phoria, monofixation syndrome, intermittent exotropia, and paralytic strabismus could be indicated of this test. manifest strabismus with suppression is difficult to test.

Place a light spot at a distance of 33 cm and 6 m in front of the patient, and place the Maddox rod according to the horizontal or vertical deviation; placing the direction of the rod horizontally in horizontal deviation and vertically in the vertical deviation. Ask for the positional relationship between the red line and the light spot seen through the lens (Fig. 5.9).

When the red line passes through the light spot, it is orthotropic. If direction of the red line is crossed to the light spot, it is exotropia or exophoria. And if it is in the same direction, it is the esotropia or esophoria. Vertical deviation is also determined by the same method. Prism diopters can be increased or decreased so that the red line is at the center of the light spot. The prism direction should be base-in when the red line intersects with the light spot and should be base-out if it is in the same direction.

The patient should have visual acuity good enough to distinguish the light through the Maddox rods and the ability to distinguish between left, right, top, and bottom. There is no distinction between tropia and phoria, and the deviation measured by this method may not be accurate. When there is abnormal retinal correspondence, the angle of deviation is measured differently.

5.1.3.3 Maddox Wing Test

It is a method to quantitatively measure the deviation at near fixation by dissociating the two eyes (Fig. 5.10). In patients who complain of asthenopia during near work, the subjective deviation can be measured easily and can be used in

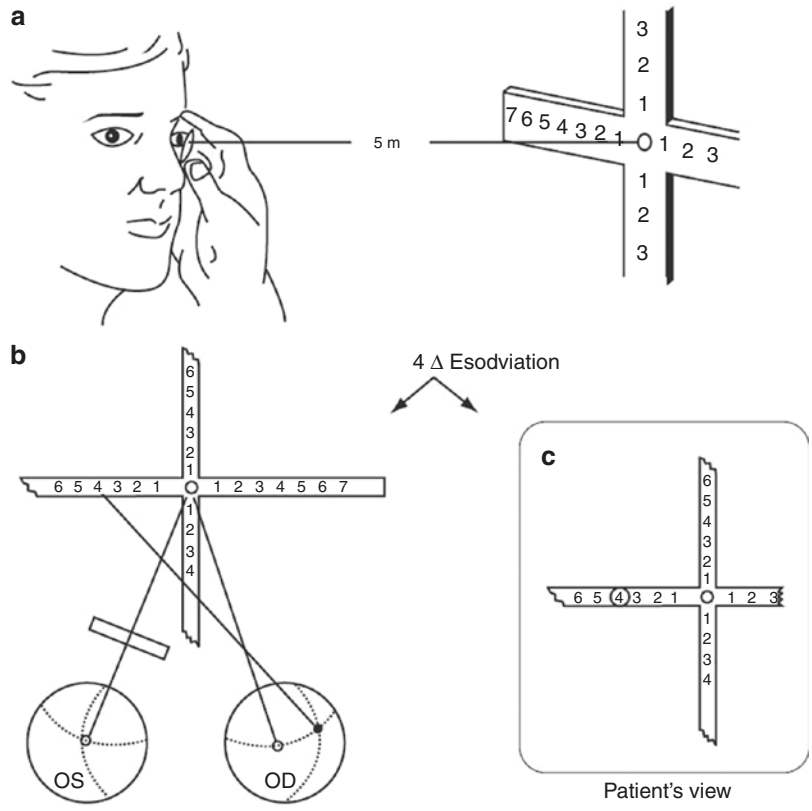


Fig. 5.8 Maddox Cross test. (**a**) Perform at a distance of 5 m (1 m can also be used with a smaller number). The patient has 4 △ esotropia. (**b**) If the patient has normal retinal correspondence, the red light overlaps the number of the fovea in the deviated eye. In the case of this patient, the red light overlaps the number 4. (**c**) Non-crossing diplopia in patient with 4△ esotropia (or esophoria)

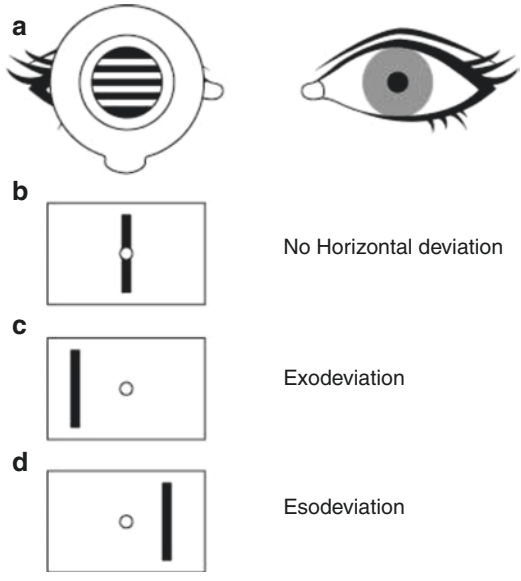


Fig. 5.9 Maddox rod test (**a**) The madox rod lens is placed in front of right eye horizontally. (**b**) No strabismus. (**c**) Exodeviation. (**d**) Esodeviation

Fig. 5.10 Maddox wing test

patients who are suspected of small angle vertical or cyclodeviation.

Holding the Maddox wings with hands, you can see the horizontal and vertical scale on left eye and the horizontal and vertical arrows on right eye. The white arrows point to horizontal

scale which indicates the vertical deviation, and the red arrows indicate the vertical scale and horizontal deviation. If the horizontal line is not parallel to the horizontal scale, it indicates that there is cyclodeviation. If the patient moves the arrow by himself until the patient feels horizontal, the value of cyclodeviation is obtained.

The visual acuity should be above the value of which the number and the arrow are clearly visible, and the relaxation of the accommodation may lead to an increase in the exotropia and a decrease in the esotropia deviation, resulting in inaccurate results.

5.1.3.4 Lancaster Red-Green Test

Two subjects are visualized in each eye, and the two subjects are stimulated to the fovea of the individual eyes. Patients with normal retinal correspondence are indicated. Using a screen with a square of 5 cm at a distance of 1 m, let the patient wear red and green glasses that can be changed each other. Prepare two linear streaks of light, green for patient and red for examiner. The examiner projects the red light on the screen, fixes the patient's head, and let the patient to match the red line light with the green line light. If the patient has normal retinal correspondence, the two streaks formed are separated objectively on the screen according to the amount of strabismus. The angle of cyclodeviation can also be examined according to the tilted angle of line. It is most useful for examining the paralytic strabismus, but it is inaccurate in intermittent strabismus.

5.1.3.5 Hess Screen Test

It can be examined if abnormal oculomotor function or paralysis is suspected in patients with normal retinal correspondence. This is a subjective measurement method that can measure qualitatively and quantitatively the deviation hyper- or hypoactivity of each extraocular muscle by measuring the direction of the nine gaze directions. This method is effective in finding paralysis and paralysis of the extraocular muscles.

Methods

- Place the patient in a dark room and 50 cm away from the Hess screen, and fix the head so that the center of the screen is at the patient's eye level. The spacing between each line of the Hess screen is 5°, and it colored red at 15° and 30° where vertical and horizontal lines meet. There are 8 red spots on the inside squares and 16 red spots on the outside squares.
- Put on red and green glasses, and watch the center of the screen with the eyes of red eyeglasses, and hold a pointer where the green target is projected.
- Move the fixing point on the screen to the top and clockwise from the center of the pattern. The examiner marks the positions indicated by patient on the small card with reduced copy of the screen (Fig. 5.11).
- The chart on the right shows the right eye deviation when fixing with the left eye, while the chart on the left shows the left eye deviation when fixing with the right eye.

Interpretation

Comparing the left and right deviation (chart), the eyes showing the reduced size of the eye movement square become the eyes with

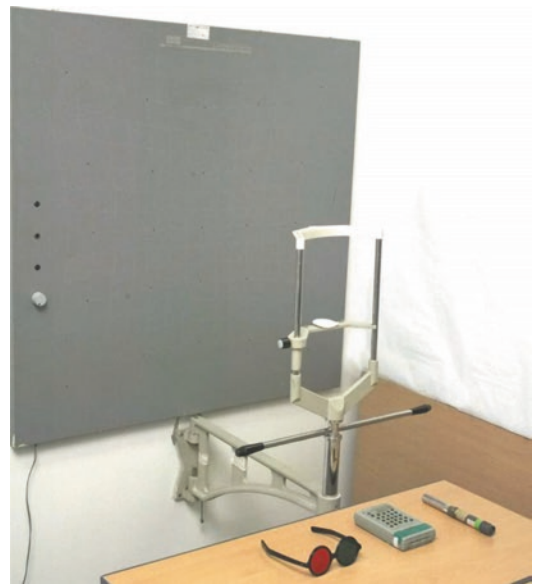


Fig. 5.11 Hess screen test

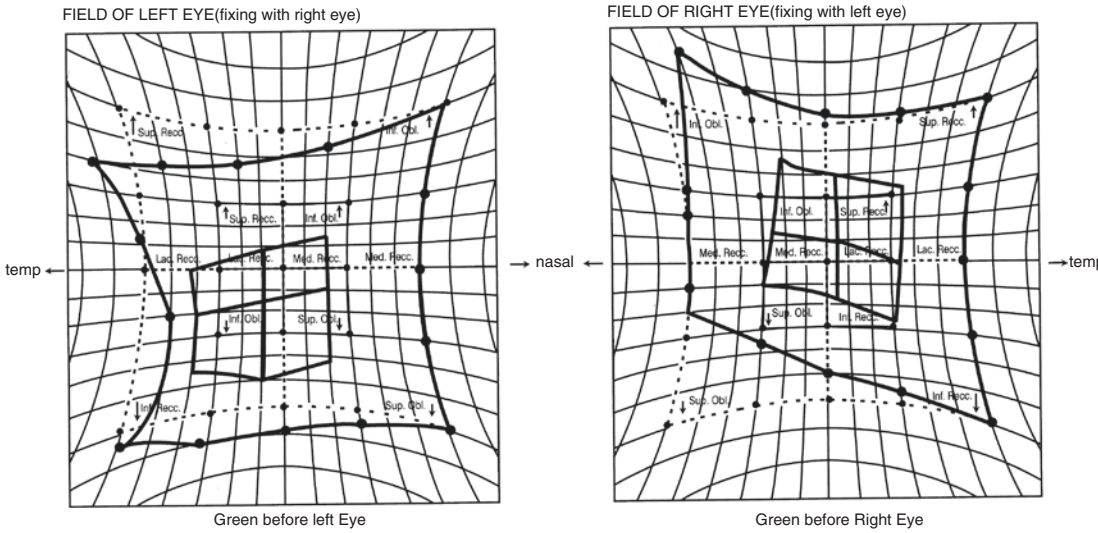


Fig. 5.12 Clinical example of Hess screen test. Right superior oblique palsy

reduced motion (paralyzed eyes), and the paretic eye is the one which direction of movement is most diminished from normal range. The direction in which most enlarged than the range of normal value is the direction of the yolk muscle of paralyzed muscle (Fig. 5.12).

5.1.4 Diagnosis of Cyclodeviation

5.1.4.1 Qualitative Inspection by Position of Double Vision

For inspection, place a horizontal ruler in front of the lower half of the midline of the eye, shielding the eyes alternately, and check whether the eye deviated. The slope of the retinal image is opposite to the slope observed by the patient. For example, if the line is tilted toward the nasal side, it is excyclodeviated. Retinal images are tilted as paralyzed muscles act alone.

5.1.4.2 Double Maddox Rod Test

It is a subjective test that can measure quantitatively the cyclodeviation. However, it is impossible to differentiate between cyclotropia and cyclophoria.

Methods

In the dark room, place a red rod filter in the eye suspected to have cyclodeviation and a white rod filter in the opposite eye, perpendicularly to the eyeglass frame, and then let the patient look the light spot on the front. Ask the patient if the red and white lines are parallel. If they are not parallel, make them parallel by rotating the handle of the red rod by patient (Fig. 5.13). In right superior oblique palsy, a red rod filter is worn on the right eye.

Interpretation

The right eye is excyclodeviated in right superior oblique palsy if the red line of the right eye is seen to be tilted to the nasal side. The two lines are perceived parallel only after the patient extorts the right rod (Fig. 5.13a). The angle of the rotation done by the patient becomes the cyclodeviation angle (Fig. 5.13b).

If there is no vertical deviation, it is convenient that the base-out 6△ prism is located in front of an eye to separate the two horizontal lines. Since the results vary depending on the fixing eye, the opposite eye of the paralyzed muscles can be judged as having cyclodeviation. Although it is possible to accurately measure the cyclodeviation, it disadvantageously dissociates the two eyes to eliminate cyclo-fusion, which is

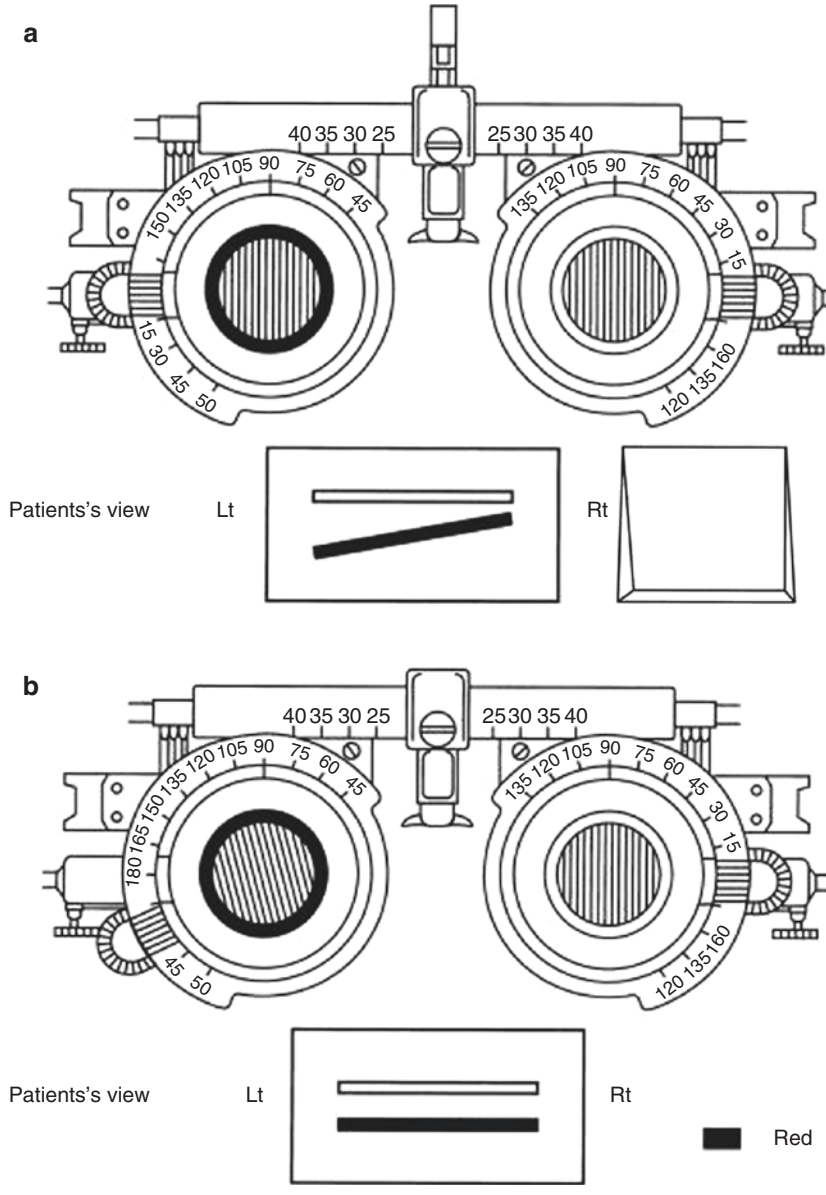


Fig. 5.13 Maddox double rod test (**a**) In suspicious of right superior oblique palsy, red filter in the right eye and White filter in the left eye are placed. The patient may feel that the red line is incyclotorted. (**b**) Rotate the red filter outward to find the point where the two lines become parallel

the most important compensation mechanism of cyclodeviation.

5.1.4.3 Maddox Double Prism Test

Maddox double prism, attaching two prisms with 4△ at the bottom, is a subjective method that can qualitatively measure the degree of cyclodeviation. Patients who are suspected to have cyclodeviation such as paralytic strabismus, inferior/superior oblique overreaction or underaction, or A- or V-type strabismus are indicated.

Methods

In a room of normal brightness, place a double prism in front of the opposite eye to be examined, and look at the white paper with a horizontal line. Three lines including a straight line seen from the strabismic eye appear at the center of two parallel lines of the double prism fitted in the opposite eye.

Interpretation

If all three lines are parallel, there is no cyclodeviation. If the center line is tilted to the outside, incyclotorsion exist. If it is tilted inward, the excyclotorsion is expected.

It is easy to examine the presence of cyclotorsion and has the advantage of not having to turn off the light of the room. However, if the prism is not set correctly, it can be misdiagnosed as having a cyclodeviation in the normal eye, and cyclodeviation cannot be quantitatively analyzed.

5.1.4.4 Bagolini Striated Glasses Test

It is used to qualitatively evaluate the cyclodeviation.

Methods

Similar to the Maddox rod test, the stripe lens make vertical line of light. Insert the stripe lens to be perpendicular each other, turn them until fusion occurs, and read the angle.

Interpretation

The direction and angle of the deviation should be interpreted to be the degree to which it has been rotated.

The test can be performed while fusion is maintained. If cyclodeviation is positive in double Maddox rod test, but negative in Bagolini striated lens test, it is possible that the patient has cyclo-fusion or compensates the strabismus by viewing the surrounding environment.

5.1.4.5 Fixation Ophthalmoscopy and Fixation Fundus Photography

It is an objective test to be used to diagnose the cyclodeviation.

Methods

Fovea is located below 0.3 disc diameter of the geometric center of the optic nerve.

This is the point passing through the middle of the lower half of the optic nerve head when the imaginary horizontal line is drawn at the fovea.

Interpretation

If the fovea is located higher, there is incyclotropia. If it is located lower, there is excyclotropia.

There may be difference between two eyes in normal person, but vertical differences more than 0.25 DD can be regarded as abnormal.

5.1.4.6 Visual Field Test

The change of blind spot position on the visual field test can discriminate the cyclodeviation. The blind spot moves upward for incyclotorsion while it moves downward for excyclotorsion.

5.2 Duction and Version Test

For strabismus patients and those complaining of diplopia or abnormal eye movement, such as eye movement restriction, movement of one or both eyes should be measured 30° from the nine directions of primary gaze (front), secondary gaze (upper, lower, left, and right), and tertiary gaze (upper right, lower right, upper left, and lower left). By testing eye movement, hyperfunctioning or hypofunctioning of muscles and the direction of decreased movement are confirmed.

5.2.1 Methods

5.2.1.1 Duction Test

The movement of the tested eye is observed while covering the other eye.

If the patient can comply, ask the patient to see a visual acuity chart of appropriate sizes or a pen light in the direction to be tested. For children, use stuffed toys or objects that make noises to gain their attention.

After confirming the position of the patient's eye in primary gaze, limitation or enhancement

of eye movement should be tested in each direction. Here, the patient should be asked to move the eyeball as much as possible.

When mild abnormalities are observed, comparisons should be made with the other eye.

5.2.1.2 Version Test

The chart should be moved in each direction from the central line between the two eyes. Hyperfunctioning of each extraocular muscle is scored as +1 to +4, whereas hypofunctioning is scored as −1 to −4. Hyperfunction often appears secondary to weakening of antagonistic muscle of the same eye or yoked muscle of the other eye (Fig. 5.14).

The distance between the edge of the cornea of both eyes should be measured. Eyeglasses should be taken off when testing the periphery.

Care must be taken due to individual differences in the shape of the eyelids. Limitation or enhancement of eye movement should be determined and recorded in association with the main direction of action of each extraocular muscle. Figure 5.15 shows the normal range of eye movement.

Adduction

Perpendicular line at the lower punctum should pass through the line between the inner 1/3 and outer 2/3 of the cornea.

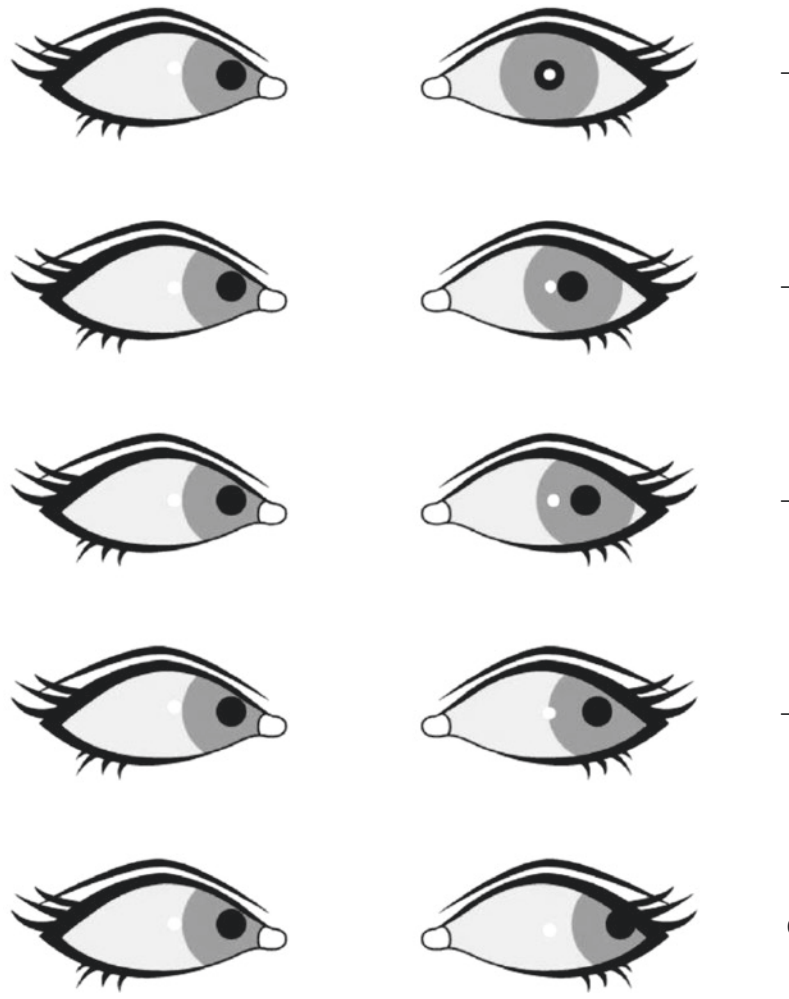


Fig. 5.14 Version test. The markings show varying degrees of hypofunction of the lateral rectus of the left eye in leftward gaze (0, normal; −4, maximum hypofunction)

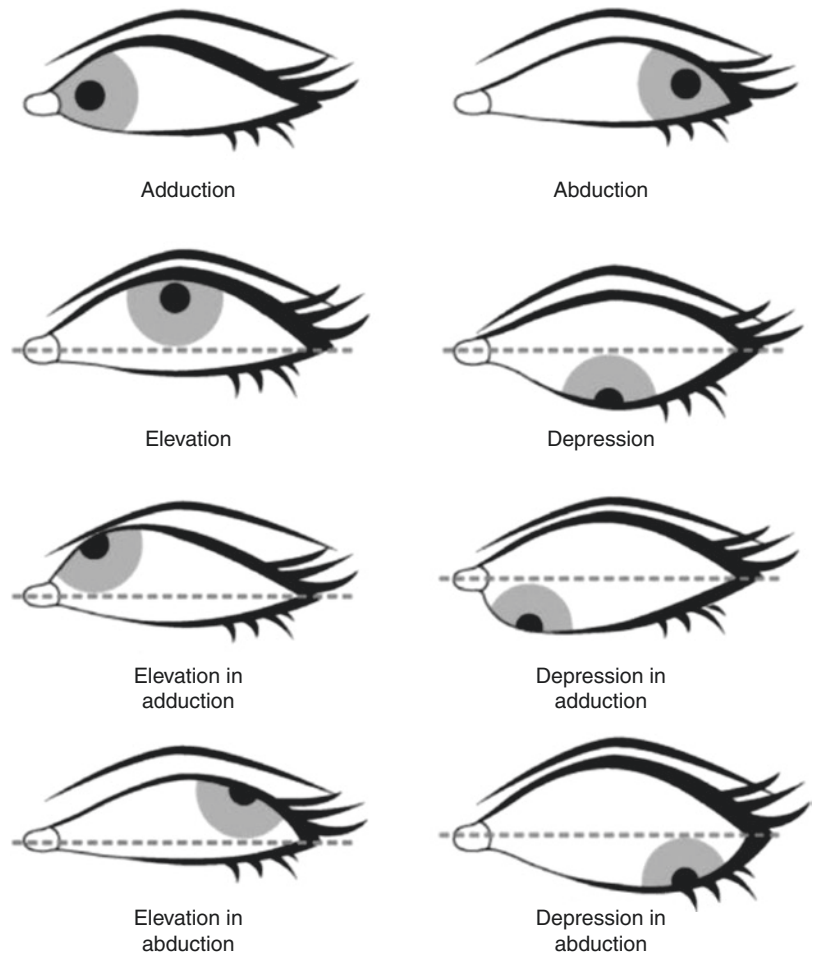


Fig. 5.15 Break point in the range of eye movement

Abduction

The edge of the cornea should meet the outer corner of the eye.

Elevation

The edge of the cornea should be above the line connecting the inner and outer corners of the eye.

Depression

The edge of the cornea should be lower than the line connecting the inner and outer corners of the eye. The distance moved by the eyeball using the edge of the cornea as the measurement point can be measured with a transparent ruler. Normal eye movement falls around 10 mm in convergence, divergence, and lowering and around 5–7 mm in lifting. The range of eye movement is around 50° in each direction, and aging leads to decreased upward gaze.

5.3 Vergence Test

Eye convergence can be divided into tonic vergence, fusional vergence, accommodative vergence, and proximal vergence. Fusional vergence arises to allow an image to form on corresponding points on both retina and is also called motor fusion. In general, vergence test used in clinic measures fusional vergence.

5.3.1 Using a Prism

5.3.1.1 Methods

Using a prism bar or rotating prism, the patient is asked to look at a target that does not cause accommodation. The target is placed at a far distance (5 m) and a short distance (33 cm).

The bottom of the prism is placed temporally when measuring the convergence amplitude and toward the nose when measuring the divergence amplitude.

Placing the prism on one eye, the patient is asked to look at the prism while making sure to not see two targets. The prism refracting power is increased gradually starting at a low strength, and the patient is asked whether they are seeing two objects.

The break point is the point where the patient fails to fuse the images and sees two images. Here, the prism refracting power is gradually reduced again, and the point at which the patient sees one image again is the recovery point.

Caution is required to increase the prism refracting power gradually. If it is increased too rapidly, the fusional amplitude is measured to be lower than actual.

If the divergence amplitude is measured immediately after measuring the convergence amplitude, the divergence amplitude is measured to be lower due to aftereffects. Therefore, the measurement should continue after causing vertical fusion. Therefore, vergence should be measured in the following order: convergence amplitude, vertical fusional amplitude, and divergence amplitude.

Since diplopia may not be present due to suppression of the deviating eye in some patients, changes in the position of the eyeball should be monitored in these patients.

5.3.1.2 Interpretation

Various normal ranges have been reported. In general, when looking far away, the convergence amplitude is around 20△, divergence amplitude around 6–8△, and vertical convergence amplitude around 3–4△. Horizontal fusional amplitude is shorter when looking far away than closely. Even with normal visual function in both eyes, various fusional amplitudes can be measured from different individuals. The recovery point is usually 2–4△ lower than the break point. In some patient, the recovery is never achieved even when the prism refracting power is very low. Such cases are observed when recovery rarely occurs once the fusion breaks, such as in intermittent strabismus.

5.3.2 Using a Major Amblyoscope (See Chap. 6)

Examination of sensory and motor abnormalities such as subjective and objective deviation measurements, fusion, retinal correspondence, suppression, stereopsis test, and training of binocular function in patients with suspicion of abnormal ocular deviation, binocular dysfunction, or abnormal eye movement disorder.

5.3.3 Using Bagolini Striated Lenses

The patient is asked to look at a bright visual acuity chart through Bagolini striated lenses, and tests are conducted using a prism. Since the target is seen smudged, it is difficult to achieve a consistent accommodation. However, binocular vision can be tested by confirming whether the two lines formed by light cross perpendicularly and patients can easily answer upon subjective realization.

5.4 Head Tilt Test

The test is used to diagnose rotating vertical strabismus.

5.4.1 Methods

Changes in vertical-oblique deviation measured when tilting the head left and right are observed while conducting an alternating cover test. Deviation is small and continuous with binocular vision at habitual head positions. However, when tilting the head in the opposite direction, deviation increases, and diplopia or suppression is observed. Paralyzed muscles are diagnosed according to the following three steps.

- In which eye is hypertropia observed when looking straight into the front?
- Does vertical deviation increase when looking with right eye or left eye?

- Does vertical deviation increase when tilting the head left or right?

5.4.2 Interpretation

Since the above three-step test is difficult to use in clinic unless the doctor is experienced, it is easier to understand if the procedure is summarized as shown below in the figures.

Step 1: Hypertropia of the right eye is caused by hypofunction of depressor muscles of the right eye, including right inferior rectus or right superior oblique, or hypofunction of elevator muscles of the left eye, including left inferior oblique and left superior rectus. In contrast, hypertropia of the left eye is caused by hypofunction of elevator muscles of the right eye, including right superior rectus or right inferior oblique, or hypofunction of depressors muscles of the left eye, including left superior oblique and left inferior rectus. Therefore, mark the two suspected extraocular muscles as shown in the figure (Fig. 5.16a).

Step 2: If hypertropia worsens in right gaze, it is caused by right gaze verticals, including right superior rectus, right inferior rectus, left inferior oblique, and left superior oblique. If hypertropia worsens in left gaze, it is caused by paralysis of left gaze verticals, including left superior rectus, left inferior rectus, right inferior oblique, and right superior oblique (Fig. 5.16b).

Step 3: If hypertropia worsens when tilting the head right, it is caused by right eye intortors, including right superior rectus and right superior oblique, or by left eye extortors, such as left inferior oblique and left inferior rectus. In contrast, if hypertropia worsens when tilting the head left, it is caused by left eye intortors, such as left superior rectus and left superior oblique, or by right eye extortors, such as right inferior oblique and right inferior rectus (Fig. 5.16c).

Final diagnosis: The muscle with three circles from the three steps can be suspected to be paralyzed (Fig. 5.16d).

5.5 Forced Duction Test

5.5.1 Methods

Whether decreased movement of extraocular muscles is restrictive or paralytic can be diagnosed in patients with eye movement restriction.

Apply sufficient amounts of topical anesthetic eye drops, such as 0.5% proparacaine and 4% lidocaine, and open the patient's eyes with eyelid speculums in a supine position.

Ask the patient to look at the direction with decreased movement (Fig. 5.17a, b).

Hold the conjunctiva and episclera near the limbus opposite to the direction of decreased movement with a toothed forceps, and pull in the direction of decreased movement (i.e., direction opposite to the suspected direction of mechanical duction) to observe the presence and strength of resistance (Fig. 5.17c).

When testing oblique muscles tightness, hold the conjunctiva at the 3 o'clock and 9 o'clock positions with two toothed forceps, and press the eyeball posteriorly. For superior oblique muscle, move eyeball inward and upward, and move inward and downward for inferior oblique. Due to the tension of the oblique muscle, the eyeball pops up across the tendon during this maneuver.

5.5.2 Interpretation

For rectus muscles, no resistance indicates decreased movement from paralytic strabismus, whereas the presence of resistance indicates decreased movement due to the contracture of antagonistic muscles or other mechanical causes. For superior oblique, anatomical abnormalities in the insertion site of the superior oblique can be suspected if no tension can be felt in duction test conducted in patients with paralysis of the superior oblique. The test can also be useful in investigating the inferior oblique function after inferior oblique surgery.

For duction test of the rectus muscles, it is accurate to conduct the test after slightly pulling the eyeball to the front. If duction tests are conducted while pushing the eyeballs posteriorly, the muscles may relax, leading to false-negative

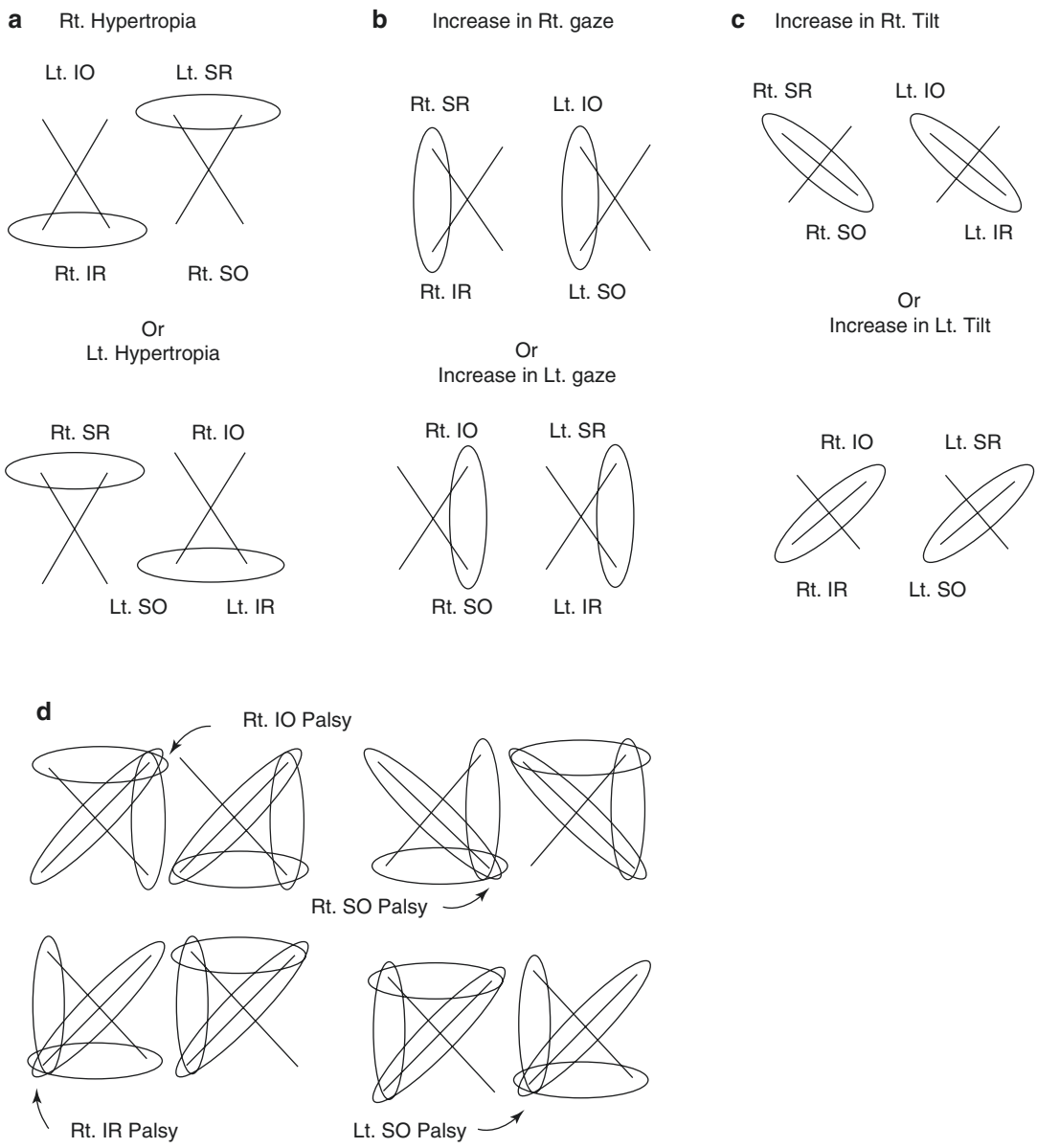


Fig. 5.16 Markings in head tilt test (**a**) direction of the hypertropia at primary position. (**b**) Change of vertical deviation when looking horizontally. (**c**) Change of vertical deviation when tilting head. (**d**) The muscle with three circles from the three steps can be suspected to be paralyzed

results. If duction does not decrease even when the eyeball is pushed posteriorly, adherence syndrome or Brown's syndrome, rather than paralysis of the rectus muscle, should be suspected. For oblique muscles, the test should be conducted with the eyeballs pushed posteriorly, with the oblique muscles tense and rectus muscles relaxed. Moreover, the conjunctiva at 90° to the direction of suspected mechanical resistance (12 o'clock and 6 o'clock positions in movement limitations of medial rectus or lateral rectus) can be held with two toothed forceps for tests. When the

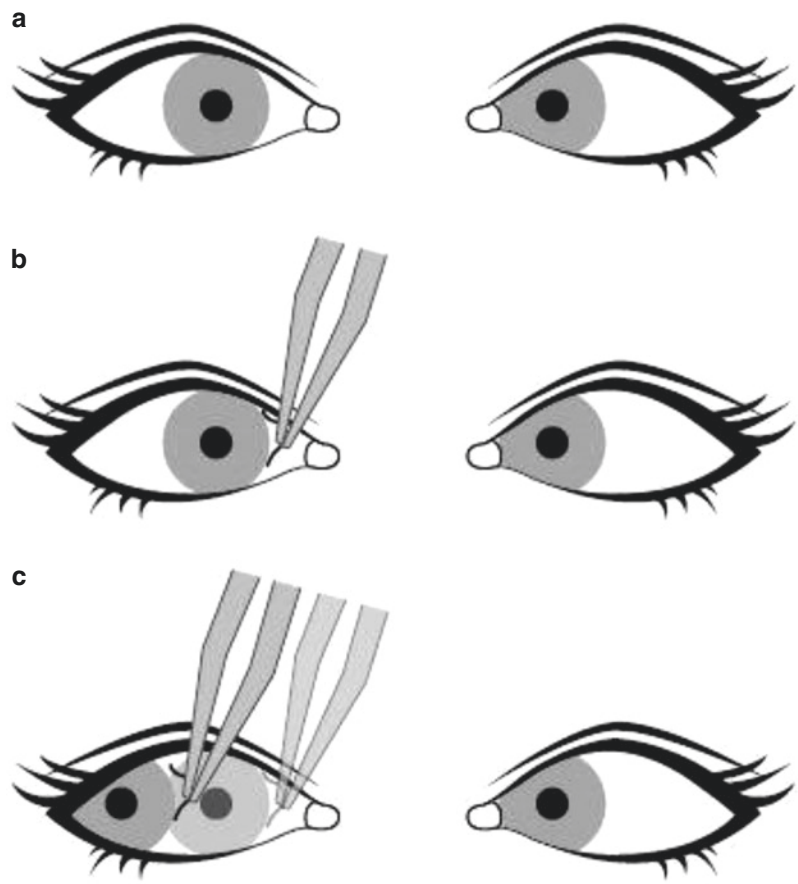


Fig. 5.17 Forced duction test. (**a**) An esotropia patient with divergence disorder of the right eye is asked to fixate on the right as much as possible. (**b**) Holding the nasal edge of conjunctiva and episclera of the right eye with toothed forceps, the patient is asked to diverge softly in the beginning and then strongly from the median plane. If resistance is felt without sufficient divergence, mechanical duction is present. (**c**) If no resistance is felt with complete divergence, there is no mechanical traction, and lateral rectus paralysis is present

patient does not comply or in young children, the test should be conducted under general anesthesia. Depolarizing muscle relaxants, such as succinylcholine, contract the extraocular muscles for approximately 20 minutes, making the test difficult; therefore, non-depolarizing muscle relaxants should be used.

5.6 Active Force Generation Test

5.6.1 Methods

This test investigates the recovery of paralyzed extraocular muscles and is important in determining surgical approach for paralytic strabismus. After local anesthesia, tissues surrounding the cornea are held with forceps. The patient is asked to look at the direction of action of paralyzed muscle, while the tester quantitatively feels the power of the paralyzed muscle. For instance, in a patient with paralysis of left lateral rectus, the patient is asked to adduct the left eye. The tester then holds the 3 o'clock position of the limbus with forceps and then asks the patient to abduct the left eye to test the muscular power.

5.6.2 Interpretation

In lateral rectus paralysis, active muscle power of the lateral rectus suggests that the function of the paralyzed muscle has recovered and recession of the medial rectus and resection of the lateral rectus are considered. If only passive movement is

present, transposition is considered. Moreover, since very strong forces for abduction indicate contracture of the medial rectus, it can be corrected only through recession of medial rectus.

5.7 Field of Fixation

Patients with eye movement restriction or enhancement are tested. Field of monocular fixation test quantitatively measures the range of monocular movement, whereas field of binocular fixation test measures the range of movement allowing for binocular vision without diplopia.

5.7.1 Methods

5.7.1.1 Field of Monocular Fixation Test

A kinetic perimeter, such as a Goldmann perimeter, is used. After fixing the head, the tested eye is placed in the center, and the other eye is covered.

Among visual acuity charts that can be clearly seen by the patient, the darkest and smallest chart is moved from the center to the edge of the perimeter.

The patient looks at the chart, and break points at which the chart cannot be seen are measured in each direction.

5.7.1.2 Field of Binocular Fixation Test

After fixing the head, the bridge of the nose in between both eyes is set as the center of the perimeter. An object that can be clearly seen is moved in each direction while confirming whether binocular vision without diplopia is possible. The patient looks at the object with both eyes, and the points at which the object appears as two are marked.

5.7.2 Interpretation

Table 5.2 shows the normal ranges. However, there are individual differences, and aging leads to decreases in test results.

5.8 Measurement of Head Posture

Patients who may have head posture abnormalities are tested, such as those with paralysis of eye muscles, incomitant strabismus, comitant strabismus, nystagmus, supranuclear pathway disorders in eye movement, ptosis, anomalies of refraction, or abnormalities of visual field.

Head posture abnormalities can cause not only esthetic problems, but also orthopedic problems, such as facial asymmetry. If they are caused by ophthalmological reasons, they should be treated in ophthalmology. The test can be divided into face turn, head tilting, and chin elevation/depression.

5.8.1 Methods

5.8.1.1 Qualitative Tests

Natural head posture is observed with both eyes open. Photographs of the upper body are taken from the front, sides, and above, and pretreatment and posttreatment photographs are compared. The observation follows the same methods with one eye covered. In compensatory head posture abnormalities arising from incomitant strabismus, the abnormalities decrease or disappear when one eye is covered. In otorhinolaryngological or orthopedic head posture abnormalities, covering the eye does not exert any influence.

Table 5.2 Normal ranges in field of monocular fixation and field of binocular fixation tests

	Field of monocular fixation test		Field of binocular fixation test	
	Left eye	Right eye	Left eye	Right eye
Lifting	44°	42°	28°	28°
Depression	45°	45°	45°	45°
Divergence	39°	45°	20°	21°
Convergence	48°	44°	35°	34°

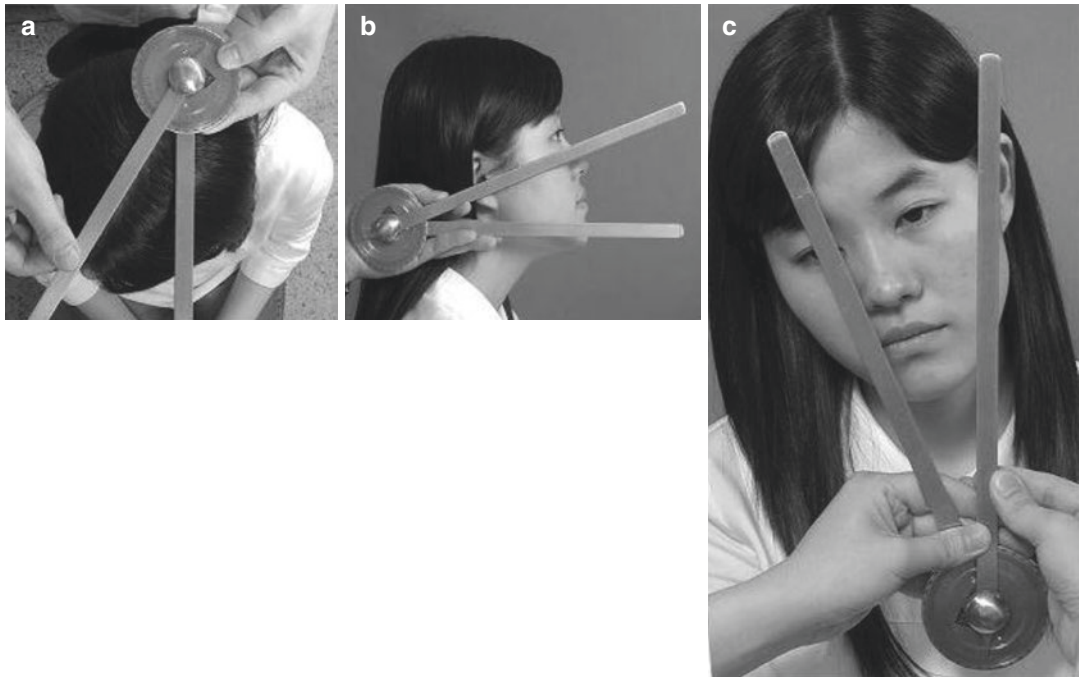


Fig. 5.18 Measurements of head posture (**a**) During face turn, the protractor is placed on the center of the head, and the angle between the tip of the nose and the gaze target is obtained. (**b**) During chin elevation or depression, the angle formed by the horizontal surface and the line connecting the external auditory meatus and inferior border of the orbit is obtained. (**c**) During head tilting, the protractor is placed on the front, and the angle between the midline of the face and perpendicular line is obtained

5.8.1.2 Quantitative Tests

Head posture abnormalities can be quantified using protractors.

During face turn, the protractor is placed on the center of the head, and the angle between the tip of the nose and the gaze target is obtained (Fig. 5.18a).

During chin elevation or depression, the angle formed by the horizontal surface and the line connecting the external auditory meatus and inferior border of the orbit is obtained (Fig. 5.18b).

During head tilting, the protractor is placed on the front, and the angle between the midline of the face and perpendicular line is obtained (Fig. 5.18c).

5.8.2 Interpretation

Face turn abnormalities appear in paralysis of nerves for divergence, esotropia in children, congenital nystagmus, acquired oculomotor nerve paralysis, retraction syndrome, acquired nystagmus, alternating periodic nystagmus, and Möbius syndrome.

Chin elevation and depression are seen in ptosis (progressive external ophthalmoplegia and congenital fibrosis), A- and V-type strabismus, bilateral trochlear nerve palsy, double elevator palsy, and Brown's syndrome. Head tilting is observed in superior oblique palsy, dissociative heterophoria, and ocular tilt reaction.

Abnormal movements of the head are observed in congenital nystagmus, Parkinson's disease, multiple cerebral infarction, spastic ectropion, and eye ataxia.

5.8.2.1 Consideration

It is sometimes difficult to observe natural head posture abnormalities when patients are nervous in doctor's office. Therefore, it is important to hear from family members about head posture abnor-

Table 5.3 Abnormal head postures seen in external ophthalmoplegia

Paralyzed muscle	Turning	Tilting	Chin elevation	Chin depression
Medial rectus	Direction of normal eye			
Lateral rectus	Direction of paralyzed eye			
Superior rectus			+	
Inferior rectus				+
Superior oblique		Direction of normal eye		+
Inferior oblique		Direction of paralyzed eye	+	

malities seen at home when the patient watches the TV or reads books. Moreover, it is also important to observe head posture in daily lives through photographs. In patients with paralytic strabismus, patients rotate their face in horizontal strabismus to avoid diplopia. In vertical or torsional strabismus, patients tilt their head or lift or depress their chin, so confirming head posture abnormalities can be important in diagnosis of paralytic strabismus. Although Table 5.3 shows head postures seen in different types of strabismus, it should be noted that they do not always hold true.

5.9 Anticholinesterase Test

In myasthenia gravis, an autoimmune disease, abnormalities in neuromuscular junctions prevent acetylcholinergic excitation from reaching the muscular tissues, thus leading to abnormal movements of orbicularis oculi and extraocular muscles. Here, cholinesterase breaks down acetylcholine, leading to weakening of muscles.

Therefore, differential diagnoses of paralytic causes are required in ptosis and extraocular muscle movement disorders. If positive results are obtained after administration of anticholinesterases, myasthenia gravis can be diagnosed.

Responses are especially fast for ptosis, and patients sometimes do not respond in cases of eye movement disorders.

5.9.1 Edrophonium Chloride (Tensilon®)

This is one of the most commonly used methods. The adult dose is 1 ml (10 mg); in the beginning, 0.2 ml (2 mg) is very slowly injected intravenously, and responses are observed for 60 seconds. If symptoms, such as ptosis, disappear or improve, the test is stopped. If no response is observed, 1–2 mg of the drug is injected every 60 seconds, and the response is monitored. In cases of severe side effects, such as hypotension, bradycardia, and arrhythmia, 0.5–1.0 ml of atropine is injected into the muscle.

5.9.2 Neostigmine Methylsulfate (Vagostigmin®)

In adults, 1 ml (0.5 mg) is injected subcutaneously or intramuscularly. Recovery is observed 10 minutes after injection.

5.9.3 Neostigmine Bromide (Prostigmin®)

Responses are observed 15–30 minutes after intramuscularly injecting the drug into the deltoid muscle. 0.5–1.5 mg for adults and 0.04 mg/kg (maximum 1.5 mg) for children are injected intramuscularly. When neostigmine bromide injection into children may interfere with future examinations, a dose of 5 mg per day is divided into three doses per day, and children aged 2–3 years are asked to orally ingest the drug for a week.

Suggested Reading

Archer SM, Sondhi N, Helveston EM. Strabismus in infancy. Ophthalmology. 1989;96(1):133–7.

Bahill AT, Brockenbrough A, Troost BT. Variability and development of a normative data base for saccadic eye movements. Invest Ophthalmol Vis Sci. 1981;21(1 PT 1):116–25.

Beard C. Ptosis. St. Louis: CV Mosby; 1981.
Biedner BZ, Marcus M, Yassur Y, et al. Stereopsis testing: at the beginning or the end of the orthoptic examination. Binoc Vis Q. 1992;7:37–9.
Bixenman WW, Von Noorden GK. Apparent foveal displacement in normal subjects and in cyclotropia. Ophthalmology. 1982;89:58–62.
Chung WS, Kim SY. Analysis of the causes of ptosis. J Korean Ophthalmol Soc. 1995;36(10):1649–54.
DeRespinis PA, Naidu E, Brodie SE. Calibration of Hirschberg test photographs under clinical conditions. Ophthalmology. 1989;96(7):944–9.
Guyton DL. Exaggerated traction test for the oblique muscles. Ophthalmology. 1981;88(10):1035–40.
Helveston E, Bick SE, Ellis FD. Differential intraocular pressure as an indirect measure of generated muscle force. Ophthalmol Surg. 1980;11:386–91.
Hess WR. I. Ein einfaches messendes Verfahren zur Motilitätsprüfung der Augen. Ophthalmologica Journal international d'ophtalmologie International Journal of Ophthalmology Zeitschrift fur Augenheilkunde. 1916;35:201–19.
Hofmann FB, Bielschowsky A. Die Verwertung der KopfneigungzurDiagnoseder Augenmuskellmungen aus der Heber und Senkergruppe. Graefes Arch Clin Exp Ophthalmol. 1900;51:174.
Lancaster WB. Terminology in ocular motility and allied subjects. Am J Ophthalmol. 1943;26:122–32.
Lancaster WB. Refraction correlated with optics and physiological optics and motility limited to heterophoria. Springfield: Thomas; 1952.
McCord CD, Tenenbaum M, Nunery WR. Oculoplastic surgery. 3rd ed. New York: Raven Press; 1995. p. 175–220.
Mitchell PR, Wheeler MB, Parks MM. Kestenbaum surgical procedure for torticollis secondary to congenital nystagmus. J Pediatr Ophthalmol Strabismus. 1987;24(2):87–93.
Noorden GKV. Burian-von noordenis binocular vision and ocular motility. St. Louis: C. V. Mosby; 1985.
Paliaga GP. Linear strabismometric methods. Binoc Vis Q. 1992;7:134–54.
Parls MM. Isolated cyclovertical muscle palsy. Arch Ophthalmol. 1989;24:162–5.
Pensyl CD, Benjamin WJ. Chapter 10: Ocular motility. In: Benjamin WJ, editor. Borish's clinical refraction. 2nd ed. St. Louis: Butterworth-Heinemann-Elsevier; 2006.
Roper KL, Bannon RE. Diagnostic value of monocular occlusion. Arch Ophthalmol. 1944;31:316–20.
Ruttum MS, Shimshak KJ, Chesner M. Photographic measurement of the angel of strabismus. In: Campos EC, editor. Strabismus and ocular motility disorders. Basingstoke: Macmillan; 1990.
Song WS, Lee SJ, Kim YH. Morphologic study of upper contour and functional evaluation of levator palpebrae superioris muscle in adult and young people. J Korean Ophthalmol Soc. 2001;42(11):1523–9.
Striph GG, Miller NR. Disorders of eyelid function caused by systemic disease. In: Bosniak S, editor. Principles and practice of ophthalmic plastic and reconstructive surgery. Philadelphia: WB Saunders; 1996. p. 72–93.
Tongue AC, Cibis GW. Brückner test. Ophthalmology. 1981;88:1041–4.
von Noorden GK, Campos EC. Binocular vision and ocular motility: theory and management of strabismus. 6th ed. St. Louis: Mosby Inc; 2002. p. 168–210.
Von Noorden G, Maumenee A. Atlas of strabismus. 3rd ed. St. Louis: Mosby; 1983.
Worth CA, Chavasse FB. Worth's squint, or, the binocular reflexes and the treatment of strabismus. London: Baillière, Tindall and Cox; 1939.

Binocular Function Test

6

Hye-Shin Jeon and Hee-Young Choi

Binocular vision means both binocular single vision and vision in both eyes recognized as monovision, and visual acuity, anisometropia, and ocular deviation are involved in binocular vision. Therefore, binocular function test should be performed during the diagnosis and treatment of the strabismus, amblyopia, and aniseikonia. The binocular function test examines the stereopsis, fusion and suppression, and abnormality of retinal correspondence, to assess whether and how much the two eyes are integrated into single vision. Because the degree of dissociation of the two eyes differs according to the individual test, careful interpretation is required.

Several stereopsis tests are divided according to the target age: the test used for a wide age range from children over 2 years old to adults and the test that is easy to perform for infants. They may be also classified by the principle of inspection or by considering qualitative or quantitative examination. Polarizing glasses or red-eye glasses can be used to separate the two eyes.

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6.1 Worth Four-Dot Test

This test is objected for patients with suspected strabismus who can distinguish numbers. The presence and degree of suppression, the presence of the dominant eye, diplopia, and abnormal retinal correspondence can be tested.

6.1.1 Methods

Worth four-dot box and red-green glasses are required, and the examination room should be dark enough to recognize the Worth four dots. Patients wear glasses with the red and green filter in the individual eyes. Generally red filter on the right eye and green filter on the left eye are applied. Patients see the Worth four-dot box which present four points (two green lights in the left and right sides, red light in the upside, and white light in the downside). Identify the number and position of the lights of which the patient recognizes.

6.1.2 Judgment

In patients with normal binocular function, the four lights are arranged well. But if the four lights are observed well-arranged when manifested strabismus is observed, it indicates that there is abnormal retinal correspondence (Fig. 6.1a).

J.-S. Lee (ed.), *Primary Eye Examination*, https://doi.org/10.1007/978-981-10-6940-6_6

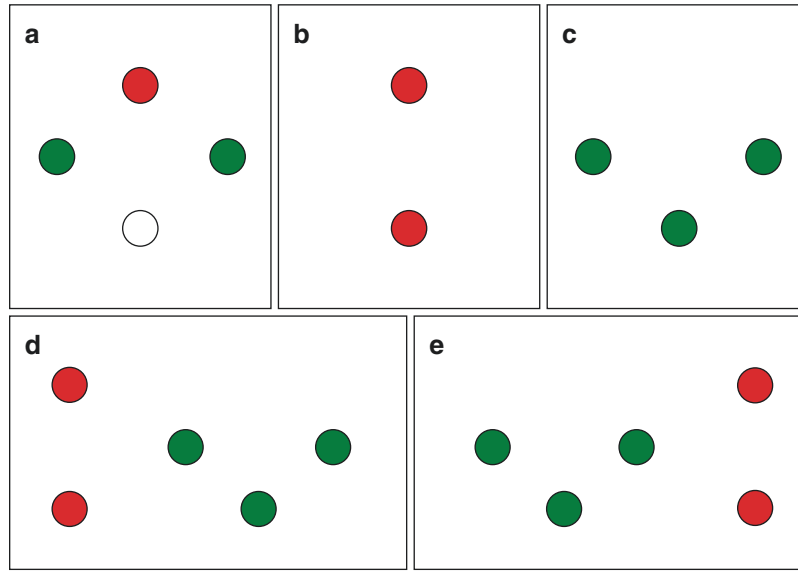

Fig. 6.1 Judgment of Worth four-dot test. Red filter in the right eye, green filter in the left eye (**a**) normal or manifested strabismus with abnormal retinal correspondence (**b**) left eye suppression (**c**) right eye suppression (**d**) crossed diplopia, abnormal retinal correspondence in esotropia, normal retinal correspondence in exotropia (**e**) uncrossed diplopia, normal retinal correspondence in esotropia, abnormal retinal correspondence in exotropia

If the left eye is suppressed, the patient can recognize two red lights on up- and downside (Fig. 6.1b). If the right eye is suppressed, the patient can recognize only three green lights (Fig. 6.1c).

If the patient sees two red lights in the left side and three green lights in the right side, it means crossed diplopia, abnormal retinal correspondence in case of esotropia, and normal retinal correspondence in case of exotropia (Fig. 6.1d).

If the patient sees three green lights in the left side and two red lights in the right side, it means uncrossed diplopia, normal retinal correspondence in case of esotropia, and abnormal retinal correspondence in case of exotropia (Fig. 6.1e).

The distance between the points varies depending on the distance between the subject and the illumination, which can be used for analysis. For example, the distance between the points is 1.25° at 6 m while 6° at 33 cm. Since it is a subjective test, the patient's comprehension and age may influence the outcome. Refractive errors should be corrected because decreased visual acuity can make false results.

6.2 Four-Prism Diopter Base-Out Prism Test

Central suppression scotoma can be examined in strabismic patients. It is useful in measuring the degree of suppression in small strabismus and helps to assess the binocularity in patients who maintain orthophoria after surgery.

6.2.1 Methods

With patient looking at the distant target, place four-prism diopter base-out prism in front of one eye, and observe the movement of the other eye. Put the prism on the other eye, and observe the movement of the contralateral eye in the same way.

6.2.2 Judgment

In a normal eye, when four-prism diopter base-out prism is placed at one eye, the eye is displaced by 2–4 prism diopters nasally, and the other eye moves temporally, but temporary diplopia may occur, and the latter eye returns to its

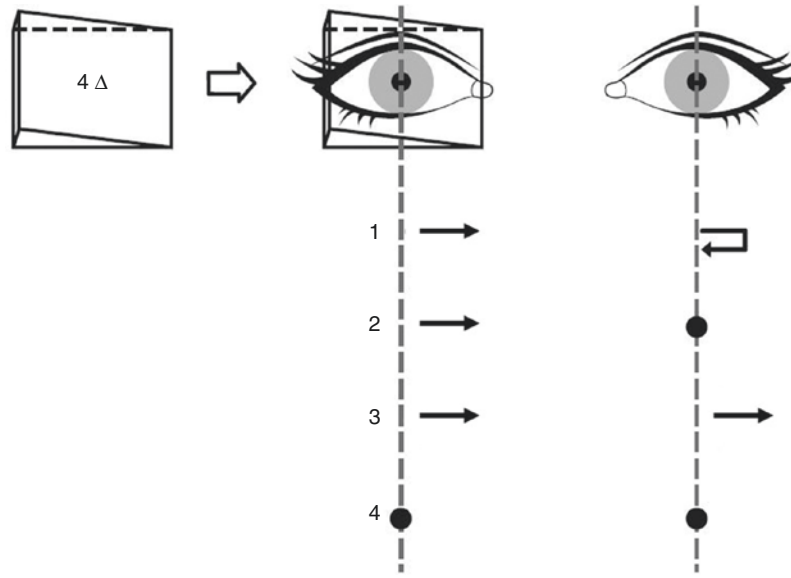

Fig. 6.2 Judgment of 4-prism base-out test. The arrow indicates the movement of the eye and the point indicates no movement. 1, 2 Normal, 3 left eye suppression, 4 right eye suppression

original position to avoid diplopia. In case of suppression on the eye without prism, both eyes move to the opposite side of the base by 4 PD, and if there is suppression on the eye with prism, there is no movement of both eyes (Fig. 6.2).

6.3 Afterimage Test

Horizontal and vertical light stimulate the individual fovea of the two eyes separately. Vertical light should be stimulated in the strabismic/nondominant eye, because suppression is less severe in vertical than horizontal stimulation. It is also important to stimulate the nondominant eye later to reduce the time to suppression. Retinal correspondence could be examined by positional relationship of the residual image in the two eyes and subjective relation of the two eyes, regardless of the objective angle of ocular deviation.

6.3.1 Methods

Have the patient sit in the dark room and place the afterimage tester in front of the patient. Occlude the strabismic eye and stimulate the fixing eye by the light in the horizontal direction. Stimulate the strabismic eye in the vertical direction. Patient can see a positive afterimage which appears as bright vertical and horizontal lines with empty center in a darkened room or with the eyes closed. Negative image(dark lines) can be observed in a lighted room or with the eyes open. Ask patient to describe the positional relationship between horizontal and vertical lines.

6.3.2 Judgment

Check the foveal fixation by visuoscopy. If the patient has eccentric fixation, the test result becomes unreliable. If the patient has normal retinal correspondence, the two lines cross at midline since the two eyes make the afterimage at the fovea (Fig. 6.3a). If a vertical afterimage appears on the right or left side of the area where the horizontal afterimage is broken, it means the two foveae have a different direction and there is an abnormal retinal correspondence. In the left esotropia, the vertical afterimage is shifted to the right, and the fovea of the two eyes does not have the common visual direction because of abnormal retinal correspondence (Fig. 6.3b). In the left exotropia, the vertical afterimage is shifted to the left and abnormal retinal correspondence exists (Fig. 6.3c).

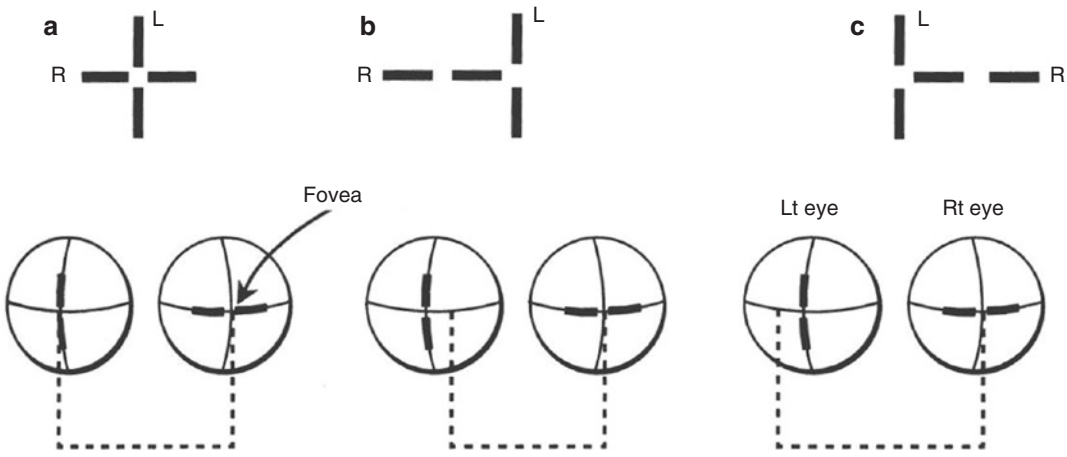

Fig. 6.3 Judgment of afterimage test. R the image of the right eye, L the image of the left eye. (**a**) Normal retinal correspondence. (**b**) Abnormal retinal correspondence in esotropia. (**c**) Abnormal retinal correspondence in exotropia

6.4 Bagolini Striated Glasses Test

Both suppression and abnormal retinal correspondence can be evaluated by examining whether the fovea of one eye and the peripheral retina of one eye have a common direction. The test is done under conditions close to normal conditions of seeing.

6.4.1 Methods

A Bagolini lens, glasses frame, and a light source are needed. Refractive errors should be corrected before the examination.

The direction of the Bagolini lens should be 45° and 135° at the individual eye. Generally, 45° in the right eye and 135° in the left eye are applied (Fig. 6.4).

Look at the light source at a distance of 6 m and 33 cm.

Have the patient draw the number and location of the lines.

6.4.2 Judgment

Judge as shown in Fig. 6.5.

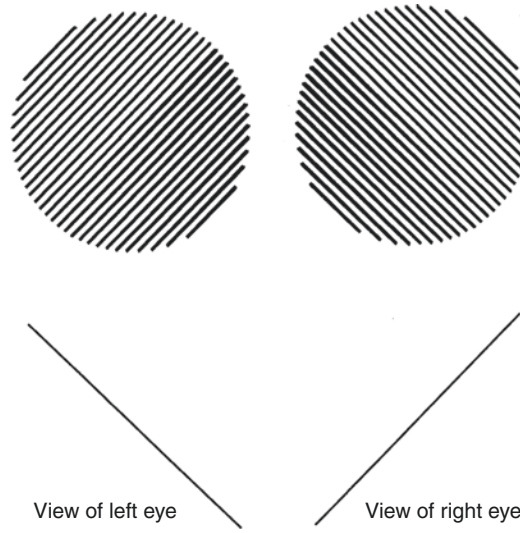

Fig. 6.4 The shape of the line through the Bagolini lens

6.5 Major Amblyoscope

Examination of sensory and motor abnormalities such as subjective and objective deviation measurements, fusion, retinal correspondence, suppression, stereopsis test, and training of binocular function in patients with suspicion of abnormal ocular deviation, binocular dysfunction, or abnormal eye movement disorder.

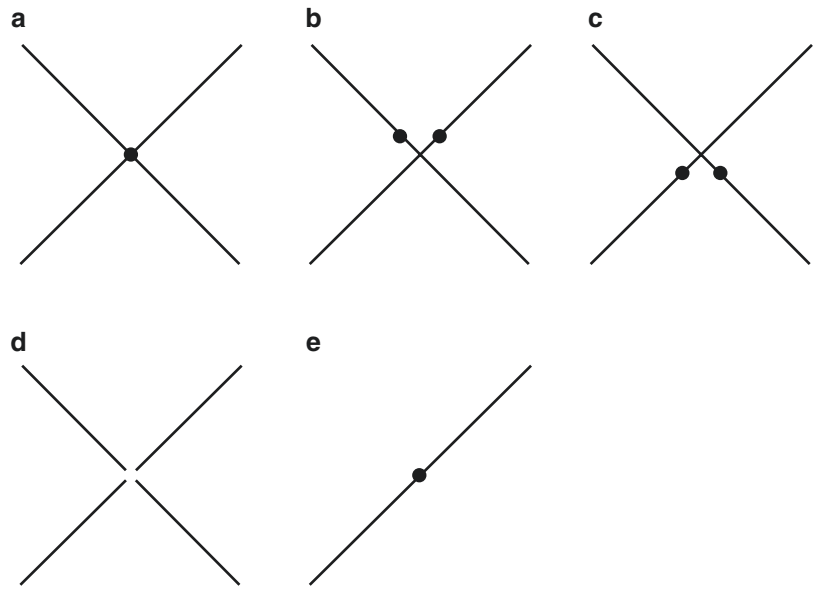

Fig. 6.5 Judgment of Bagolini lens test. 45° in right eye, 135° in left eye. (**a**) Abnormal retinal correspondence if there is manifested eye deviation. (**b**) Normal retinal correspondence with exodeviation. (**c**) Normal retinal correspondence with esodeviation. (**d**) Central scotoma of the left eye. (**e**) Suppression of the left eye

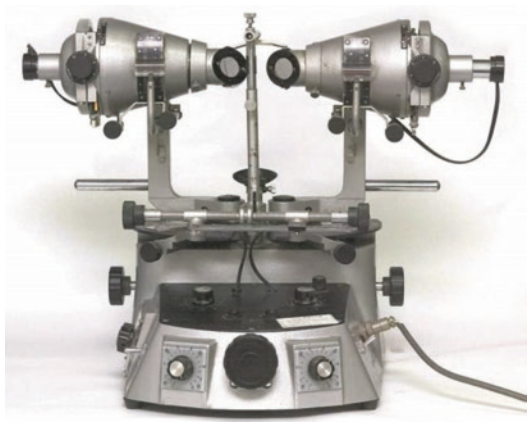

Fig. 6.6 Anomaloscope

6.5.1 Methods

Slides are selected according to the purpose. Slides are used for alignment, fusion, stereoscopic, and Kappa angle.

First, adjust the patient's pupil distance, and place the slides on the left and right slide barrels individually according to the purpose. Second, place the patient's face on the exact place and fix the forehead. Third, make sure that all adjustment screws are at zero and refractive errors are corrected (Fig. 6.6).

6.5.1.1 Ocular Deviation

Two simultaneous test slides (e.g., birds and cage) that do not have sameness are needed. Put small target slides (birds) with small target size on the dominant eye and slides with large target (cage) on the deviated eye. Rotate the horizontal rotary screw little by little and observe the movement of the deviated eye by alternately blinking the two targets. The numerical value when the eyeball is not moving is the objective ocular deviation. When you change the slit of the left eye and the right eye and measure the deviation in the same way, if the deviation is more than ten prism diopters, it is an incomitant strabismus.

6.5.1.2 Binocular Vision

Two simultaneous test slides (e.g., birds and cage) that do not have sameness are needed. Fix the lens barrel, with small-sized target slide in the fixing eye, at 0°. Move the barrel of the large target slide (cage) at the angle of deviation to the left or right to ask whether the two slides overlapped (whether the bird enters the cage). When two slides are overlapped, there is binocular vision, and the angle of the barrel is subjective ocular deviation. If two slides do not overlap and disappear instantly while approaching and appear on the opposite side, there is suppression on the deviated eye.

6.5.1.3 Retinal Correspondence

Perform an angle deviation test which is an objective deviation test and the binocular vision test which is a subjective deviation test. Compare the results of the two tests. If both the subjective and objective deviations are consistent, the patient has normal retinal correspondence (Fig. 6.7a). In other cases, there is an abnormal retinal correspondence. If the picture overlaps with the handle angle of the machine to 0, subjective deviation is 0 and the ocular deviation corresponds to the objective deviation and the sensory adaptation is complete, which is the harmonious abnormal retinal correspondence (Fig. 6.7b). When the observed angle is smaller than the objective deviation, it is called unharmonious abnormal retinal correspondence (Fig. 6.7c).

6.5.1.4 Fusion and Fusional Amplitude

Two targets with the same size and shape, but with partial defects, are required.

Place the two slides in each barrel (e.g., a flowerless rabbit and a tailless rabbit, Fig. 6.8b), and move the barrel to make it a complete rabbit. Ask to see if a complete rabbit with a tail and flower is visible and record whether it is fused or not. Move both horizontal barrels to the outside (abduction direction) and exam when the two rabbit start to appear, the point where the fusion breaks, to record the fusional amplitude. Move the barrel inside (adduction direction) and record the point where fusion starts. Continue moving inside and record the point at which fusion is broken again, the convergence fusional amplitude. If two targets are found to be completely consistent, there is fusion.

6.5.1.5 Stereoacuity

Insert the stereoscopic slide into the barrel.

Ask for stereopsis. Stereopsis of normal adult is recorded as 40 arc seconds.

6.5.1.6 Fusion

For first-degree fusion, ask whether the two phases overlap by using the slide of the first-degree fusion slide (Fig. 6.8a). For second-degree fusion, after fitting the amblyoscope to the subjective deviation, ask whether the image of the slides is made as a complete image (Fig. 6.8b). For third-degree fusion, the slide for third-degree fusion is inserted, and the patient is asked whether it looks three dimensional (Fig. 6.8c).

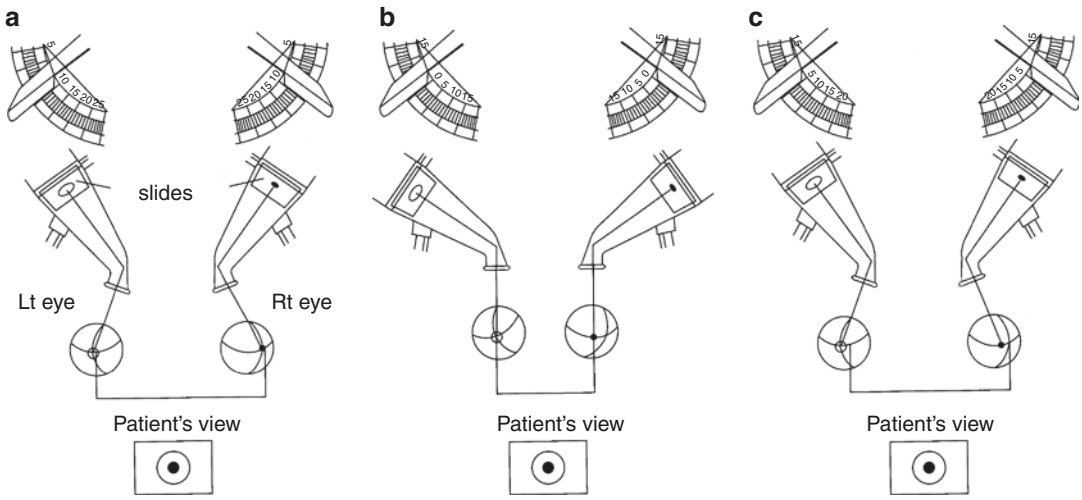

Fig. 6.7 Retinal correspondence test by anomaloscope. (**a**) Normal retinal correspondence. (**b**) Harmonious abnormal retinal correspondence. (**c**) Unharmonious abnormal retinal correspondence

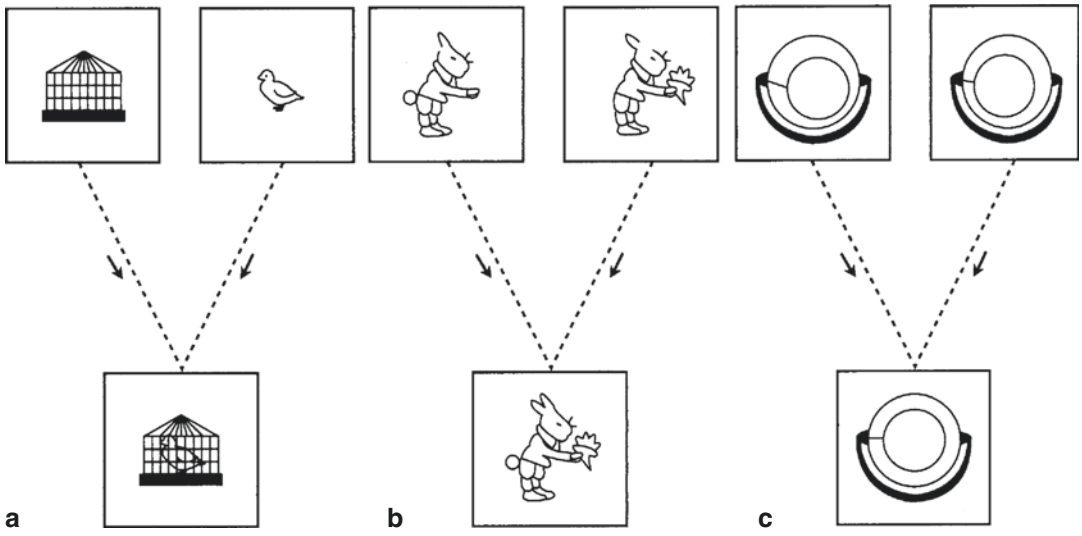

Fig. 6.8 Fusion test by anomaloscope. (**a**) First-degree fusion. (**b**) Second-degree fusion. (**c**) Third-degree fusion

6.6 Red Filter Test

Suppression, abnormal retinal correspondence, diplopia, and strabismic angle can be measured in strabismus patients.

6.6.1 Methods

Apply a red filter to one eye (mainly the dominant eye). Instruct the patient to open eyes and see the light. Ask the patients what they see.

6.6.2 Judgment

When two lights are visible, the fixing eye and the strabismic eye have normal retinal correspondence that considers the red light and the white light separately.

If a red filter is placed on the right eye, a red light is shown on the right side in esotropia, and on the left side in exotropia. Sometimes the direction of diplopia is reversed to that of strabismus. This is because, if the abnormal retinal correspondence in the long-lasting esotropia develops, the abnormal retinal correspondence acts as a fovea even after the surgery becomes orthophoria or undercorrected.

6.7 Prism Test

Prisms can be used to detect the size of the suppression scotoma. Patients may not notice diplopia when they put red glasses in front of their eyes. The examiner may put the prism in front of the eyes and find the prism diopter in which the patient notice diplopia. The fixing light should be small, and it may be stimulated on the location outside the scotoma which is not suppressed, and thus the patient feels diplopia.

The size of suppression scotoma may be presumed by prism diopters, and the direction of the base needs to make diplopia (Fig. 6.9). For example, if the right eye is esotropic, place the red filter in front of the left eye to see the light, and then place the base-out prism on the right eye to increase the angle until crossed diplopia occurs. Then, put the base-in prism on the right eye to make an uncrossed diplopia; the horizontal diameter of the suppression scotoma is the sum of the diopters of the two prisms.

6.8 Stereoacuity Test

It is test for evaluating the presence and degree of stereopsis and hence the effect of strabismus treatment and the expected treatment outcome.

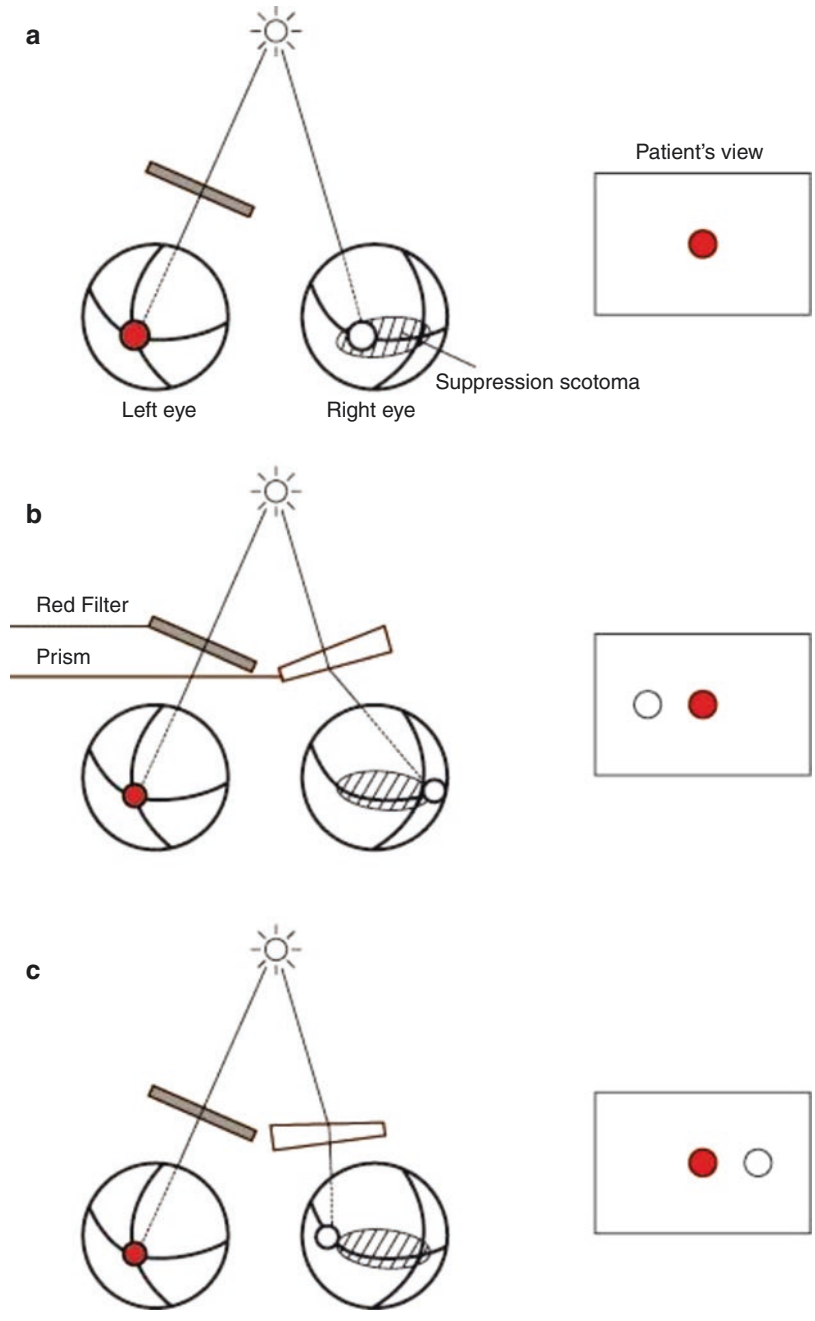

Fig. 6.9 Prism test to measure the size of the suppression scotoma (**a**) red glass is placed in front of left eye the patient who has suppression scotoma in his right eye may not feel diplopia (**b**) place the base out prism on the right eye to increase the angle until crossed diplopia occurs (**c**) place the base in prism on the right eye to make an uncrossed diplopia

Separate the left eye and right eye and have the patient see a parallax picture. If it looks stereoscopic, it is normal and normal stereoacuity is 40 seconds of arc.

6.8.1 Titmus Test

The polarizing filter separates the two eyes, and the two targets are polarized at 90° that matches

Fig. 6.10 Titmus test

the filter. Circles and animals are in the left page and fly is in the right page (Fig. 6.10). It is the most widely used stereoacuity test because it is simple and easy. However, because of monocular clue, it is not suitable for screening test.

6.8.1.1 Methods

Wear polarized glasses at a distance of 40 cm. Have the patient hold the fly using the thumb and index finger. Pick a circle floating in the air among the four circles arranged in a rhombic shape. If the patient gets the correct answer, go to the next step. Pick an animal floating in the air among the five animals. If the patient gets the correct answer, go to the next step.

6.8.1.2 Judgment

The threshold of the fly represents 3000 seconds of arc. If the patient holds the wing in the air, it is judged as having stereopsis. Each animal plate of A, B, C represents stereoacuity threshold of 400, 200, and 100 seconds of arc, respectively. The nine circles indicate stereoacuity thresholds ranging from 800 to 40 seconds of arc. So, it is possible to quantitatively measure the stereoacuity threshold based on the last picture which the patient figures out correctly. The test can be performed turning the plate as 90° to evaluate whether the patient is actually able to see stereoscopically or is using monocular clue. Since only horizontal disparity produces stereopsis, if the patient finds a stereoscopic picture during the plate is turned 90°, the patient might have used a monocular clue.

Fig. 6.11 Random dot E test

6.8.2 Random Dot E Test

It contains a polarizing filter glasses and random dot stereogram. It can be used for the screening of the stereoacuity since there is little monocular

clue; the stereoscopic disparity varies depending on the examination distance (Fig. 6.11).

6.8.2.1 Methods

Wear polarized glasses at a distance of 50 cm. Show one polarized card containing E that does not have stereoscopic ability but confirm the shape of E. Ask the patients of which side the E character to be seen between the cards consisting of only random numbers without a stereoscopic image and a polarizing card with an E-shaped stereoscopic image.

6.8.2.2 Judgment

The stereoacuity of 500 seconds of arc can be judged at a distance of 50 cm, and 50 seconds of arc can be judged at 5 m.

6.8.3 Randot Stereo Test

The polarized glasses are used to separate the two eyes to see the random dot pattern, the shape of the animal, and the specific shape. The test book is similar to Titmus test (Fig. 6.12).

6.8.3.1 Methods

Wear polarized glasses at 40 cm.

Pick a circle floating in the air among the three circles. If the patient gets the correct answer, go to the next step. Pick an animal floating in the air among the five animals. If the patient gets the correct answer, go to the next step. Have the patient answer the shapes such as circles, stars, E, squares, triangles, and crosses in four squares.

6.8.3.2 Judgment

One animal among the five was imaged disparately of which thresholds are 400, 200, and 100 seconds of arc, respectively. The circles were imaged disparately with thresholds ranging from 400 to 20 seconds of seconds of arc. The right side is divided into upper and lower and consisted of four squares individually. The upper part shows circle, star, and E shape of which stereopsis is 500 seconds of arc. The lower part is consisted of a square, triangle, and cross shape with stereopsis of 250 seconds of arc. It is possible to quantitatively measure the stereoacuity on the basis of the degree of disparity of the last picture which the patient figures out correctly.

6.8.4 TNO Test

TNO test can be used to evaluate the presence of stereopsis and suppression in patients with strabismus and screen examination for stereopsis and quantitative measurement of stereopsis by separating the two eyes using red-green filter.

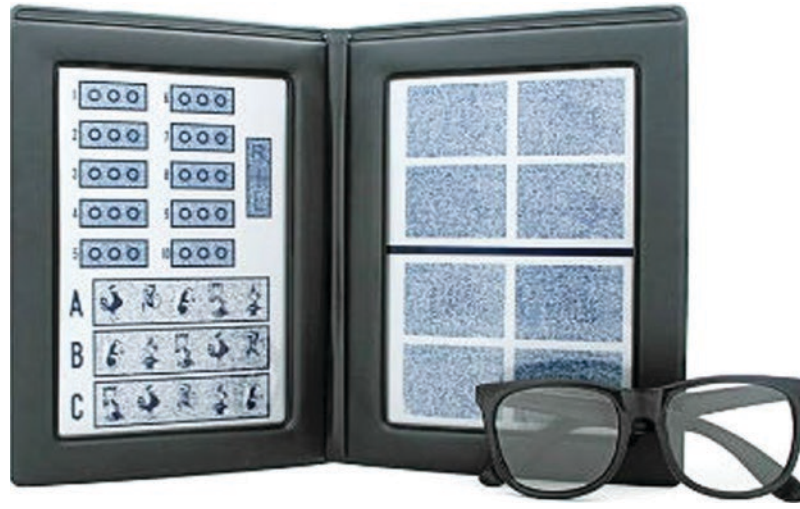

Fig. 6.12 Randot stereoacuity test

Fig. 6.13 TNO test

6.8.4.1 Methods

The plate is placed perpendicular to the gaze at 40 cm with the green filter on the right eye and the red filter on the left eye (Fig. 6.13).

Ask a question about the number and location of butterflies in Panel I. Ask a question about the largest circle and the smallest circle in Panel II. Ask a question about the position of the figure of five shapes including circle, triangle, square, rhombus, and cross in Panel III. In the plate IV, there is a large circle on both sides of one small circle. If only two circles are visible, let the patient tell where the big circle is. Plates V, VI, and VII have a circular sector defect. Let the patient answer the direction of the defect.

6.8.4.2 Judgment

Panels I, II, and III represent stereopsis of 1980 seconds. In plate IV, the patient sees two circles in the right side on the green glass and two circles in the left side on the red glass, and three circles with both eyes so the examiner can check the inhibition and see which eye the patient is using. Plates V, VI, and VII have six levels of stereopsis ranging from 480 seconds of arc to 15 seconds of arc, so the TNO test can determine stereoacuity threshold in the most detailed quantitative manner.

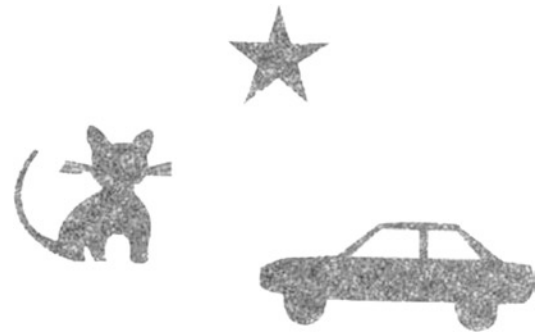

Fig. 6.14 Lang test

6.8.5 Lang Test

It used the random dot, but the cylinder gratings are on the surface individually, so the object appears to be stereoscopic even without glasses. Therefore, it can examine the stereopsis easily by separating the two eyes without using glasses in children aged 2–3 years who refuse to wear glasses (Fig. 6.14).

6.8.5.1 Methods

Place the exam plate perpendicular to the line of sight at a distance of 40 cm.

Have the patient say what he sees among cat, star and car.

6.8.5.2 Judgment

The cat represents stereopsis of 1200 seconds of arc, the star indicates 600 seconds of arc, and the car signifies 500 seconds of arc. If all three are met, it is judged as normal.

6.8.6 Frisby Test

The test tool consists of three plastic plates with thicknesses of 6 mm, 3 mm, and 1.5 mm. Each plate has a random square and circle arranged on the front and back. Each inspection panel consists

of four-square sections, one of which actually looks like a round shape. Since the actual depth is known, examination glasses are not necessary.

6.8.6.1 Methods

Lift the plastic plate so that is perpendicular to the patient's view. Make sure that you find a rectangle with a round shape protruding out of the four-square areas printed.

6.8.6.2 Judgment

When examined at a distance of 30 cm, the 6 mm plate indicates a stereoacuity of 600 seconds of arc, the 3 mm plate demonstrates a 300 seconds of arc, and the 1.5 mm plate signifies a 150 seconds of arc.

Suggested Reading

Bagolini B. Anomalous correspondence: definition and diagnostic methods. Doc Ophthalmol. 1967;23(1):346–86.

Bagolini B. Sensorial anomalous in strabismus (suppression, anomalous correspondence amblyopia). Doc Ophthalmol. 1976;41:23.

Burian HM. Normal and anomalous correspondence. Paper presented at: strabismus ophthalmic symposium 1950.

Frank JW, France TD, Harrington J. The Worth four dot test: is it really "worthless"? Am Orthopt J. 1981;31(1):68–71.

Irvine SR. A simple test for binocular fixation: clinical application useful in the appraisal of ocular dominance, amblyopia ex anopsia, minimal strabismus, and malingering. Australas J Optom. 1944;27(12):536–47.

Jampolsky A. The prism test for strabismus screening. J Pediatr Ophthalmol Strabismus. 1964;1(1):30–4.

Lovasik JV, Szymkiw M. Effects of aniseikonia, anisometropia, accommodation, retinal illuminance, and pupil size on stereopsis. Invest Ophthalmol Vis Sci. 1985;26(5):741–50.

Noorden GKV. Burian-von noordenis binocular vision and ocular motility. St. Louis: C. V. Mosby; 1985.

Romano PE, Von Noorden GK. Atypical responses to the four-diopter prism test. Am J Ophthalmol. 1969;67(6):935–41.

Eyelid and Lacrimal System Exam

7

Jung-Yul Park and Hee-Young Choi

7.1 Eyelid Exam

Eyelid exams can be divided broadly into eyebrow and eyelid examinations. Located where the frontalis and orbicularis oculi muscles meet, the eyebrows provide support to the eyelids. When examining the position of the eyelids, it is essential to check the position of the eyebrows.

These examinations focus on diseases that cause blepharoptosis of congenital, neurological, muscular, external injury or mechanical etiology, with the aim of differentiating eyelid edema and tumors and determining treatment plans in patients with blepharoptosis.

7.1.1 Methods

7.1.1.1 General Examination

The patient is examined while sitting straight or lying on a bed. When examining blepharoptosis or abnormalities of eyelid position, it is preferable to perform the assessment in a seated position.

The patient's overall condition is observed under diffuse illumination. The position and shape of the eyelids, changes in the skin, the eyebrows, and the palpebral fissure are observed; if any particular abnormalities are detected, that area is examined in more detail under magnification and local illumination.

If necessary, further examinations are performed by scraping or palpation.

7.1.1.2 Brow Ptosis Test

First, the height and shape of the eyebrows is observed. In males, the eyebrows are in level with the superior margin of the orbit and have a relatively straight shape; in females, the eyebrows are positioned approximately 1 cm superior to the superior margin of the orbit and show a slight rise in the lateral direction. The relative positions of the eyebrow and the superior margin of the orbit can easily be verified by palpation with the thumb and index finger. If the distance from the middle of the upper eyelid to the inferior margin of the eyebrow is $\leq$10 mm in the primary eye position, this indicates brow ptosis, which can also be detected based on the lack of conformity in the angles of forehead wrinkles. The tail of the eyebrow often develops ptosis with aging, since it is not connected to the frontalis muscle.

7.1.1.3 Blepharoptosis Test

In the case of unilateral blepharoptosis, the severity can be determined by comparison with the contralateral eye. However, in bilateral blepharoptosis, this can be determined by inspecting the amount of the cornea covered by

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the upper eyelid during primary gaze. It is necessary to assess the vertical height of the palpebral fissure, the position of corneal reflex, and the function of the levator palpebrae superioris (LPS) muscle. During the examination, the patient should be instructed to keep their eyes open comfortably without using the frontalis muscle; to facilitate this, the examiner should press gently on the patient's forehead while conducting the examination.

Table 7.1 Blepharoptosis severity based on the palpebral fissure

Blepharoptosis severity		Relation between the pupil and the lid margin
Mild	2 mm	The lid margin is superior to the pupil margin
Moderate	3 mm	The lid margin slightly covers the pupil margin
Severe	≥4 mm	The lid margin covers more than half the pupil margin

Method Based on Measurement of the Palpebral Fissure Height

The patient is instructed to focus on a distant point without looking to the side or trying to deliberately open the eyes wider. In this position, the examiner measures the distance, in mm, from the middle of the upper eyelid to the middle of the lower eyelid (Fig. 7.1).

Interpretation

The palpebral fissure height of typical individuals is 7–8 mm in Koreans and 9 mm in Westerners. Normally, the corneal diameter is approximately 11 mm, and the upper eyelid covers the upper 1.5–2 mm of the cornea. Thus the amount of the cornea covered by the upper eyelid can be subtracted from 1.5–2 mm to determine the extent of blepharoptosis (Table 7.1). This method can be affected by abnormalities of the lower eyelid, such as ectropion or retraction, which can result in inaccuracies.

Method Based on Measurement of the Marginal Reflex Distance (MRD)

The marginal reflex distance-1 (MRD1) is the distance from the corneal reflex to the middle of the upper eyelid in the primary eye position. A normal value in Western individuals is 4–5 mm, and this is slightly smaller in Asians, at 3–4 mm. The extent of blepharoptosis can be calculated by subtracting the patient's MRD1 measurement from 4 to 5 mm. To measure the marginal reflex distance-2 (MRD2), the patient and examiner have their eyes at the same height, the patient

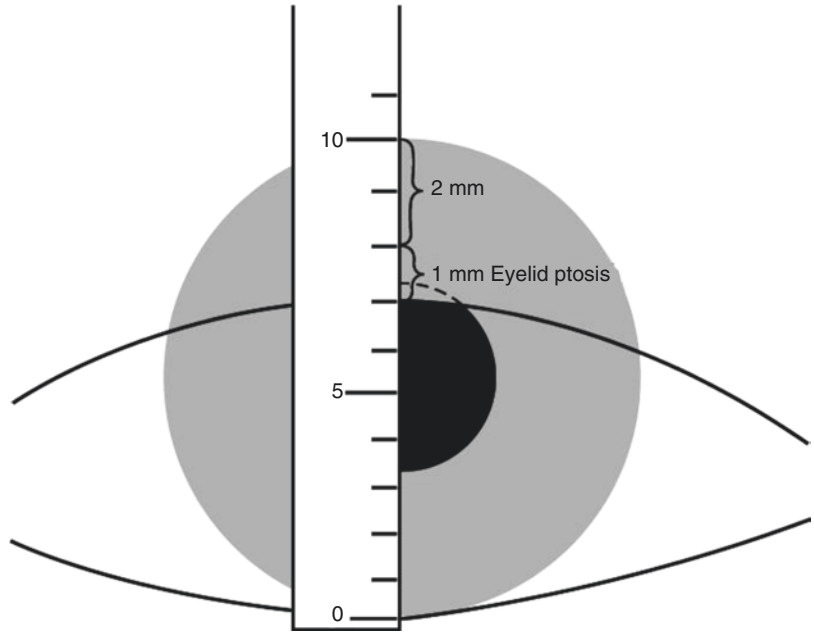

Fig. 7.1 Measurement of the vertical height of the palpebral fissure (assuming that 8 mm is a normal value)

fixates on a distant object, and the examiner measures the distance from the corneal reflex to the middle of the upper eyelid in the primary eye position while shining a light at the same height as the patient's eyes. A typical measurement is 5.5 mm, and this increases in cases of lower eyelid retraction. During the measurement, it is important to make sure that the patient is not using the frontalis muscle to open their eyes wider (Fig. 7.2).

7.1.1.4 Levator Function Test (Berke Method)

Method

A ruler is placed vertically in the midline of the palpebral fissure, and the distance moved by the upper eyelid is measured, while the patient shifts from downward gaze to upward gaze. Here, in order to prevent frontalis muscle activity, the brow should be pressed firmly with the examiner's thumb (Fig. 7.3).

Interpretation

Normal values are in the range 12–16 mm. Values ≥13 mm are classified as "excellent," and among abnormal values, 8–12 mm is classified as "good," 5–7 mm as "fair," and ≤4 mm as "poor." Blepharoptosis patients may require frontalis sling or levator resection, depending on levator function.

Iliff Sign

Following upper eyelid eversion, if the eyelid does not return to its proper position when the patient shifts their gaze upward, this indicates reduced levator function.

7.1.1.5 Margin Crease (Lid Crease) Distance (MCD)

Method

After instructing the patient to look downward, the examiner uses their hand to lift the upper eyelid and measures the distance from

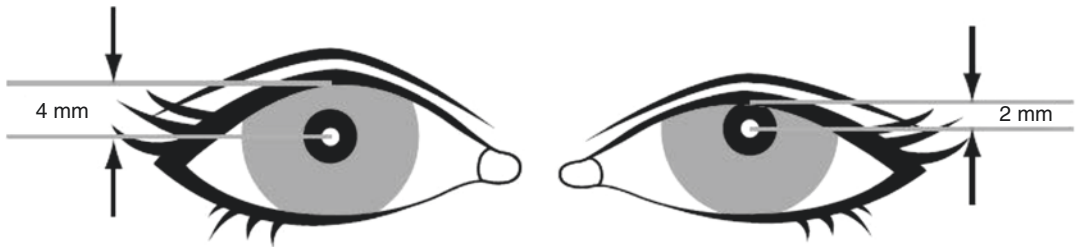

Fig. 7.2 Measuring marginal reflex distance 1

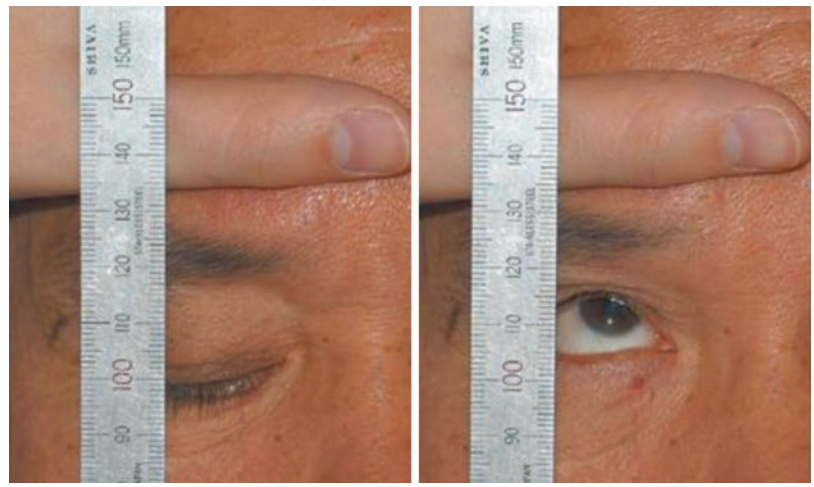

Fig. 7.3 Examination of levator palpebrae superioris function

the middle of the upper eyelid to the middle of the lid crease using a ruler (Fig. 7.4).

Interpretation

Normal values are 8–10 mm for Western adult females and 6–8 mm for Western adult males. These values are smaller in Asian individuals, and the lid crease is absent in many cases.

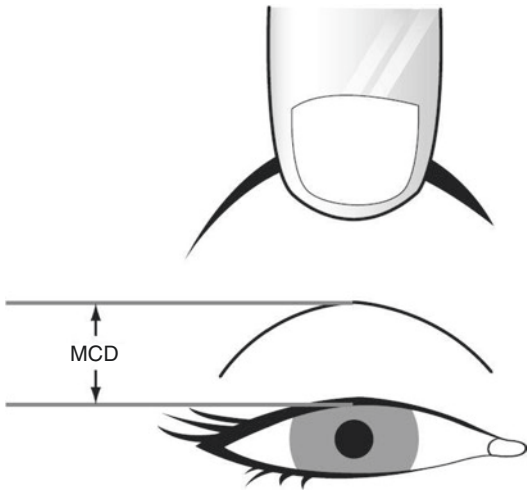

Fig. 7.4 Lid crease test. The examiner uses their hand to lift the upper eyelid with the patient looking downward

7.1.1.6 Lower Lid Horizontal Laxity Test

Snap Back Test

The examiner pulls down on the lower eyelid with their fingers (Fig. 7.5a) and then observes how quickly the eyelid returns to its original position after it is released (Fig. 7.5b).

If the lower eyelid does not return immediately to its proper position and requires the patient to blink, this indicates the presence of lower lid horizontal laxity.

Grade I: The eyelid immediately returns to its original position.
Grade II: The eyelid returns to its original position slowly but spontaneously.
Grade III: The eyelid does not return to its original position spontaneously but does return after blinking.
Grade IV: The eyelid does not return to its original position even after blinking.

Pinch Test (Distraction Test)

The lower eyelid is distracted anteriorly, and the length of distraction from the eyeball is measured. Normally, the eyelid cannot be distracted beyond 6 mm. If the lower eyelid can be dis-

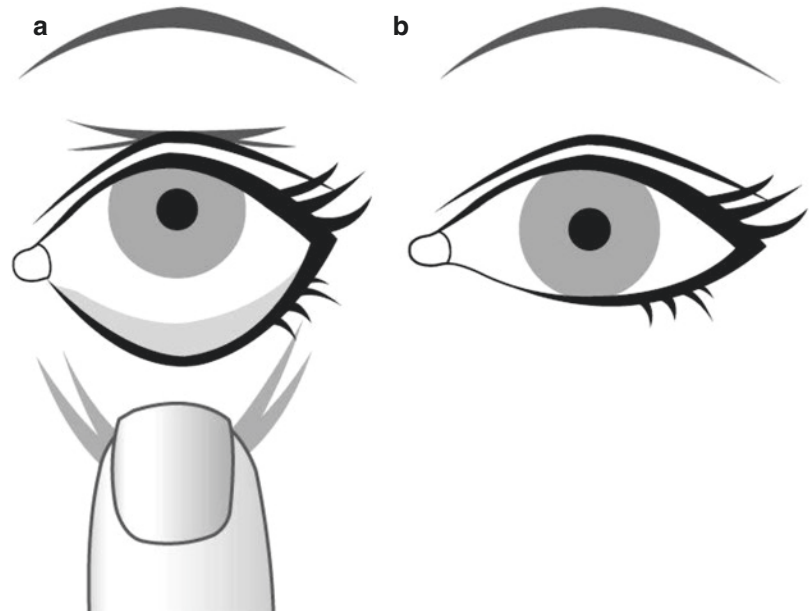

Fig. 7.5 Snap back test to evaluate the lower lid horizontal laxity

tracted more than 6–8 mm from the eyeball, this indicates the presence of lower lid horizontal laxity.

Medial and Lateral Canthal Tendon Laxity Test

Normally, when the lateral canthus is pulled toward the nose or the medial canthus is pulled toward the ear, they only move <1 mm in the case of the medial canthal tendon and <2 mm in the case of the lateral canthal tendon. In patients with severe medial canthal tendon laxity, the lacrimal puncta is moved ≥4 mm laterally; in patients with severe lateral canthal tendon laxity, the lateral canthus reaches the margin of the cornea.

7.1.1.7 Eyelid Retraction Test

Method

With the patient in primary gaze, the distance is measured between the superior corneal margin and the upper eyelid margin or between the inferior corneal margin and the lower eyelid margin.

Interpretation

The upper eyelid should be 1–2 mm below the superior corneal margin in typical individuals; in mild lid retraction, the upper eyelid meets the superior corneal margin; in moderate retraction, <4 mm of sclera is visible superior to the cornea; in severe retraction, ≥4 mm of sclera is visible. The lower eyelid should meet the inferior corneal margin, and if any sclera is visible inferior to the cornea, this can be diagnosed as lower lid retraction.

7.1.1.8 Lid Lag Test

The patient is made to gaze downward, and the examiner checks whether the upper eyelid fails to follow the ocular movement and remains in a higher position than normal.

7.1.1.9 Drug Tests

Anticholinesterase Test

This test is used to diagnose severe myasthenia gravis. The interpretation can differ slightly depending on the types of drug used. The examiner checks for clear improvement in ocular symptoms such as ptosis or diplopia.

Following intravenous infusion of edrophonium chloride 5–10 mg (Tensilon test), the drug starts acting within 30–60 s, and the effect wears off within 5 min. Following intramuscular injection of neostigmine methylsulfate 0.5 mg, the drug begins acting after 10–15 min; the maximum effect is achieved after around 30 min; hence, the examination is performed 30–45 min after the injection. This is useful in pediatric patients and other patients who cannot readily receive intravenous infusion. Alleviation of symptoms can also be checked after 1-week use of oral neostigmine bromide 5 mg. Edrophonium chloride (Tensilon test) was used commonly in the past, but discontinuation of the drug means that this test can no longer be performed.

Sympathomimetic Test

This test is used to examine the function of Müller's muscle and is used in the diagnosis of Horner syndrome. A positive result can also be seen in myasthenia gravis patients, so care is required in the interpretation. After instilling 2.5% or 10% phenylephrine hydrochloride into the eye with blepharoptosis and waiting for 5 min, the extent of blepharoptosis is measured again. If the extent of ptosis decreases, this reflects the action of the sympathomimetic drug on Müller's muscle. Since these drugs can also cause lower lid retraction by acting on the lower lid retractors, care must be taken when examining the extent of blepharoptosis. If the patient's medical history shows thoracic or neck surgery, this can help in the diagnosis of Horner syndrome.

7.1.1.10 Ice Test

This test is useful for differentiating myasthenia gravis; the change in height of the palpebral fissure is measured after holding ice against the patient's affected eye for 2 min. A difference of ≥2 mm is considered a positive result. This test is reported to have a sensitivity of over 90% and a specificity of up to 100%.

7.1.1.11 Sleep Test

This test can be used to differentiate myasthenia gravis. The patient enters a dark, quiet room and keeps their eyes closed for at least 30 min; the test is positive if this results in complete disappearance of blepharoptosis or an increase of ≥2 mm in the height of the palpebral fissure.

7.1.1.12 Electromyography (Jolly Test)

This test is used to differentiate blepharoptosis of muscular or nervous etiology. In myasthenia gravis, the extraocular muscles show reduced activity in electromyography.

7.1.1.13 Radiography

The structure of the orbit and paranasal sinuses is inspected using X-ray, CT, or MRI.

7.2 Exophthalmometry

These examinations focus on increases in orbital contents, such as orbital masses, orbital cellulitis, thyroid eye disease, or leukemia, and on vascular abnormalities in the orbit, such as carotid-cavernous fistula, or orbital varices. They can also be performed in cases with orbital hypervolemia, such as craniofacial dysmorphism; cases with increased axial length of the eye, such as high-degree myopia or congenital glaucoma; and cases of proptosis accompanied by extraocular muscle palsy.

Measuring the extent of proptosis and the difference between the two eyes can be used to differentiate between diseases causing proptosis. Often, unilateral proptosis indicates an intraorbital disease, while bilateral proptosis indicates a systemic disease.

7.2.1 Methods

7.2.1.1 Hertel Exophthalmometer

The two arms of the Hertel exophthalmometer are pressed against the lateral margins of the orbits with the same force; the visual axes are aligned by having the patient look into the eyes of the examiner sitting opposite. To measure the patient's right eye, the examiner uses their left eye, places it in alignment with the patient's visual axis, and measures to vertical distance to the corneal apex reflected in the mirror of the exophthalmometer. To measure the patient's left eye, the same procedure is performed on the other side. The two measurements are recorded along with the distance between the lateral margins of the two orbits (base line) (Fig. 7.6).

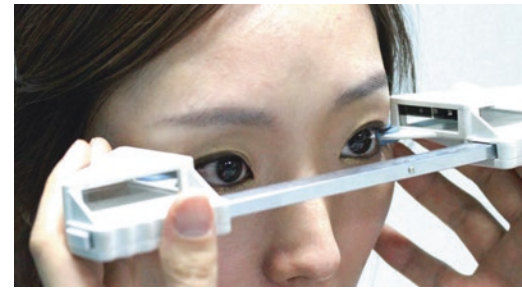

Fig. 7.6 Measuring proptosis using a Hertel exophthalmometer

7.2.1.2 Naugle Exophthalmometer

This test measures proptosis based on the superior and inferior orbital margins. It is especially useful in patients with an injury to the lateral orbital margin, such as lateral orbitotomy patients. This method enables pain-free measurement in patients who may complain of pain during measurement with a Hertel exophthalmometer, such as children or individuals with thyroid eye disease, conjunctivitis, or trauma. It is also possible to measure vertical deviation of the eye.

7.2.1.3 Measurement with a Ruler

A transparent ruler is placed vertically at the lateral orbital margin, and the height of the patient's corneal apex is measured by the examiner looking horizontally at the patient's eye level (Fig. 7.7).

7.2.1.4 Visual Inspection

With the patient in a supine position and their eyes closed, proptosis is observed from the supero-anterior and supero-posterior positions. The height of the eyelashes was observed relative to the eyebrows, and this was compared for the

Fig. 7.7 Measuring proptosis using a ruler

right and left sides. Here, taking photographs helps to compare progression over time. Proptosis is easiest to see when the patient's head is tilted back and the examiner looks up from below.

7.2.1.5 Radiography

Measurements can be made using X-ray or CT imaging.

7.2.2 Interpretation

Hertel exophthalmometry results are expressed as the vertical distance between the corneal apex and the line connecting the left and right lateral orbital margins. Normal values are reported to be 10–14 mm for Asians and 12–20 mm for Western individuals. The mean values for Koreans are in the range 13.6–14.7 mm. A difference of >2 mm between the two eyes is considered to be abnormal.

7.3 Evaluation of Watering Eye

Watery eyes can be divided into epiphora and hypersecretion, depending on the underlying mechanisms. Epiphora is caused by abnormalities of the lacrimal drainage system. Unilateral epiphora is most commonly caused by obstructive disease of the lacrimal drainage system or by lower eyelid malposition, and it is usually unaccompanied by other ocular symptoms. During medical interview, it is important to check the patient's history, including intermittent red eye, viscous secretions, excessive discharge, pain in the lacrimal apparatus, and dacryocystitis.

Hypersecretion is caused by overactive tear production and is usually accompanied by eye irritation.

Diseases that can show hypersecretion due to abnormal irritation of the lacrimal gland include neurological diseases such as trigeminal nerve irritation, optic nerve stimulation by strong light, and facial nerve irritation, as well as systemic diseases such as thyroid disease and inflammatory disease. Local eye diseases that can cause hypersecretion include corneal disease, intraocular disease, and periocular disease, especially of the paranasal sinuses or nasal allergies.

7.3.1 Examination of External Structures Using a Slit Lamp

7.3.1.1 Punctum

First, the patency of the punctum is checked; the position of the lacrimal lake should not be visible without everting the lower eyelid. Fluorescein stain is instilled and its flow into the puncta is observed. Swelling and redness around the punctum suggest canaliculitis. Punctal stenosis can occur in cases of chronic lid ectropion or due to various acquired causes.

7.3.1.2 Eyelid Movement

In typical individuals, the blinking force is conveyed toward the nose, and the eyelid moves in close contact with the eye.

7.3.1.3 Eyelid and Corneal Disease

In cases of eyelid eversion, epiphora can occur if tears fail to reach the punctum; in cases of lid inversion, trichiasis, or distichiasis, corneal irritation can cause reflex tearing. Lacrimal pump dysfunction can be caused by dysfunction or deformity of the eyelids due to trauma or scarring, incomplete blinking due to facial nerve palsy, or degenerative lower eyelid laxity. As potential causes of hypersecretion, it is important to check for physical indicators of dry eyes, such as filaments, reduced tear meniscus, meniscus floaters, mucous strands, and papillary conjunctivitis.

7.3.2 Lacrimal Secretion Function Tests

The sequence of lacrimal secretion function tests is shown in Fig. 7.8.

7.3.2.1 Tear Film Breakup Time (BUT)

This is performed before the Schirmer test and before anesthetic instillation. This is an objective method used to diagnose dry eyes that measures the instability of the tear film.

Method

After touching fluorescein paper to the inferior inside surface of the bulbar conjunctiva or instilling one drop of 2% fluorescein solution to the inferior conjunctival sac, the patient blinks several times to spread the stain evenly throughout the tear film. The corneal surface is observed under broad illumination by a slit lamp with a blue filter. The patient blinks once before looking straight ahead without blinking; the examiner measures the time after blinking, in seconds, until dry spots first appear due to breakup of the fluorescein within the tear film. The test is repeated five times for each eye, and the mean time is calculated.

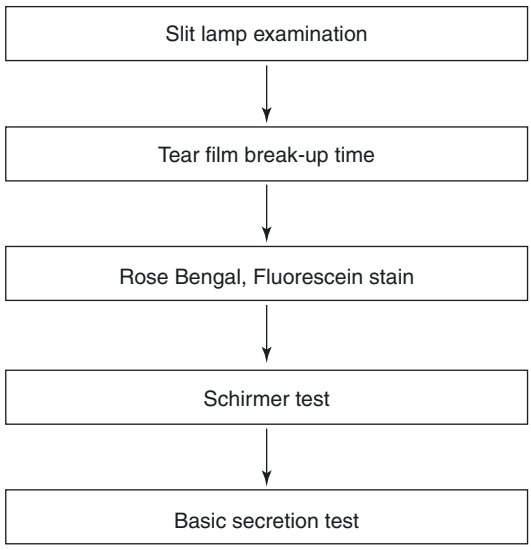

Fig. 7.8 The sequence of lacrimal secretion function tests

Interpretation

Normal values are in the range 10–30 s, and results ≤10 s are diagnosed as a lacrimal disorder due to mucin deficiency.

7.3.2.2 Rose Bengal Stain

Reduced tearing causes degeneration or defects in the corneal and conjunctival epithelia. The rose bengal stain not only stains epithelial defects but also degenerated epithelial cells and contaminated mucin.

Method

Soluble 1% rose bengal is applied to a cotton swab, which is then touched to the fornical conjunctiva.

The patient blinks several times and waits 30 s before washing the eye with normal saline.

Interpretation

Dry eye syndrome is diagnosed if both the cornea and conjunctiva are stained under a slit lamp. The extent of staining of the corneal epithelium is assessed by slit lamp or macroscopically (Table 7.2).

7.3.2.3 Schirmer Test

This test examines lacrimal gland function and provides a quantitative measurement of tear secretion into the conjunctival sac in patients with suspected dry eye syndrome.

The Schirmer test I is a standard test of lacrimal fluid secretion that examines lacrimal gland function as the sum of basic physiological secretion and reflex tearing. The basic secretion test is used to examine accessory lacrimal gland function, by administering anesthetic instillation to eliminate reflex tearing; however, some reflex tearing is still included in the measurement, and

Table 7.2 Interpretation of rose bengal stain results

±	No staining
+	Spotted staining only in the area of interest
++	Staining of the area of interest and the surrounding area, including the bulbar conjunctiva
+++	Staining up to the superior bulbar conjunctiva

conflicting opinions have led to this test being used less often.

The Schirmer test II examines reflex tearing caused by irritation of the ocular and nasal mucosa, meaning that it essentially examines the main lacrimal gland. This test sometimes produces a normal value in dry eye syndrome.

Method

Schirmer test I

First, the patient looks straight ahead without anesthetic instillation. After cutting one end of a 5 × 35 mm piece of standard filter paper (Watman No. 41 filter paper) into a round shape, this end is folded approximately 5 mm and inserted into the conjunctival sac in the lateral 1/3 of the lower eyelid by pulling on the eyelid. The patient is then instructed to gaze upward and close their eyes. Anesthetic instillation is not applied. It is convenient to use paper specifically designed for this test (Fig. 7.9a), and it is important to be careful not to let the paper touch the cornea.

The patient keeps the paper in their conjunctival sac with their eyes open and moving their eyelids freely; after 5 min have passed, the length of paper soaked in lacrimal fluid is measured. Here, the patient is instructed to look slightly above straight ahead and to blink normally. If the patient wants to close their eyes, they may close them naturally, but they should not move their eyes from side to side (Fig. 7.9).

Basic Secretion Test

In order to prevent reflex tearing, anesthetic instillation is applied and both eyes are gently closed.

After wiping any lacrimal fluid in the medial canthus with a cotton swab, the lower eyelid is everted and a folded piece of filter paper is inserted to cover the lower punctum.

After 5 min, the length of filter paper that has been soaked in lacrimal fluid is measured. A normal value is 7–8 mm, while values of ≤4 mm are suggestive of tear hyposecretion.

Schirmer Test II

Like the basic secretion test, anesthetic instillation is applied, and filter paper is inserted into the conjunctival sac, before inserting a cotton swab into the ipsilateral nostril and rubbing to stimulate the nasal mucosa. After 2 min, the length of paper soaked in lacrimal fluid is measured. A normal value after 2 min is >15 mm, and values of ≤15 mm are suggestive of reduced reflexive tearing.

Interpretation (Table 7.3)

7.3.2.4 Other Examinations

Tear Film Protein Analysis

In dry eye syndrome, a lysozyme assay shows reduced concentration, and this is measured by spectrophotometry or the solution method. Lactoferrin is a tear protein with antibacterial

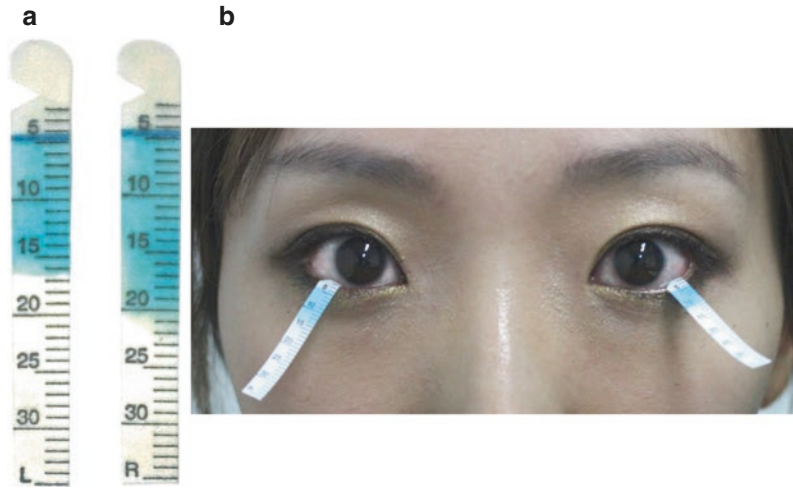

Fig. 7.9 Schirmer test (**a**) Schirmer test paper and (**b**) method

Table 7.3 Interpretation of the Schirmer test results

Type of test	Normal value	Interpretation
Schirmer test	10–30 mm after 5 min	Reduced lacrimal secretion suspected when ≤10 mm
Basic secretion test	7–8 mm after 5 min	Reduced lacrimal secretion suspected when ≤4 mm
Schirmer II test	>15 mm after 2 min	Impaired reflex tearing suspected when ≤15 mm

activity that is used as an indicator of lacrimal gland function, and it shows a reduced concentration in dry eyes.

Tear Osmolarity

Osmolarity is known to increase in dry eye syndrome. Although this test has high sensitivity, it requires expensive equipment and is rarely used outside of research purposes.

Conjunctival Impression Cytology

In dry eye syndrome, this test is used to measure the density of goblet cells, which secrete mucin. A special type of filter paper is pressed to the inferior nasal conjunctiva and removed; the paper is then observed after staining with a specific stain. In typical individuals, the maximum goblet cell density in the inferior nasal conjunctiva is 1500/mm^2, and this value is lower in individuals with dry eye syndrome.

Ocular Ferning Test

In typical individuals the conjunctival mucus shows ferning when dry, and this response may be limited in cases of reduced mucus. This is a very sensitive test.

7.4 Evaluation of Lacrimal Drainage System

When the cause of epiphora cannot be determined after general ophthalmological examinations, such as slit lamp examination, the following examinations are performed, in order: digital compression of the lacrimal sac, fluorescein retention test, lacrimal duct irrigation, probing, dacryocystography, and dacryoscintigraphy.

The typical order of examinations in patients with epiphora symptoms is listed below:

- Medical history
- Slit lamp microscopy
- Palpation and digital compression of the area around the lacrimal sac
- Irrigation and probing of the canaliculus
- Fluorescent staining; testing functional obstruction
- Intranasal examination
- Radiography; X-ray, CT
- Dacryocystography
- Dacryoscintigraphy

7.4.1 Medical History

The examiner should ask in detail about whether the patient ever experiences red eye, a large amount of rheum in the morning, pain or swelling near the lacrimal sac, or has previous experience of dacryocystitis. These symptoms are suggestive of chronic or intermittent dacryocystitis. If there has been any symptomless period between severe but intermittent epiphora and dacryocystitis, this is suggestive of a dacryolith causing a “ball valve” effect.

The examiner should ask whether the patient has previously received examinations, surgery, or probing of the lacrimal duct; overly invasive punctoplasty can impair lacrimal drainage. The examiner should ask about the patient’s history of sinusitis, chronic allergy, sinus surgery, central facial fractures, or irradiation, as well as previous facial nerve palsy, and whether tears are produced while eating. These are all important considerations to help evaluate the possibility of nasolacrimal duct obstruction. For quantification or grading of epiphora, there is the Munk scale and a slightly more simplified epiphora grading.

7.4.2 Visual Inspection

The examiner checks for eyelid ectropion, entropion, and trichiasis. The examiner also checks for eyelid dysfunction or deformity caused by

trauma or scarring, unstable blinking caused by facial nerve palsy, and degenerative lower lid laxity, since these can also cause lacrimal pump impairment. The patency of the puncta in the medial canthus is inspected using a slit lamp microscope.

Grading of punctual patency and the corresponding treatments are as follows:

7.4.3 Digital Compression, ROPLAS Test (Regurgitation on Pressure over Lacrimal Apparatus System)

If the patient has previously suffered from dacryocystitis, they should be considered to have lacrimal duct obstruction. When the patient has experienced dacryocystitis, examinations are performed to rapidly confirm whether there is infection or obstruction of the lacrimal sac and nasolacrimal duct.

7.4.3.1 Method

The examiner uses their finger to apply upward pressure to the lacrimal sac at the medial canthus and observes whether there is any reflux of mucopurulent fluid from the puncta. If there is reflux of mucus or pus, this indicates dacryocystitis or obstruction of the lacrimal sac or nasolacrimal duct. There is rarely reflux in the case of a dacryolith or tumor.

7.4.4 Lacrimal Irrigation

This test verifies the patency of the canaliculus and the nasolacrimal duct.

7.4.4.1 Method

An irrigation cannula or a blunt 26-gauge needle is attached to a 5 cc syringe and inserted into the canaliculus. As the physiological saline in the syringe is injected, the examiner checks that the saline exits via the nose or throat. The results of irrigation can help to identify the location of any anatomical abnormalities (Tables 7.4 and 7.5).

Table 7.4 Punctal patency grading

Grade	Clinical finding	Way to enter
Grade 0	No papilla and punctum (punctal atresia)	Requires surgical creation of papilla
Grade 1	Papilla covered by a membrane(exudative or true membrane) or fibrosis and is difficult to recognize	Requires #25 needle, followed by a punctal finder and then standard punctum dilator
Grade 2	Less than normal size but recognizable	Requires a punctal finder and then a standard
Grade 3	Normal	Requires a regular punctum dilator
Grade 4	Small slit (<2 mm)	No need for intervention
Grade 5	Large slit (>2 mm)	No need for intervention

Table 7.5 Interpretation of irrigation results

Result	Interpretation
Difficulty advancing the irrigation needle Irrigation is unsuccessful	Complete obstruction of the canaliculus
Difficulty advancing the irrigation needle Reflux of saline from the other ipsilateral canaliculus	Complete obstruction common canaliculus
Irrigation needle cannot be easily inserted Mucous reflex from the canaliculus or expansion of the nasolacrimal duct with no reflux	Complete obstruction of the nasolacrimal system
Irrigation needle enters easily Saline reflux and secretion into the nose	Partial obstruction of the nasolacrimal system Functional obstruction in a normal state
Irrigation needle enters easily Successful irrigation	Only functional obstruction can be suspected, and further examinations are required for secondary hypersecretion

7.4.5 Probing

A Bowman probe is inserted into the canaliculi and nasolacrimal duct via the puncta to check for obstruction or stenosis for diagnostic purposes in

adults. In children, this procedure can also be used for treatment purposes.

7.4.5.1 Method

0.5 cc of 0.5% proparacaine is injected into the lacrimal sac for anesthesia.

A probe is inserted 1–2 mm into the puncta, vertical to the lid margin (Fig. 7.10a).

The probe is rotated 90° toward the lateral canthus such that it is parallel with the lid margin, then the eyelid is pulled laterally while pushing the canaliculi nasally, and the probe is advanced until its tip collides with the wall of the lacrimal sac (Fig. 7.10b).

After rotating the probe another 90°, a gentle force is applied in the direction of the lateral part of the nose in adults and the medial part of the nose in children, as the probe is advanced in the inferior direction until it reaches the inferior meatus (Fig. 7.10c–f).

7.4.5.2 Interpretation

In areas of obstruction or stenosis, resistance is felt during probe insertion. When the canaliculi and the common canaliculus are patent and the probe touches the hard bone of the lacrimal sac, this is described as a "hard stop"; if the canaliculi or common canaliculus are obstructed, the probe does not touch the bone, and this is described as a "soft stop."

7.4.5.3 Considerations

This procedure is used for treatment in children and is used to diagnose the location of stenosis in adults, as well as for correction in some cases. The size of the probe is 2-0 or less, and a large probe is used in cases of partial obstruction. Before removing the probe, it can be marked at the point of insertion in order to measure the distance from the punctum.

Usually a Bowman probe is used; the largest size is 6, and smaller numbers correspond to a smaller size. Beyond size 0, the next smallest sizes are 00 and 000, and the smallest size is 0000. During the examination, it is crucial to pull the eyelid laterally while inserting the probe into the canaliculus, in order to prevent misinterpretation as soft stop due to canalicular kinking.

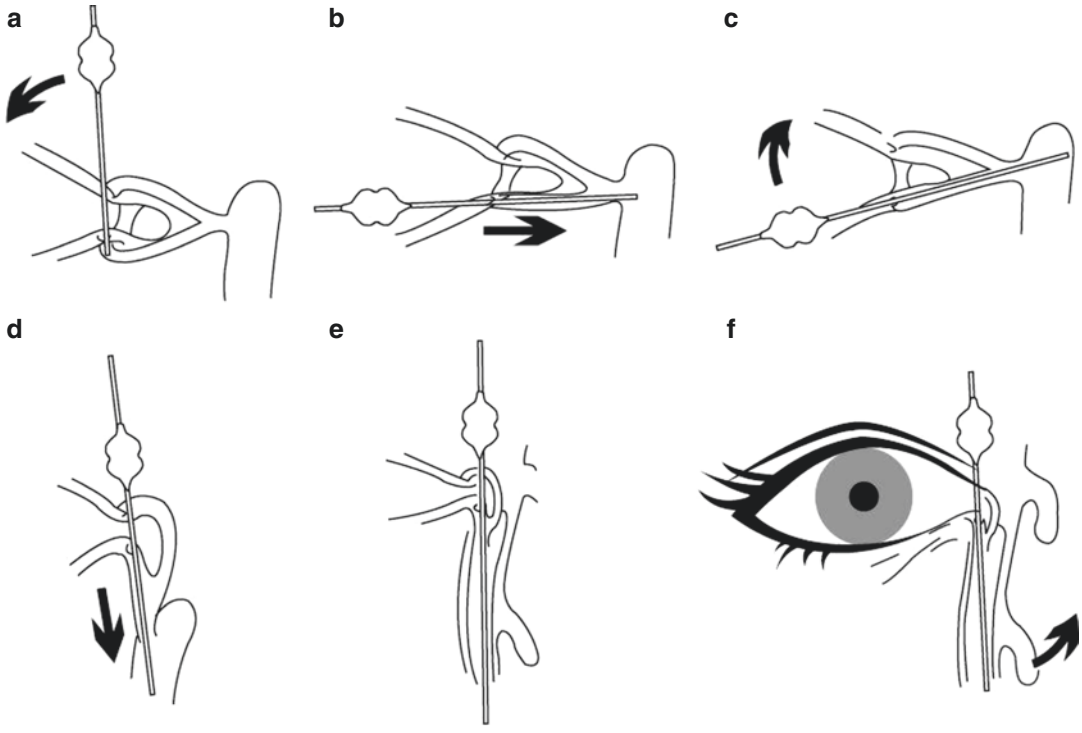

Fig. 7.10 Order for probing

7.4.6 Fluorescent Staining

7.4.6.1 Fluorescein Dye Disappearance Test (FDDT, FDT)

This is a very important test for differential diagnosis of complete, incomplete, or functional obstruction of the nasolacrimal duct or lacrimal sac in epiphora patients. It is also useful for evaluating lacrimal drainage after conjunctivodacryocystorhinostomy (CDCR).

Method

Two percent fluorescein or wet fluorescein test paper is applied to the lower conjunctival sac.

The stain is examined after 5 min, during which time the patient must not tap or rub their eyes.

Interpretation

The fluorescein should be distributed symmetrically between both eyelids. Cases with no stain remaining are classified as grade 0; cases with a faint band of staining at the lid margin are classified as grade 1; cases with a broad, bright band of stain are classified as grade 3; and intermediate cases are classified as grade 2. From grade 2, the result is considered to be FDDT positive.

Comparison between the two eyes is more important than the grade for a single eye. An asymmetric response indicates relative obstruction. As temporary causes, it is impossible to exclude examination abnormalities caused by allergy, dacryoliths, or nasal polyps.

7.4.6.2 Jones Primary Dye Test

This test is used to differentiate incomplete mechanical obstruction and functional obstruction.

Method

Two percent fluorescein solution is instilled.

Decongestant and local anesthetic is sprayed into the inferior meatus.

A cotton swab is placed in the anterior one-half of the inferior meatus.

The cotton swab is removed after 5 min and inspected for fluorescein staining.

Interpretation

A positive result, when the cotton swab has been stained with fluorescein, indicates that the lacrimal fluid is being properly drained through the nasolacrimal duct, meaning that epiphora is caused by hypersecretion. A negative result, when no fluorescein is detected on the cotton swab, indicates anatomical or functional obstruction of the lacrimal duct. These need to be differentiated using Jones secondary dye test (Fig. 7.11).

7.4.6.3 Jones Secondary Dye Test

This test is used to differentiate anatomical and functional obstruction following a negative result in Jones primary dye test and can be used to locate the obstruction.

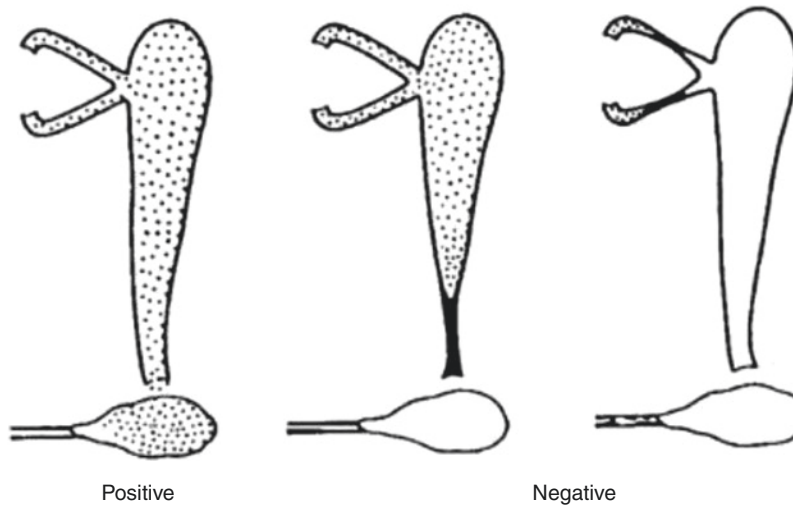

Fig. 7.11 Jones primary dye test

Method

In the case of a negative result in Jones primary due test, local anesthesia is induced by instillation, and any remaining fluorescein is washed out of the conjunctival sac.

The punctum is anesthetized using 0.5% proparacaine on a cotton swab.

The punctum is enlarged.

Physiological saline is used to wash the lower punctum.

A cotton swab is placed in the inferior meatus, or the irrigation fluid is collected from the nose for inspection (Fig. 7.12).

Interpretation

The test is positive if fluorescein is detected and negative if fluorescein is not detected.

If fluorescein is detected and there is no reflux, this indicates partial or functional obstruction. In this case, CDCR is performed and lower lid ectropion is corrected if present.

If fluorescein is not detected, it means that the fluorescein was unable to reach the lacrimal sac. In cases of punctal or canalicular stenosis or abnormalities in the canalicular opening into the lacrimal sac, these obstacles can be passed through by the irrigation syringe needle. For treatment, depending on the extent of stenosis, a Jones tube can be placed, or the valve of Rosenmuller can be cut and a silicone tube placed.

If reflux is observed from the other ipsilateral punctum, this is indicative of dacryocystitis or obstruction of the common canaliculus or nasolacrimal duct. The presence of stain indicates complete obstruction of the nasolacrimal duct, whereas the absence of stain indicates complete obstruction of the canaliculus. CDCR is performed in cases of nasolacrimal duct obstruction, while a Jones tube is placed in cases of common canaliculus obstruction.

If reflux is observed near the irrigated canaliculus, this is indicative of canaliculus obstruction and the upper punctum is irrigated. Here, successful irrigation of the upper punctum indicates lower canaliculus obstruction, whereas failure indicates complete obstruction of the common canaliculus requiring Jones tube placement.

If the lower canaliculus is obstructed but irrigation can be performed via the upper canaliculus, the patient's complaint of eye watering needs to be re-evaluated. In normal circumstances, even if the lower canaliculus is nonfunctional, the upper canaliculus is sufficient for lacrimal drainage.

7.4.7 Dacryocystography

This test is used as a preoperative examination before CDCR and is also used to identify lacrimal duct disorders and to locate obstruction.

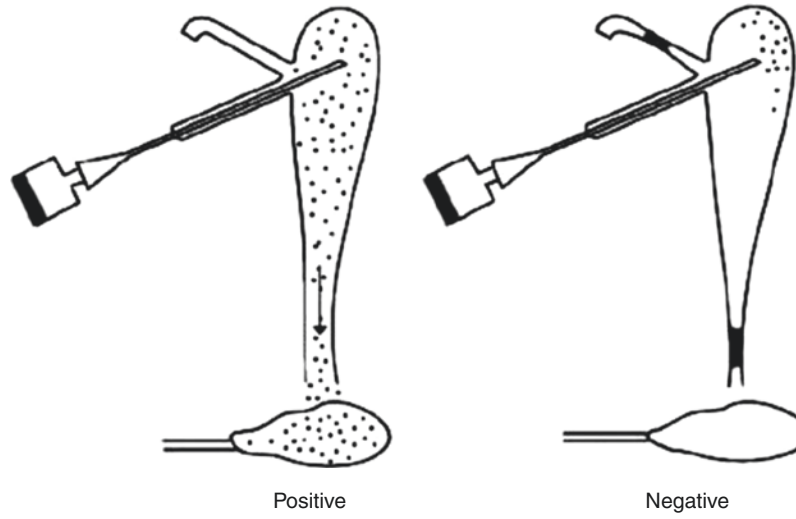

Fig. 7.12 Fluorescein irrigation test

7.4.7.1 Method

An irrigation needle or polyethylene tube is used to inject a contrast agent into the lower canaliculus, and images are taken in the Caldwell view and lateral view to check for obstruction (Fig. 7.13).

7.4.7.2 Interpretation

It is possible to observe the size of the lacrimal sac, and the presence or absence of diverticula, fistula, or filling defects such as lacrimal sac tumor (Fig. 7.14).

Distension of the lacrimal sac and stagnation of the contrast agent are observed in dacryocystography.

7.4.7.3 Considerations

Because the contrast agent is injected forcefully, it is not possible to diagnose functional obstruction. In addition, if the placement of the tube is incorrect or if the contrast agent is injected too slowly or too rapidly, the image may be unclear, resulting in artifacts. For this reason, dacryocystography is used as an additional examination to confirm a

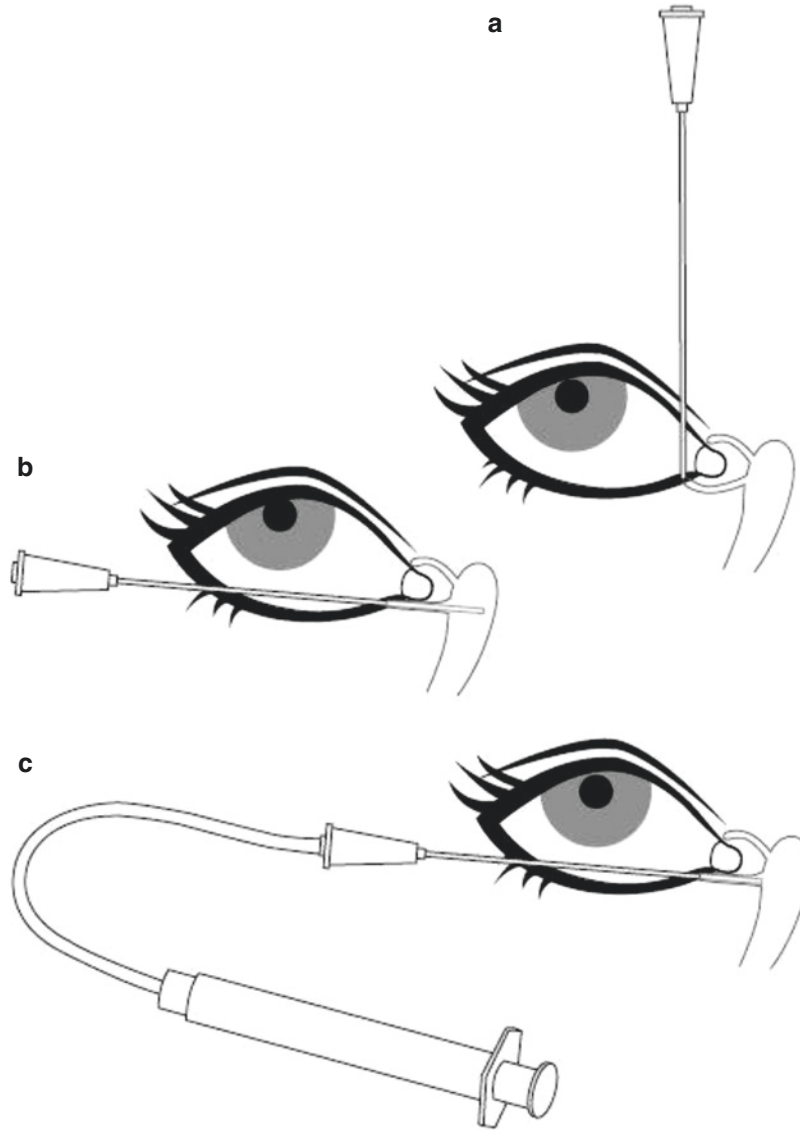

Fig. 7.13 Inserting the cannula for dacryocystography

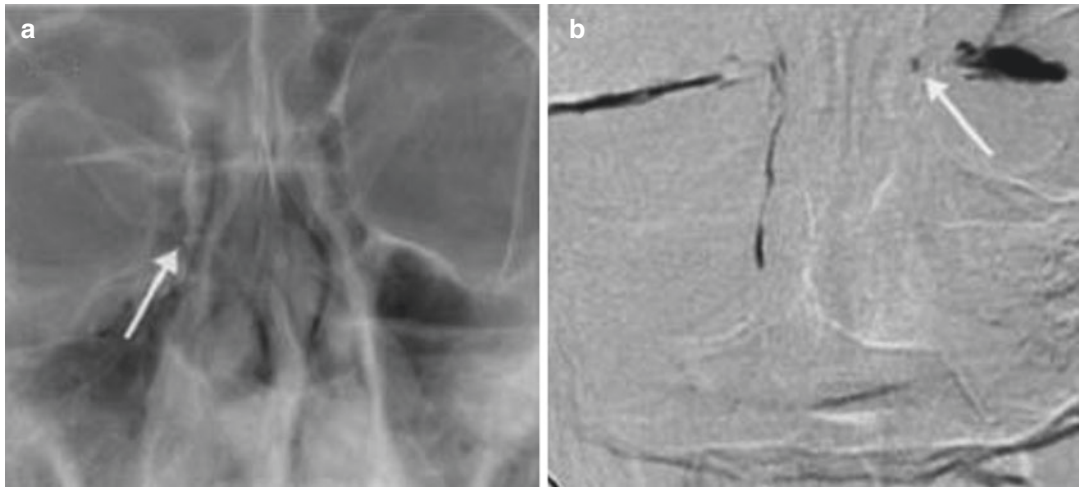

Fig. 7.14 Dacryocystography. (**a**) Obstruction of the right nasolacrimal duct. (**b**) Obstruction of the left nasolacrimal duct (digital subtraction DCG)

diagnosis. Computerized digital subtraction dacryocystography provides a better image.

7.4.8 Dacryoscintigraphy

This test is used to examine the anatomical structure of the lacrimal drainage system, as well as to observe its function in a physiological state.

7.4.8.1 Method

A micropipette is used to instill 10 μL of 99mTc-pertechnetate or 99mTc-sulfur colloid, a volume corresponding to twice that of the tear film. Thereafter, a gamma camera is used to observe the flow of isotope over time, with a radioactivity of 50–100 μCi, which is approximately 2% the amount of radiation in a cranial X-ray.

7.4.8.2 Interpretation

The flow of isotope is imaged every 10 s during the first 160 s (dynamic study) and then at 5, 10, 15, and 20 min (static view).

- Presac delay: Isotope does not reach the lacrimal sac by the end of the dynamic study.
- Preductal delay: The lacrimal sac fills, but the isotope remains in the sac after 5 min of imaging.
- Intraduct delay: Isotope is observed to fill the nasolacrimal duct after 5 min, but is not drained any further in the subsequent 15 min (Fig. 7.15).

7.4.8.3 Considerations

This test enables more accurate diagnosis of functional obstruction, produces more normal results when compared with the fluorescein retention test, and provides a record of images. It is also easier to compare the results with the other eye. Compared with dacryocystography, although the radiation exposure is lower, it does not show the detailed anatomical structure. In terms of its downsides, this test requires expensive equipment and takes a long time, at approximately 1 h per test.

7.4.9 Other Examinations

X-ray and CT are used to diagnose nasal sinus disease, tumors, ethmoid bone disorders, and mucoceles. In patients with lacrimal duct or nasolacrimal duct obstruction, more detailed intranasal examination would be needed, such as nasal endoscopy, in order to differentiate intranasal tumors.

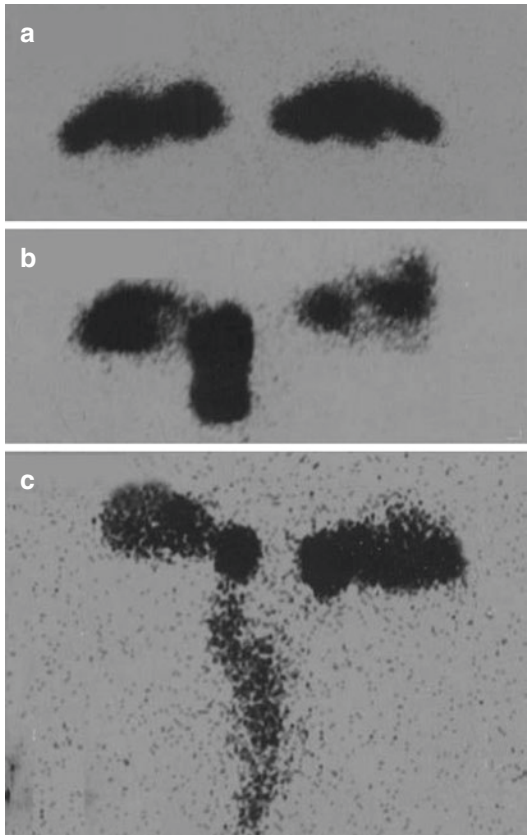

Fig. 7.15 Dacryoscintigraphy findings in a patient with obstruction of the left nasolacrimal duct. (**a**) presac delay (**b**) preductal delay (**c**) intraduct delay

Suggested Reading

Allen KM, Berlin AJ, Levine HL. Intranasal endoscopic analysis of dacryocystorhinostomy failure. Ophthalmic Plast. Reconstr. Surg. 1988;4:143–5.

American Academy of Ophthalmology. Basic and clinical science course: orbit, eyelid, and lacrimal system, sect 7, San Francisco, 1998–1999. p. 199–233.

American Academy of Ophthalmology. Basic and clinical science course: orbit, eyelid, and lacrimal system, vol. sect 7. San Francisco; 2007–2008. p. 265–99.

American Academy of Ophthalmology. Basic and clinical science course: orbit, eyelid, and lacrimal system San Francisco, 2007–2008, sect 7. p. 21–34.

Anderson RL. Age of aponeurotic awareness. Ophthal Plast Reconstr Surg. 1985a;1(1):77–9.

Anderson RL. Age of aponeurotic awareness. Ophthal Plast Reconstr Surg. 1985b;1:77–9.

Anderson RL, Baumgartner SA. Strabismus in ptosis. Arch Ophthalmol. 1980;98(6):1062–7.

Anderson RL, Dixon RS. Aponeurotic ptosis surgery. Arch Ophthalmol. 1989;97(6):1123–8.

Beard C. Ptosis. St. Louis: CV Mosby; 1981.

Choi O, Rho SH. The Palpebral Fissure of the Korean Youth. J Korean Ophthalmol Soc. 1981;22(3):491–8.

Crawford JS. Intubation of obstruction in the lacrimal system. Can J Ophthalmol. 1977;12:289–92.

Dallow RL, Pratt SG, Green JP. Approach to orbital disorders and frequency of disease occurrence. In: Albert DM, Jakobiec FA, editors. Principle and practice of ophthalmology, vol. 4. 2nd ed. Philadelphia: W.B. Saunders Company; 1999.. Chap. 234.

Dortzbach RK. Ophthalmic Plastic Surgery. New York: Raven Press; 1994. p. 65–90.

Grove AS Jr. Orbital disease: examination and diagnostic evaluation. Ophthalmology. 1979;86:854–63.

Hornblass A. A simple taste test for lacrimal obstruction. Arch Ophthalmol. 1973;90:435–6.

Jones LT. Conjunctivodacryocystorhinostomy. Am J Ophthalmol. 1965;59:773–83.

Jones LT, Linn ML. The diagnosis of the causes of epiphora. Am J Ophthalmol. 1969;67:741–4.

Kones LT, Linn ML. The diagnosis of the causes of epiphora. Am J Ophthalmol. 1969;67:751–4.

Lyon DB, Dortzbach RK. Entropion, trichiasis, and distichiasis. In: Dortzbach RK, editor. Ophthalmic plastic surgery. New York: Raven Press; 1994; chap. 2.

McCord CD, Tanenbaum M, Nunery WR. Oculoplastic surgery. 3rd ed. New York: Raven press; 1995. p. 341–77.

Nerad JA. Oculoplastic surgery. St. Louis: Mosby; 2001a. p. 157–92.

Nerad JA. The diagnosis and treatment of entropion. In: Krachmer JH, editor. Oculoplastic surgery in the requisites in ophthalmology. St. Louise: Mosby; 2001b; chap. 5.

Nerad JA. Oculoplastic surgery, the requisites in ophthalmology. St. Louis: Mosby; 2001c. p. 215–53.

Park JW, Lee BH, Keong SK, Kim JB. Morphological evaluation of upper eyelid in Korean. J Korean Ophthalmol Soc. 2000;41(4):879–85.

Robert AW. Orbital Disease. In: CD MC, Tanenbaum M, Nunery WR, editors. Oculoplastic surgery. 3rd ed. New York: Raven Press; 1995; chap. 15.

Soiberman U, Kakizaki H, Selva D, Leibovitch I. Punctal stenosis: definition, diagnosis, and treatment. Clin Opthalmol. 2012;6:1011–8.

Song BY, Ji YS, Wu MH, Jeong SK, Yoon KC. The clinical manifestations and treatment results of congenital lacrimal fistula. J Korean Ophthalmol Soc. 2006;47:871–6.

Striph GG, Miller NR. Disorders of eyelid function caused by systemic disease. In: Bosniak S, editor. Principles and practice of ophthalmic plastic and reconstructive surgery. Philadelphia: WB Saunders; 1996. p. 72–93.

Toti A. Nuovo metodo conservatore di cura radicale delle suppurazionicronishe del sacco lacrimale (Dacriocistorinostomia). Clin Moderna Firenze. 1904;10:385–7.

Slit Lamp Exam

8

Jong-Soo Lee

The slit lamp examination is a basic ophthalmologic examination method that allows the eye tissue to be examined through an optical section by cutting each tissue of the eye with a slit light beam. By using a light bulb with a vertical filament as a light source and reducing a circular light beam to a square, the width and length of the circular light beam can be arbitrarily adjusted, and the image can be enlarged up to about 40 times.

We can observe several layers with different contrasts depending on the path of the ray. Therefore, we can observe various layers of the eye such as cornea endothelium, anterior chamber and measure corneal thickness, anterior chamber depth.

8.1 Slit Lamp Biomicroscope

The basic structure of the slit lamp microscope is composed of a slit lamp illumination device, a binocular stereoscopic microscope, and an accessory apparatus. Zeiss type, Haag-Streit type (Fig. 8.1), and Rodenstock type are available now.

It is possible to observe the structures and disease progression of the anterior segment of the eye including the conjunctiva and cornea, the anterior chamber, the lens, and the anterior vitreous and to accurately track the location of the lesion. Using the auxiliary lens, three-dimensional observation of the anterior chamber, fundus, vitreous, and retina is also possible.

8.1.1 Principle and Structure (Table 8.1)

Depending on the model, the Zeiss and Rodenstock slit lamps are located at the bottom of the apparatus for projecting the slit light beams. The light rays from the halogen light source are directed upward and pass through a focus lens, a slit light aperture, a filter, and an objective lens and are turned 90 ° from the prism at the top of the slit light projection to the eye to be observed. Haag-Streit's Goldmann 900 type has a tungsten light source on top of the illuminator.

Observed microscopes include Kepler-type refracting telescopes (convex objective and convex eyepieces) and Galileo-type telescopes (convex objective and concave eyepieces). The Zeiss, Rodenstock, and Goldmann slit lamps were placed at the first object lens (focal length 100–125 mm) in front of binoculars focused at infinity to focus at close range and the second objective lens (focal length 125–170 mm). Goldmann 900BM is a system with one convex objective lens designed to focus on the position

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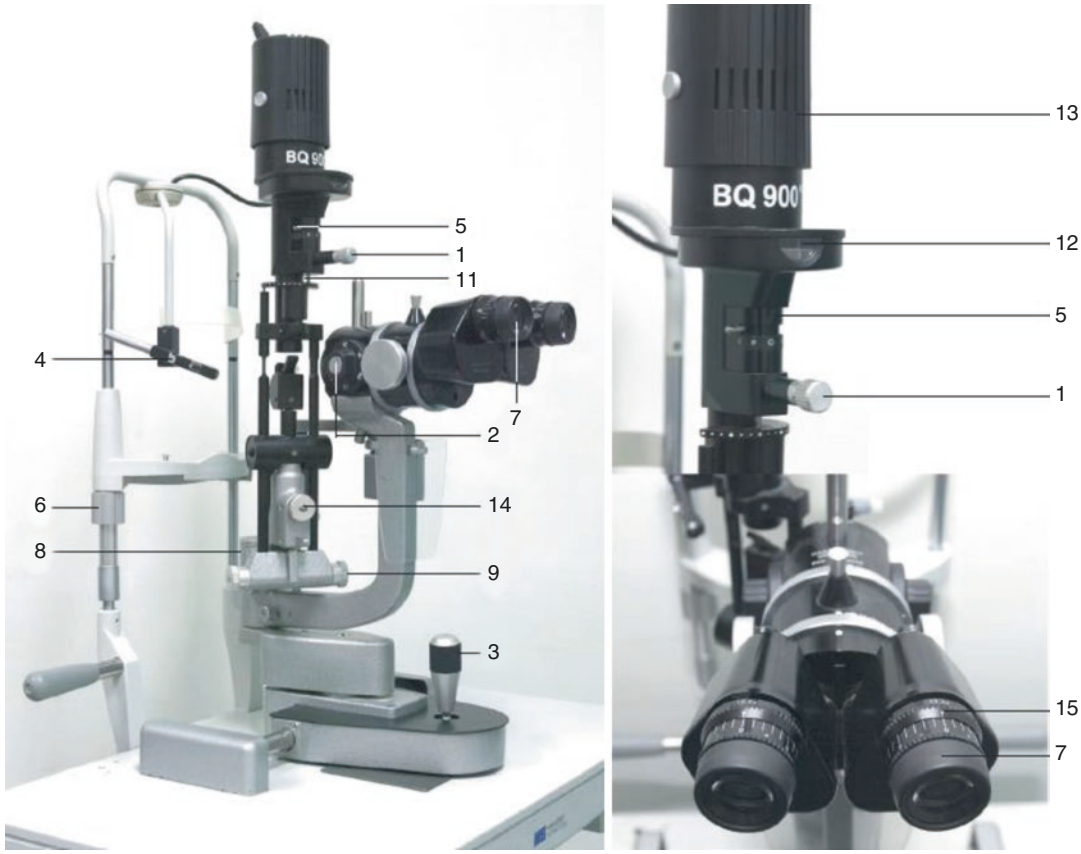

Fig. 8.1 Haag-Streit 900-type slit lamp microscope. (1) Handle to rotate and adjust the length of the beam; (2) lever to change magnification; (3) adjustable handle to move the slant lamp forward and backward, up and down, and left and right; (4) fixation light; (5) lever for filter selection; (6) upper and lower control knob; (7) focusing eyepiece; (8) Goldmann applanation tonometer fixed plate; (9) handle to control the width of the beam; (10) locking device to raise or lower the elevation angle; (11) a fixing device for turning the slit lamp device in the vertical direction to turn the light horizontally; (12) height of beam; (13) lamp cover; (14) coaxial set screw; (15) corrected the refraction error of the inspector

of the object being observed. The microscope for left and right eyes is independent, so that the optical axis is not parallel but facing the object.

You can change the brightness, hue, length, width, rotation, and axis of the slit light by adjusting the light from the light source. It is also possible to change the elevation angle to illuminate the slit lights from below. In case of brightness and color tone, it can be converted by inserting the filter into the lever. A heat rejection filter that blocks heat rays without a filter or a light reduction, an ND50 filter that reduces the amount of light by 50%, and an invariant color filter that facilitates the observation of retinal nerve fibers (Fig. 8.2). If you adjust the length and width of the slit light and rotate the lamp house, you can also rotate the slit light.

Table 8.1 Comparison of slit lamp microscopes

	Zeiss SL	Haag-Streit SL (Goldmann 900BQ)	Rodenstock SL(RO5000SE)
Microscope magnification	Galileo binocular type 5–32 times	Galileo binocular type 6.3–40 times	Galileo binocular type 6–45 times
Light source	Halogen 6 V 20 W (660,000 lux)	tungsten 6 V 4.5A(330,000lux) Halogen 7.5 V 38 W(600,000lux)	Halogen 6 V 20 W(660,000lux)
Lighting method	Erected type	Inverted type	Erected type
Adjust pupil distance	50–75 mm	52–78 mm	50–75 mm
Slit light width	0–14 mm continuous change	0–8 mm continuous change	0–12 mm continuous change
Slit light rotation	0–180°	0–180°	0–360°
Variable adjustment range slit light length	0.3–9 mm step 6, three slit light 30 mm manual	1–8 mm continuous change 30 mm manual	2.25–12 mm continuous change 30 mm electric lift type
Front/back left/right adjustment range	Left/right 110 mm Front/back 90 mm	Left/right 100 mm Front/back 80 mm Up/down 29 mm	Left/right 100 mm Front/back 80 mm
Depth of focus aperture	Optional	None	Exist
Elevation angle scanning	0–20° continuous change	0–25°, 5° interval	None
Filter	Blue, green, gray (10,20,40% light reduction)	blue, green, gray (10% light reduction)	Blue, green, gray Correction glass
Stereo angle	12.5°	13°/4.5° (Convertible)	11°
Stereovariator	None	Exist	None
Features and accessories	Beam splitter, depth of focus aperture	Stereoscopic view enlargement by using stereovariator	Fundus exam by Hruby lens can achieve clear image quality
Light brightness	Continuous change	No adjusting screw	No adjusting screw

1. Open
2. Heat rejection filter
3. 50% light reduction filter
4. Invariant color filter
5. Open (In some slit lamp, cobalt blue)

The Goldman slit lamp can change the illumination in the vertical direction by tilting the lighting device forward, resulting in an elevation angle from below to above the lighting (Fig. 8.3).

This is mainly used when observing the cross section by illuminating the slit light horizontally or obliquely, particularly when observing the peripheral retina with a three-dimensional mirror. Goldman slit lamps have two long and short reflectors, long reflectors for anterior segment examination and short ones for fundus examination. A long reflector uses a short reflector to prevent stereoscopic vision from disappearing during fundus examination because it blocks one side of the microscope objective lens when the angle between the illumination device and the microscope is about 6°. If the reflector is short, the light quantity of the vertical three-pole light becomes small. Therefore, the slit light is inclined forward so that the entire slit light is reflected on the reflector.

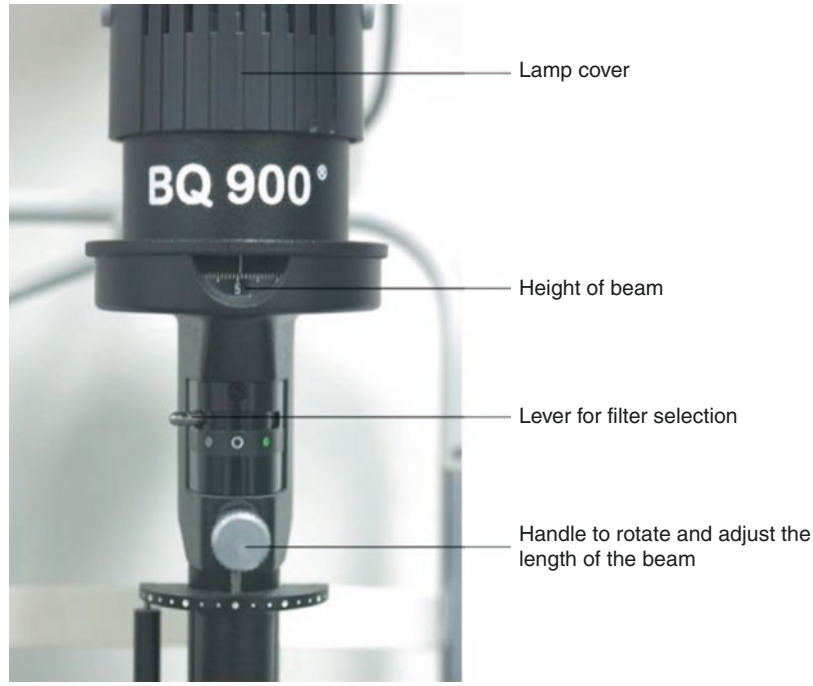

Fig. 8.2 Adjustment of brightness and color tone, type, and function of filter

Fig. 8.3 Change of elevation angle

The Zeiss slit lamp can turn the prism mirror of the lighting device to change the angle of the reflector continuously from 0 to 20° so that the light is illuminated from bottom to top. When illuminating the slit light horizontally, the angle between the illumination device and the microscope is 0°, which is coaxially observed.

If a stereovariator is attached to a Goldman slit lamp, binocular vision is possible, and the observation range is widened. The Hruby lens has been used for fundus examination as a concave lens, but now the +90D lens is often used.

The slit lamp is set so that the alit light of the illuminating device fits at the position where the microscope is focused even if the angle of the axis of the illumination device and the axis of the observation microscope is changed. When the coaxial setscrew is released in a counterclockwise direction, the coaxial axes of the microscope and the illuminating device are released and can move independently of each other, so that the illumination can be moved to the left and right and rear of the observation site.

8.1.2 Illumination

Direct illumination that directly observes light by observing an object to be observed according to an illumination method, and indirect illumination that observes light by irradiating light around the object to be observed and reflected or transmitted (Fig. 8.4).

8.1.2.1 Diffuse Illumination

It is a method of observing a wide range of light rays at a low magnification by broadening the width of the slit light by setting the light beam to acute angle, and it is suitable for general observation of the conjunctiva, eyelid, and cornea, but detailed findings can't be obtained. Wide-angle illumination can be observed easily in the con-

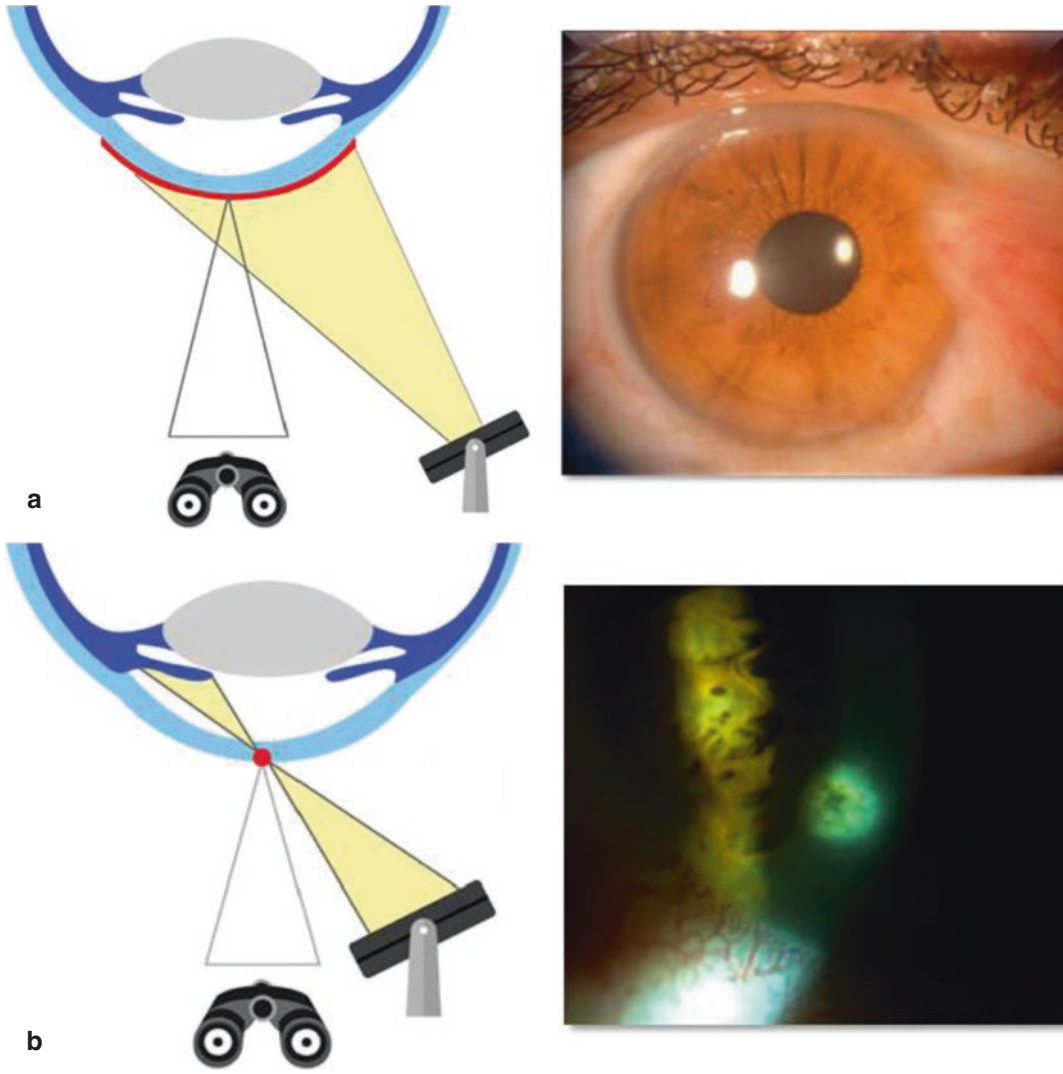

Fig. 8.4 (**a**) Diffuse illumination shows general observation of conjunctiva, cornea, iris, and pterygium. (**b**) Direct focal illumination shows corneal rust ring after removal of corneal foreign body. (**c**) Indirect illumination is easy to observe mutton fat keratopricipitate on endothelium. (**d**) Sclerotic scatter shows stromal deposition of Avellino dystrophy. (**e**) Retro-illumination. (**e-1**) shows corneal endothelial precipitates with retro-illumination from the iris. (**e-2**) shows after cataract with red reflex in fundus. (**f**) Specular illumination shows endothelial cell of the cornea, a hexagonal corneal endothelial cell

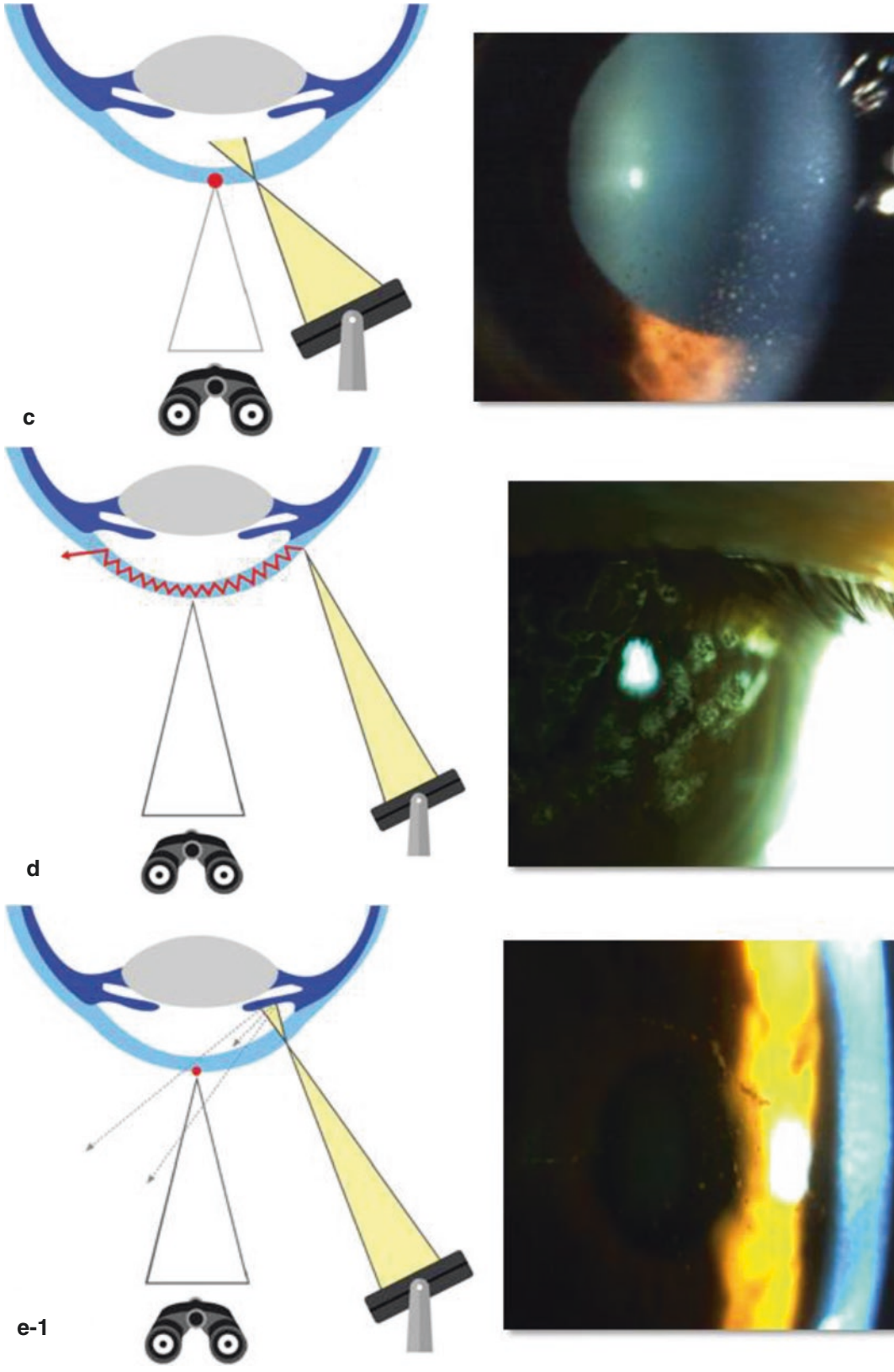

Fig. 8.4 (continued)

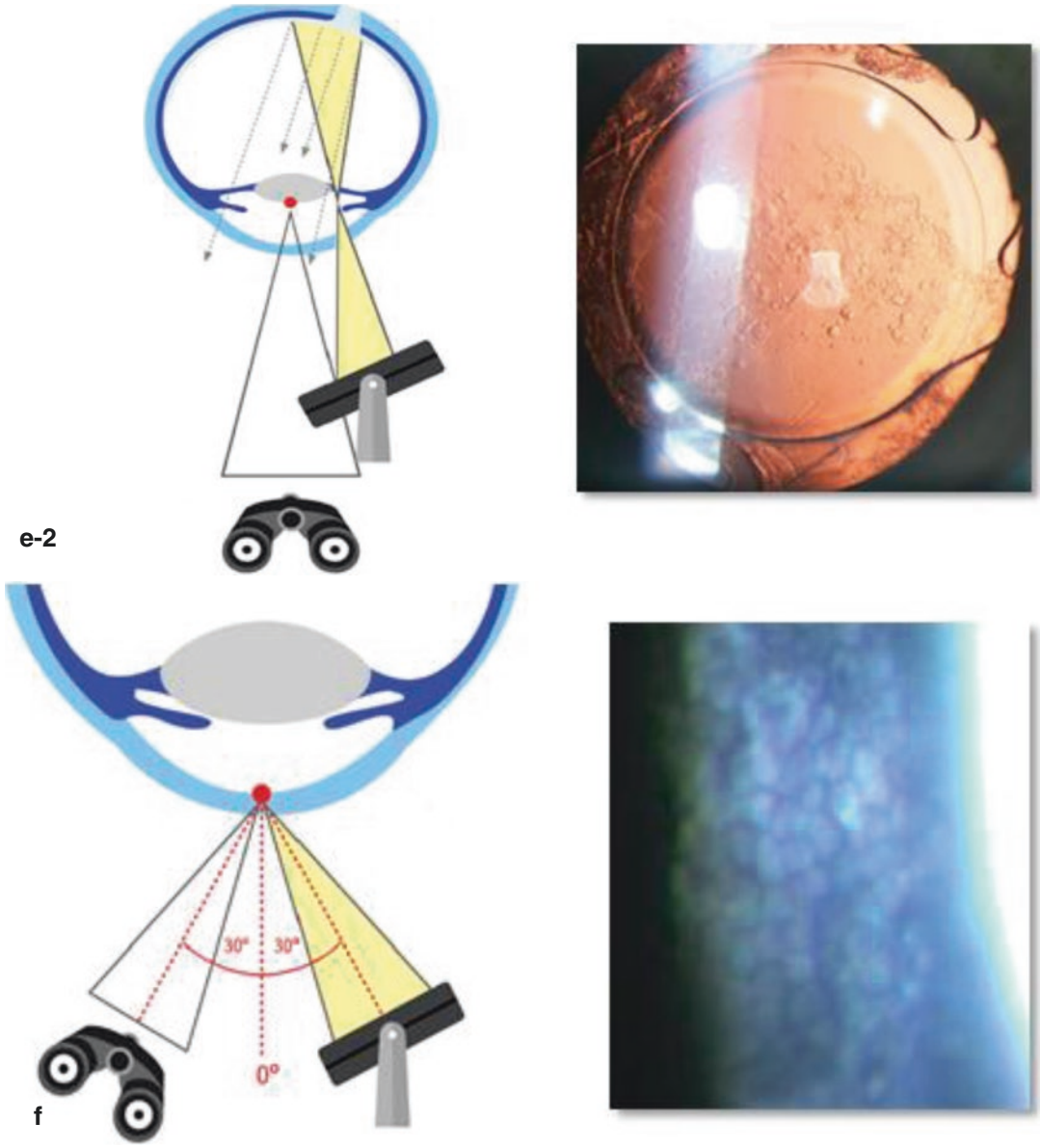

Fig. 8.4 (continued)

junctival sac, conjunctival follicles, conjunctival papillae, and corneal scars (Fig. 8.4a).

8.1.2.2 Direct Focal Illumination

The most commonly used illumination method is to focus the slit light directly on the part to be observed and to observe the lesion through an optical section. The larger the angle between the illumination and the microscope, the thicker the optical segment and the deeper lesion be obtained. By controlling the thickness of the optical section, the position and extent of the cornea, the anterior chamber, and the lens opacity can be accurately observed. To create an effective optical segment, it is important to maximize the intensity of light and to use the narrowest possible light to identify the object (Fig. 8.4b).

8.1.2.3 Indirect Illumination

The coaxial fixation screw is loosened to move the slit light axis to either the left or the right, and the lesion is observed in the periphery of the slit light without directly irradiating the region to be observed. It is easy to observe the surface with haze because it can reduce the scattering due to direct illumination, and it is helpful to observe the change under the object surface to be observed or the buried foreign object by using the retroreflected light from the tissue. Focusing the light on the iris allows you to observe bleeding or abnormal findings in the vicinity (Fig. 8.4c).

8.1.2.4 Sclerotic Scatter

It is also referred to as indirect lateral illumination. It is a method of unrolling the coaxial fixing screw, irradiating the sclera near the edge of the cornea, and observing the cornea center with a slit lamp. When the light is reflected in the corneal tissue, it passes through the opposite edge, so that the inside of the cornea is observed using light transmitted as an optical fiber. There is an advantage of being able to easily observe microscopic corneal opacity, corneal edema, and posterior corneal deposition (Fig. 8.4d).

8.1.2.5 Retro-illumination

It is a type of indirect illumination method in which three polarized light are irradiated behind the observation part and the lesion is observed using the reflected light. The slit light has the maximum brightness, but the width of the pole is reduced to a minimum, and the angle between the illumination axis and the microscope axis is positioned near the center where the backlight is maximized. If necessary, the coaxial fixing screw can be loosened to move the illumination light transversely by changing only the angle of the illumination while the position of the microscope axis and the illumination axis is fixed. The cornea is a reflected light from the iris and the front of the lens. It can detect fine lesions such as corneal edema, blisters, deposits, blood vessels, and iris pigmentation, and the anterior surface of the lens can be observed as reflected light from the back of the lens. The lens opacity, such as after cataract, is observed by red reflex in the fundus. At this time, the length of the slit light is 2–3 mm, and the width is 3–4 mm, and a bright image can be obtained by adjusting it to the optic nerve head (Fig. 8.4e). Figure 8.4e-1 shows retro-illumination from the iris. It can detect corneal endothelial precipitates. Figure 8.4e-2 shows after cataract. It is observed by red reflex in the fundus.

8.1.2.6 Specular Reflection

This is a type of direct local illumination method in which the microscope axis is aligned with the optical axis where the slit light is reflected and the mirror surface of the reflection surface is observed using Snell's law. In other words, the incident angle and the reflection angle of the light beam become the same, and the total reflection occurs at the boundary of the medium. Typically, the cornea is used to observe the corneal endothelial cell morphology and size by focusing on the posterior surface of the cornea. Adjust the angle of the slit light to 2–3 mm and the width to 1–2 mm so that the angle of the axis of the illumination device and the axis of the microscope is about 60° and the magnification of the microscope is 20–40 times the maximum. When the corneal surface is observed, the reflection from the tear layer is strong, and light reflected from the corneal endothelium is faintly visible on the side. At this time, when the observation microscope is pushed forward about 0.5 mm and the focus is adjusted to the endothelial cell of the cornea, a hexagonal corneal endothelial cell can be observed (Fig. 8.4f).

8.1.3 How to Proceed with Slit Lamp Examination

Always observe the anterior segment and the entire face with a flashlight or penlight before the slit lamp examination. Adjust the eyepiece of the slit lamp to match the refractive error of the examiner (Fig. 8.5).

Fit the calibration bar (or use the fingers of the examiner), and make the slit light the smallest in the center of the field of view. Next, observe each eye on the left and right eyes, and adjust the eyepiece by rotating the eyepiece

Fig. 8.5 Adjusting the eyepiece

lever so that the rim of the slit light is most clearly focused. Adjust the eyepiece pupil distance to match the eyes of the examinee so that the slit light on the calibration bar looks like one with two eyes. Rotate the adjustment knob to adjust the front, back, left, and right directions of the slit lamp microscope, and set the height of the microscope to the middle.

The examiner and the patient face each other with a slit lamp microscope in between. The height of the patient's chair should be adjusted so that the patient's chin is placed on the chin rest and the forehead is fixed firmly on the forehead support to fix the face. It is very important to adjust the height of the chair so that the patient is in a comfortable position.

Fluorescent test paper, 1% Rose Bengal solution, eye anesthetic, methyl cellulose, eye drops of antibiotics, and saline solution are prepared. Main power is 5.5 V or 6.0 V. The current 7.5 V is overloaded and should be used only for a short time. Adjust the adjustment knob to the left or right by adjusting it to the left or right eye to be inspected. The illuminator is located on the patient's ear, the microscope is on the front, and the angle between the illuminator and the microscope is 20–30°.

First, the lesion is observed as a whole at a wide magnification with a low magnification of about ten times. If necessary, increase the observation magnification, increase the illumination, reduce the patient's glare, and narrow the width of the slit light beam for detailed observation of the cross section. Observation of the presence (depth), extent, and extent of the lesion by illuminating slit light of various widths and lengths from various directions and angles. The narrower the width of the slit light, the better the depth of the lesion. The wider the width of the slit light, the easier it is to observe the planar view. In children, it is best to sit on the guardian's knees, hold the head lightly, and observe the eye of the children. However, if the children are not cooperative, the portable slit lamp can be used to examine the eye (Fig. 8.6).

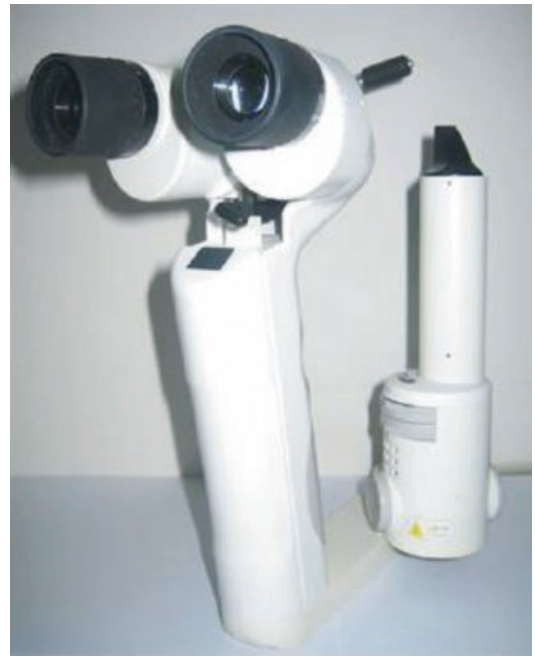

Fig. 8.6 The portable slit lamp

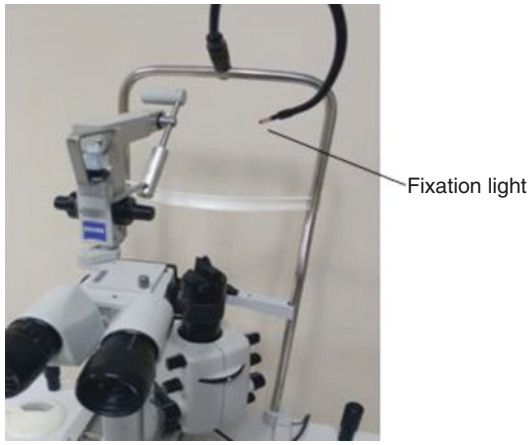

Fig. 8.7 The fixation light

The examination starts from the outer part of the eyelid, conjunctiva, and sclera and progresses to the inside of the eye gradually, such as the cornea, the anterior chamber, and the lens. In general low-magnification observation, eye movements of the patient's eye are minimized by watching the ears, shoulders, and fingers of the examinee. For high-magnification examinations, fixation light should be fixed in front of eyes that are not examined. Focus on the target and allow the patient to watch accurately (Fig. 8.7).

8.1.4 Site-Specific Observation (Table 8.2)

We can observe the general eyelid position, shape, change of skin, and eyelid clearance with the diffuse illumination. Observe the number of eyebrows, arrangement, direction, and scales.

We also observe the color and pigmentation, congestion, blood vessels, edema, and scarring of the palpebral and bulbar conjunctiva with the diffuse illumination or direct focal illumination. Then, we can observe the thickness, retention time of tear, and tear film breakup time.

In the slit light, the cornea is observed as a parallel hexahedron. When narrowing the slit light and intensifying the illumination, two distinct lines appear on the surface of the cornea. The outer line is reflected from the surface of the tear film, the inner line is the Bowman's membrane, and the dark part between the two lines is the corneal epithelium. These findings are clearly appeared from the edge of the cornea, to observe whether the epithelial advised to start a scan from the edge of the cornea.

Table 8.2 Main observation points of the anterior segment of the eye

Lid	Shape, color, injection, shape of punctum, Meibomian gland opening, scar, thickening, discharge, mass
Eyelashes	Number, arrangement, direction, scale, attachment
Palpebral conjunctiva	Color, pigmentation, injection, vessel, chemosis, pustule, scar, stone, infarction, mass, wound
Bulbar conjunctiva	Position of blood vessel, caliber, meandering, hemocyte
Tears	Tear meniscus height, reservoir, tear breakup time
Cornea	Transparency, shape, surface curvature, blister, epithelium, detachment, ulcer, foreign body, neovascularization nerve, parenchymal deposits, endothelium deposits
Anterior chamber	Floater, haziness, hyphema, exudates, hypopyon
Iris	Color, pigmentation, congestion, opacity, edema, bleeding, neovascularization, mass, defective area, degenerated atrophy, synechiae, pupillary membrane
Lens	Transparency, opacity, pigment, vesicle, cortex, nucleus

Corneal epithelial edema can be seen with small droplet-shaped epithelial edema with retro-illumination, specular reflection, and scleral scatter. The corneal epithelium defect appears to be pale turbidity when observed by direct or indirect illumination, and yellow fluorescence can be observed by observing through the cobalt blue filter with a fluorescent dye. Droplet-shaped epithelial edema is observed by narrowing the slit light, and the surface line rising is seen, and the space of the blur appears dark under it.

In case of corneal neovascularization, superficial neovascularization under the epithelium is easy to observe directly, and erythrocytes flowing in the corneal stromal neovascularization are observed by retro-illumination using the reflected light from the iris and the lens.

Corneal edema, cell infiltration, and scarring, which are lesions of the corneal stroma, are observed by retro-illumination by reflected light from the fundus. The corneal edema is cloudy and the thickness of stroma is increased.

The corneal scar has sharp margin and the scar area is turbidity deeply observed. Observe the range, depth, and thickness of the corneal lesion by narrowing the slit light. The apparent line on the back of the cornea reflects from the Descemet's membrane, and the nerve appears to be thin like a thread in the corneal stroma, which is long, thick, and clear in the pathological state.

The keratic precipitate (KP) can be observed in size, number, and color by direct or indirect illumination, and the morphology and size of the corneal endothelial cells can be observed using specular reflection.

We also can observe the depth and shape of the anterior chamber while moving the left and right by narrowing and shortening the slit light by direct focal illumination. The pupil is a dark background, and microscopic inflammatory cells float; cloudiness, hemorrhage, and hypopyon are examined. When the aqueous humor is cloudy, the convective phenomenon of aqueous humor is easily seen. The angle of the anterior chamber, trabecular pigmentation, and iris synechiae is observed using gonio lens. Direct focal illumination is used to observe iris color, posterior synechiae, and neovascularization. Iris atrophy should be observed with retro-illumination.

We also can observe the crystal lens. First, widen the slit light and observe overall, and observe the state of transparency, opacity, pigment, vacuole, and nucleus. By direct focal illumination, the entire image is observed while sequentially focusing each layer of the lens from the anterior capsule to the posterior capsule. In mydriasis state, relatively weakly localized cataracts are observed on the whole plane by retro-illumination, so if you examine them again with direct focal illumination, you will not miss cataracts. In the specular reflection method, the front and back shagreen of the lens can be observed well. We also can observe the vitreous and retina through the fundus examination. See at the chapter fundus examination (chapter 15).

The vital staining is a method of observing fluorescence by staining with an eye drop or a test strip. Fluorescence can easily detect the state of migration in the corneal epithelium and the retention of the tissue defect. We can easily observe the lesion with the use of a cobalt blue filter to prevent patient glare even if the light amount is maximized. The vital staining is used to measure the papillary proliferation of the palpebral conjunctiva of upper eyelid, cone in the keratoconus, the seidel test, intraocular pressure measurement.

Suggested Reading

Arffa RC. Grayson's diseases of the cornea. 3rd ed. St Louis: Mosby; 1991.

Bennett TJ, Miller GE. Lissamine green dye-An alternative to Rose Bengal in photo slit-lamp biomicrography. J Ophthal Photo. 2002;24(2):74–7.

Berliner ML. Biomicroscopy of the eye, vol. 1. New York: Paul B. Hoeber; 1949.

Fuchs E. Textbook of ophthalmology. New York: D. Appleton & Co; 1892.

Justice J Jr, Soper JW. An improved method of viewing topical fluorescein. Trans Am Acad Ophthalmol Otolaryngol. 1976;81:927–8.

Mártonyi CL, Bahn CF, Meyer RF. Slit lamp: examination and photography. Sedona: Time One Ink, Ltd; 2007.

Romanchuck KG. Seidel's test using 10% fluorescein. Can J Ophthalmol. 1979;14:253–6.

Shahinian L. Corneal valance: a tear film pattern in map-dot-fingerprint corneal dystrophy. Ann Ophthalmol. 1984;16:567–71.

Van Herick W, Schaffer RN, Schwartz A. Estimation of width of angle of the anterior chamber. Am J Ophthalmol. 1969;68:626–9.

Conjunctiva and Cornea Exam

9

Jong-Soo Lee

9.1 Lymph Node Exam

The purpose of this examination is to evaluate the presence or absence of lymph node metastasis in various conjunctivitis and eyelid malignancies. The preauricular lymph node and the submandibular lymph node are visualized and promoted to determine whether they are painful.

A grossly visible lymph node is seen in Parinaud syndrome and epidemic keratoconjunctivitis. If you have pain, you may suspect herpes simplex conjunctivitis, epidemic conjunctivitis, inclusion conjunctivitis, and trachoma. Small, painless lymph nodes are seen in pharyngoconjunctival fever and acute hemorrhagic conjunctivitis. The temporal conjunctiva, 2/3 of the upper eyelid, and 1/3 of the lower eyelid are excreted into the preauricular lymph node, and the rest of the eye are excreted into the submandibular lymph nodes (Fig. 9.1). These lymph nodes are important to metastasis of eyelid malignant tumor.

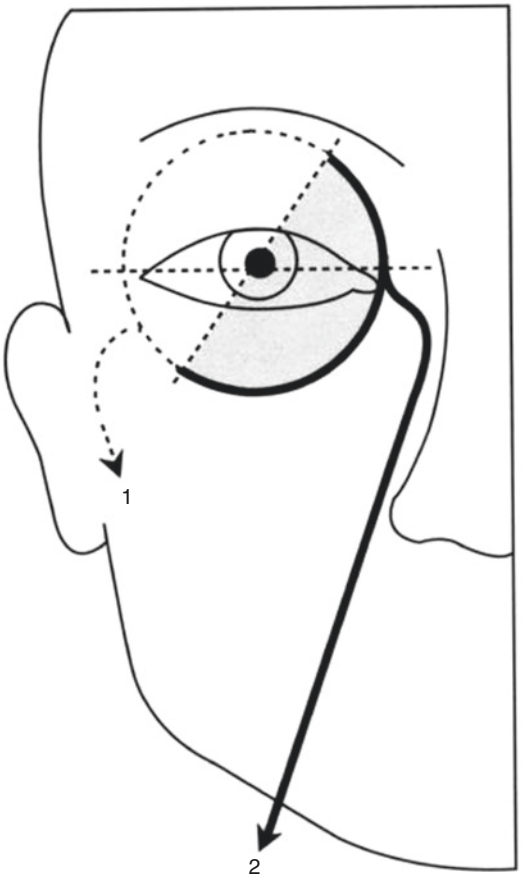

Fig. 9.1 Emission of lymphatic fluid from the eye. 1. Preauricular lymph nodes. 2. Submandibular lymph nodes

9.2 Eyelid Eversion Method

Since gross finding is important in examining the conjunctiva, the conjunctiva is exposed by inverting the upper and lower eyelids, and the overall condition of the conjunctiva is observed.

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9.2.1 Lower Eyelid Eversion Methods

You can see the entire conjunctiva of the lower eyelid by allowing the patient to sit upright or lying down and pulling down with the thumb of the left hand slightly pressed down on the lower eyelid (Fig. 9.2).

9.2.2 Upper Eyelid Eversion Methods

Point the patient's gaze downward, and then wrinkle the upper eyelid skin of the upper eyelid with the thumb and index finger. The index finger pushes the eyeball and twists the eyelid frame with the thumb. Remove the index finger, and fix the thumbed skin to the orbit (Fig. 9.3).

Place the thumb of the opposite hand against the lower eyelid and push the eyeball into the orbit, lifting the upper eyelid to expose the conjunctival fornix. When inverting the eyelids using ancillary equipment, grasp the eyelash with the thumb and index finger, place the choker or swab horizontally on top of the eyelid plate with one hand, lift the eyelash up while pushing it toward the eyeball, and remove the choker (Fig. 9.4).

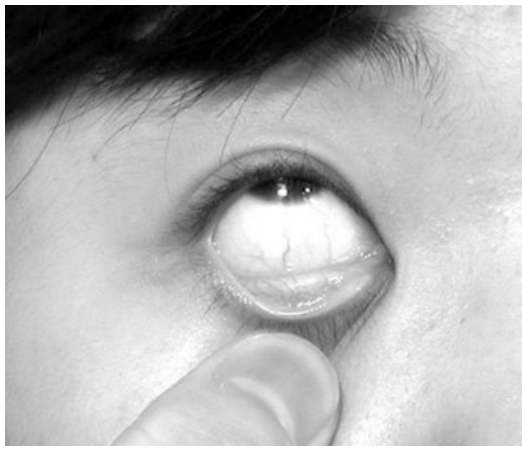

Fig. 9.2 Lower eyelid eversion methods

9.3 Vital Staining

Small erosions or defects in the cornea and conjunctiva are difficult to detect. When the surface of each conjunctiva and cornea is stained, it can be easily used for the diagnosis of epithelial erosion or defect. Characteristic staining pattern is helpful for diagnosis of cornea and external eye disease. When describing the staining, the depth and scope should be set to micropunctate, macropunctate, coalescent (patch), and whether the depth is limited to the corneal epithelium or the corneal stroma. Fluorescein is stained green on Bowman's membrane, a defective part of the cornea in the intercellular lesions, and rose bengal is reddish in dead cells or cells with no function. In addition, lissamine green is less irritating than

Fig. 9.3 Upper eyelid eversion methods

rose bengal and can be used for the diagnosis of dry eye syndrome because it is stained with abnormal mucin (Table 9.1).

9.3.1 Fluorescein Staining

Fluorescein staining can be used to diagnose eye diseases that are suspected of corneal epithelium defect, corneal erosion, or corneal ulcer. Fluorescent materials are useful for applanation tonometer, contact lens fitting, nasolacrimal duct penetration and obstruction testing, tear film break-up time measurement, and seidel testing (Fig. 9.5).

The stained state of the cornea or conjunctiva is observed by injecting sterile 2% fluorescein or test strip into the conjunctival sac. After placing a drop of water into the conjunctival sac, flush the eyelid about 3–4 times (after about 15 min) and check for lesion under cobalt blue filter. When using the test strip, drop saline solution without preservative onto the test strip and shake off the test strip. After the upper sight, contact the lower temporal conjunctival sac and perform the examination. The lower eyelid should be pulled to avoid conjunctival or eyelid border damage.

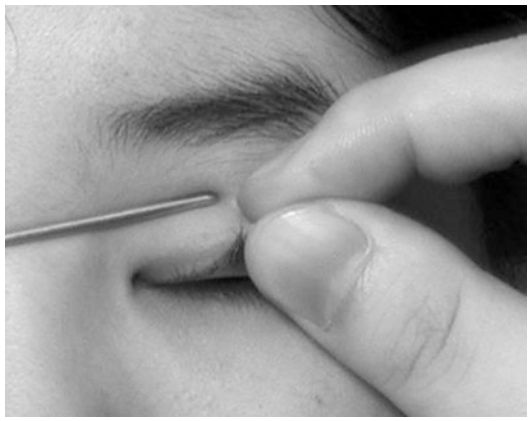

Fig. 9.4 Upper eyelid eversion methods using ancillary equipment

9.3.2 Rose Bengal Staining

It is useful for diagnosis of ocular epithelium defect, staining of mucin, and dry eye syndrome.

After 1% solution is instilled into the conjunctival sac, the eyelid is blinked about 3–5 times, and the conjunctival lesion is observed. The cornea and conjunctival lesions were severely damaged as the score increased from 0 to +9 according to the intensity of staining, divided into three areas: the nasal conjunctiva, the temporal conjunctiva, and the cornea (Fig. 9.6).

9.3.3 Lissamine Green Staining

It is useful to diagnosis in dead or denatured cells, abnormal mucin, and dry eye syndrome.

Use a 0.5% lissamine green test strip, and use it in the same way as using fluorescence or rose bengal test strips. Normal corneal epithelium is not stained in the pigmented point, but there are various types of staining when there is a corneal epithelium defect. For example, dendritic defects are suspected to be herpes simplex keratitis and

Table 9.1 Types and differentiation of vital staining

Differentiation	Flourescein	Rose bengal	Lissamine green B
Normal cell staining	No stain	Stain	No stain
Dying or degenerated cell staining	No stain	Stain	Stain
Staining inhibition by mucin	None	Exist	None
Comparative spread through collagen parenchyma	Fastest	Slowest	Fast
Mechanism of staining promotion	Intercellular cleavage	Inadequate defense of tears	Intercellular cleavage and cell death/degeneration

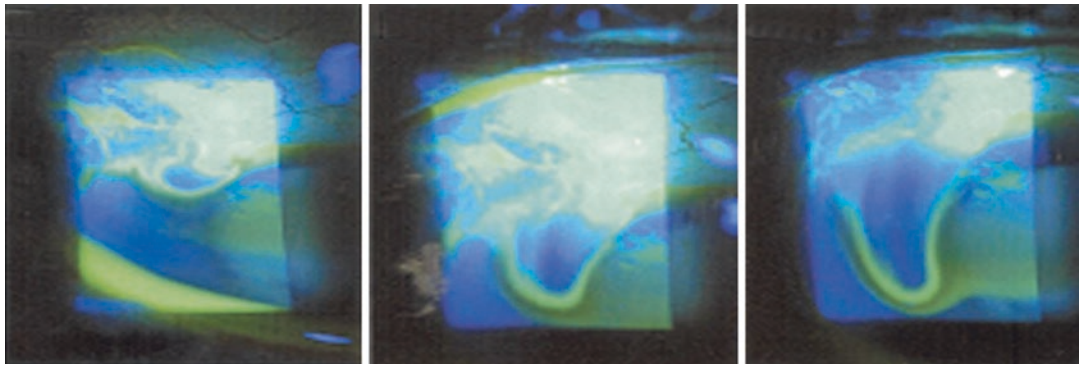

Fig. 9.5 Leakage of aqueous identified in the bleb fistula during fluorescein staining

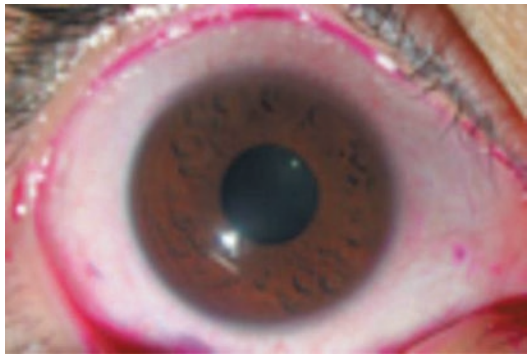

Fig. 9.6 Rose bengal staining in dry eye

Table 9.2 Superficial punctate epitheliopathy

Location	Cause
Upper	Foreign body in the eyelid Vernal keratoconjunctivitis Superior limbic keratoconjunctivitis
Lower	Staphylococcal blepharitis Entropion Lagophthalmos Drug toxicity
Interpalpebral	Seborrheic blepharitis Dry eye syndrome UV exposure Neurological disease

herpes zoster keratitis, and spot defects are caused by herpes simplex, epidemic keratoconjunctivitis, and trichiasis. Irregular erosion may be caused by improper use of contact lenses, trauma, and ultraviolet radiation. The causes of superficial punctate epitheliopathy are shown in Table 9.2.

9.4 Bacteriological Exam

Diagnosis of bacterial keratitis is not sufficient with clinical findings and should be accompanied by bacteriological examination. Bacteriological tests are not only helpful for diagnosis, but also for selecting appropriate therapy, and should be performed before administration of antibiotics.

9.4.1 Notes on Sampling

As a pre-treatment, use 0.5% proparacaine, an eye-topical anesthetic. The eyelids are opened by using a sterilized speculum, and then the corneal materials for microbial culture are collected. Since the live bacteria may not exist in the mucous or mucous secretions, the specimens should be obtained after mucous or mucous secretion removal. Corneal material is obtained by scraping corneal tissues from the advancing borders of the infected area using a sterilized surgical knife or a bent needle.

When culture and smear samples are prepared, smear samples are prepared after culturing. The basic mediums are blood, chocolate, and fungus medium. If anaerobic bacteria are suspected, anaerobic medium is used. If acanthamoeba infection is suspected, non-nutrient medium coated with *E. coli* is used. Gram stain, acridine orange stain, and Giemsa stain are basically used in smear samples. The hypopyon that occurs in

eyes with bacterial keratitis is usually sterile, and aqueous or vitreous taps should not be performed in order to avoid intraocular inoculation of the microorganisms, unless there is a high suspicion of microbial endophthalmitis.

9.4.2 Culture and Scratch

Laboratory investigation includes corneal scraping to identify organisms and determine sensitivity to antibiotics. Samples are taken from the eyelid, conjunctival sac, and corneal ulcer surface with cotton swabs and planted in the medium (Fig. 9.7).

Scratch the corneal ulcer base and border with a sterile surgical knife or Kimura spatula to collect the specimens and examine them for smear and culture (Fig. 9.8).

9.4.3 Biopsy

Indications for corneal biopsy include corneal biopsy of the deep cornea in which lesions are difficult to obtain by corneal scarring or if inflammation progresses without previous detection of bacteria. The corneal biopsy method uses a small 2–4 mm round trephine. Care should be taken not to puncture the cornea. As a test method, the removed tissue may be directly cultured in a culture medium or inoculated into a liquid culture medium.

9.4.4 Stains

Microbial pathogens may be categorized by examining stained smears of corneal scrapings. The material for smear is applied to a clean glass microscope slide in an even, thin layer for microbial staining. After drying, it is advisable to immobilize the slides in a 95% alcohol fixative for about 5 min.

9.4.4.1 Acridine Orange Stain

This is useful as a primary staining method to quickly detect the presence or absence of bacteria. The acridine orange dyes used are diphenylmethane dyes, which bind to double-stranded nucleic acids and display bright fluorescence under a fluorescence microscope. Bacteria have bright orange fluorescence, and human cells and other background substances have green or yellow fluorescence (Fig. 9.9). Therefore, when the number of bacteria is small, the method is more sensitive than Gram stain. However, since it is not known whether bacteria are Gram-positive bacteria or Gram-negative bacteria, Gram stain is additionally required.

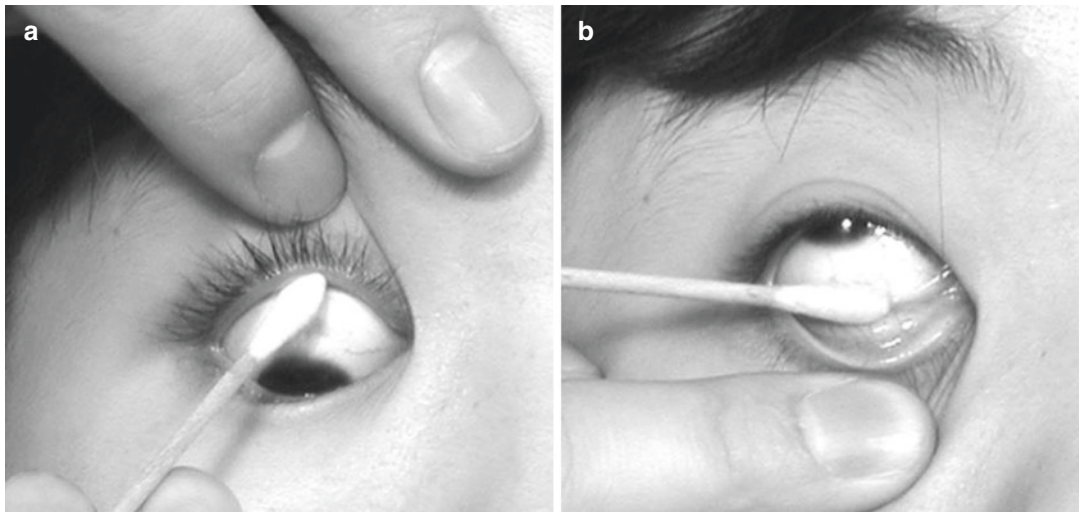

Fig. 9.7 Sampling with a cotton swab. (**a**) Eyelid margin. (**b**) Conjunctival Sac

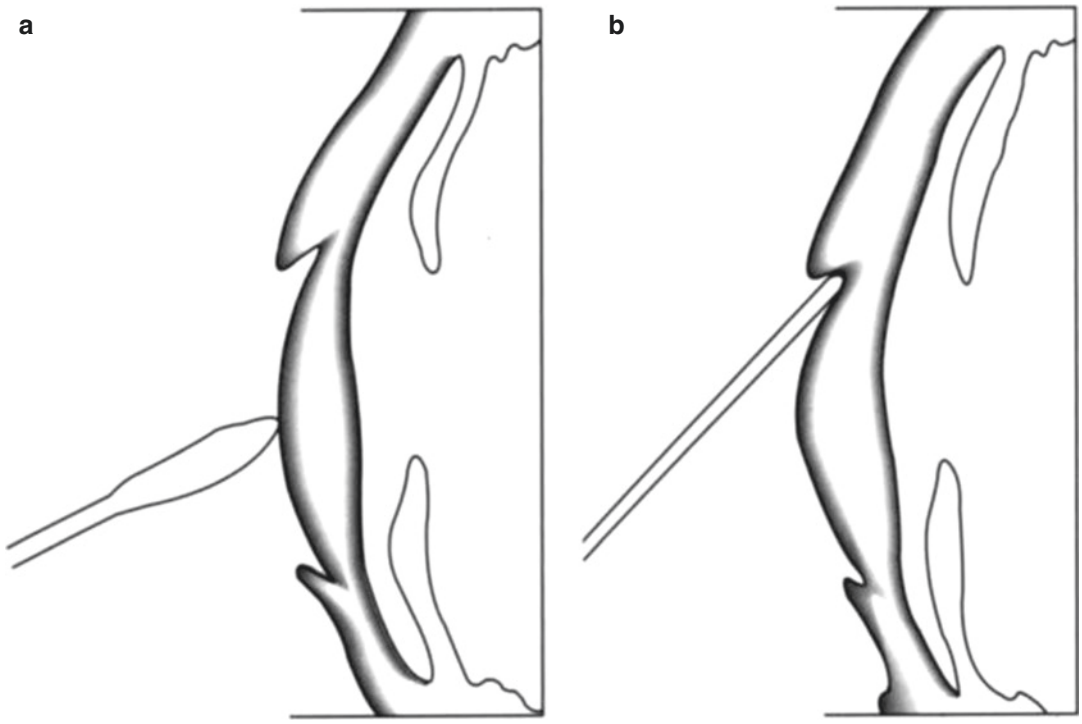

Fig. 9.8 Sampling of corneal ulcer. (**a**) Ulcer base. (**b**) Ulcer borderline

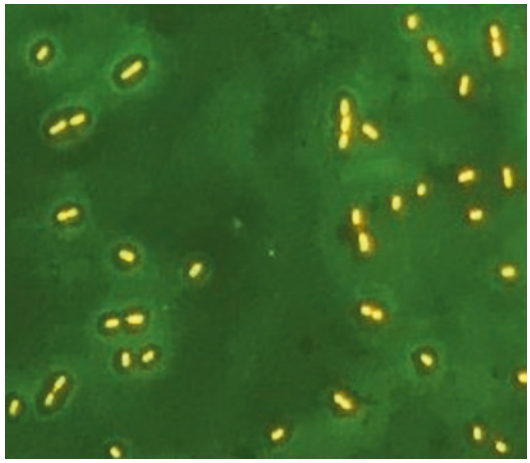

Fig. 9.9 Acridine orange stain in *Streptococcus pneumoniae* keratitis

9.4.4.2 Gram Stain

This is the most basic dye for smears testing. Due to differences in cell wall structure and chemical composition of bacteria, Gram-positive bacteria appear blue, and Gram-negative bacteria appear pink (Fig. 9.10).

9.4.4.3 Giemsa Stain

It is used for the discovery of fungi and the structural observation of cells. If infection with a fungus or acanthamoeba is suspected, calcofluor-white, methenamine silver, trichrome stain is helpful. If a mycobacterial infection is suspected, antacid staining is preferred. Recently, a fluorescent antibody test has been attempted to diagnose bacterial keratitis. It has the advantage of being able to test even if it is being treated by detecting the antigen of bacteria.

9.5 Pachymetry

Because corneal edema occurs mainly on the posterior surface of the cornea, and cornea stromal edema is controlled by the corneal endothelium, the measurement of corneal thickness is an indicator of endothelial function.

A device for measuring the thickness of a cornea is called a pachymeter. There are optical methods using a slit lamp, using an ultrasonic

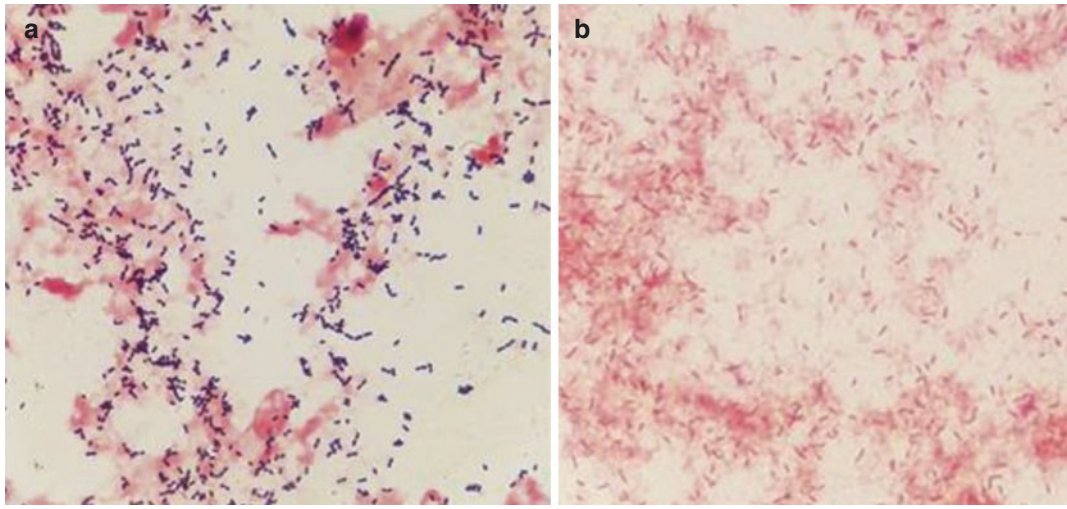

Fig. 9.10 Gram stain. (**a**) Gram-positive bacteria retain the color of the crystal violet stain in the Gram stain. (**b**) Gram-negative bacteria lose the crystal violet stain and take the color of the red of pink counterstain

Table 9.3 Diseases requiring examination of corneal thickness

Application for refractive surgery
Thinning of the cornea
Keratoconus Pellucid marginal degeneration Terrien marginal degeneration
Corneal endothelial decompensation
Corneal endothelial degeneration
A state in which corneal endothelial function is predicted to decrease
After laser iridotomy Contact lens user Those who use antipsychotic drugs (butyrophenone)
Corneal thickness affects clinical evaluation
Glaucoma (intraocular pressure)

probe, using a specular microscope, using a confocal microscope, and using Orbscan. Recently, it is an indispensable test for preoperative evaluation of corneal surgery including corneal refractive surgery. Corneal thickness is also important in the diagnosis of glaucoma and is also used to evaluate corneal status after corneal transplantation, keratoconus evaluation, and corneal edema (Table 9.3).

It is a clinically useful technique for evaluating corneal edema that can occur after intraocular surgery, eye disease, or corneal guttata. The measurement error is usually about 0.2%.

9.5.1 Classification of Pachymetry

Corneal thickness measurements can be made with contact and noncontact methods. The differences are shown in Table 9.4.

Ultrasonography is a contact type, so it is possible to measure the corneal opacity even though it has a risk of infection. In particular, it can be measured regardless of the position of the patient and can be measured during surgery. The noncontact type is an Orbscan measurement method using an optical method, which can interpret the shape of the front and back of the cornea by projecting the slit light, obtaining the image, and analyzing it with a triangular measurement method. In addition, when using a specular microscope, it is possible to measure not only the thickness of the cornea but also the morphological abnormality of the corneal endothelial cell and the functional abnormality of the corneal tissue. Corneal thickness measured with Pentacam using a Scheimpflug camera is clinically useful because of its small error.

In general, in order to alleviate the burden on the patient, noncontact measurement method which can perform various examinations including corneal endothelial cell and anterior angle shape analysis is widely used. The ultrasonic

Table 9.4 Comparison of two corneal thickness measurement methods

Contact	Noncontact		
Ultrasound method	Slit scanning	Specular method	Scheimpflug method
Instrument SP-3000	Instrument ORB	Instrument FA-3509	Instrument Pentacam
Noninvasive	Noninvasive	Noninvasive	Noninvasive
Measured during surgery	Corneal shape analysis	Corneal endothelium analysis	Anterior segment analysis
Error between inspectors by probe manipulation	Noncontact and less error	Noncontact and less error	Noncontact and less error

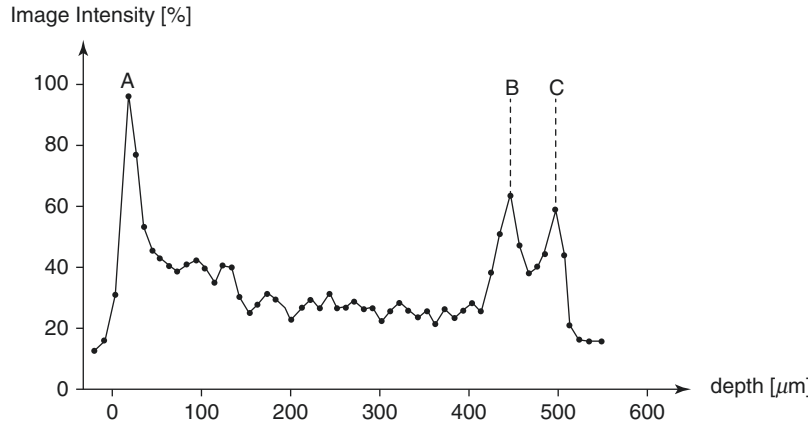

Fig. 9.11 Z-scan curve. (**a**) Corneal endothelial layer. (**b**) Corneal stromal cell. (**c**) Corneal epithelial layer

measurement method, which can measure the surgical region without depending on the position of the patient, is useful.

9.5.2 Types of Pachymetry

9.5.2.1 Using an Ultrasonic Probe

The most widely used method is to place the observer perpendicular to the corneal surface to measure the exact thickness. However, it is difficult to measure the corneal thickness if posterior corneal folding or corneal opacity is severe. At the same time, the corneal center and peripheral thickness cannot be measured at the same time. The measurement position is not known precisely, and the cornea is depressed by contact with the cornea at a right angle within 10°, which has a disadvantage that it affects the cornea measurement value.

The normal finding is that the cornea is transparent and has a thickness of 0.5 mm. If edema of the corneal epithelium occurs, it becomes thicker to 0.65–0.75 mm. Even in the presence of normal corneal thickness, corneal endothelial dysfunction is associated with increased corneal thickness, especially in the morning. If the thickness of the cornea is 0.7 mm, it can be diagnosed as corneal endothelial cell decompensation or corneal epithelial cell edema.

9.5.2.2 Using a Confocal Microscope

This method is performed using Z-scan (confocal microscopy through focusing, CMTF). Based on the principle that each layer of the cornea emits a different reflective intensity, the thickness of the corneal epithelium layer, the stromal layer, and the entire layer can be accurately measured. When the corneal layer is measured by Z-scan, three wavelengths are observed in the endothelial layer (a), the area where the corneal epithelium and the stromal layer meet, or the subepithelial neural network or the corneal stromal cell (b), and the corneal epithelial layer (c). This can be used to measure the thickness of the cornea (Fig. 9.11).

9.5.2.3 Using an Orbscan

Orbscan divides the cornea into several sections along each border, with 20 tilted right and 20 tilted left, totaling 40. By using the corneal cross section, the shape of the front and back faces is changed to the three-dimensional point and analyzed, and accurate information on the shape of the anterior and posterior cornea is obtained, and the corneal thickness can be measured at the same time. The thickness of the central cornea and the thickness of the peripheral cornea can be measured simultaneously without direct stimulation of the cornea. The corneal thickness and the change of state according to each part of the cornea can be measured because the state of the tear film can be reflected without pressing the cornea. The disadvantages are the focus depth error of slit-scanning method. It is important to note that the corneal thickness may be too thin when corneal opacity is present or may be misdiagnosed as keratoconus due to abnormal protrusion of the posterior cornea.

9.5.2.4 Using a Specular Microscope

A part of the slit light reflected from the aqueous humor is reflected from the endothelial layer of the cornea to measure the distance between the anterior and posterior corneas, that is, the thickness of the cornea. In case of contact, eye contact should be made at the center of the cornea, and eye anesthesia is necessary. It is difficult to measure if corneal edema or opacity is severe. The morphology of corneal endothelial cells, such as cell density, mean cell area, hexagonal cell structure, and coefficient of variation, can be verified with less deviation and reproducibility than with ultrasonography.

9.5.2.5 Using a Pentacam

Pentacam is based on the principle of a Scheimpflug camera that rotates 360°. It has the advantage of getting a clear image that is not distorted because the depth of focus is deeper than the Orbscan method. An image obtained by three-dimensionally scanning the cornea from the front of the lens to the back of the lens provides various information about the anterior segment. In other words, in addition to corneal thickness, various information such as anterior chamber depth, anterior chamber angle, anterior chamber volume, and corneal topography are shown at once. Recently, the Galilei G6 has been introduced and used in combination with the placido method used in the Orbscan while using the double Scheimpflug. Pentacam can measure 25,000 points, while G2 can measure 122,000 points, resulting in more accurate images.

9.5.2.6 Using an Anterior OCT

The image of the anterior segment was imaged by changing the light source of OCT used in the conventional retinal disease or optic nerve disease using the interference pattern from 820 nm to 1310 nm. A representative 1310 nm anterior OCT system displays the anterior segment structure as a high-resolution direct cross-sectional image, which allows for in vivo imaging and measurement of the cornea, anterior chamber, and anterior angle including the central part of the lens. Furthermore, as the measurement speed is increased and the resolution is gradually increased, the clinical application value is also increasing.

9.6 Specular Microscope

Since corneal endothelial cells play an important role in maintaining the transparency of the cornea, corneal endothelium test is one of the most important exams in corneal transplantation. Currently, specular microscopy is the most commonly used instrument for examining corneal endothelial cells.

The specular microscope is a machine that allows direct observation of corneal endothelial cells, which can measure the density and morphology of corneal endothelial cells.

In case of contact microscope, endothelial cells of central cornea and upper, lower, inner, and outer sides were observed by direct contact with the cornea after local anesthesia. It is difficult to measure the number of cells enlarged on a

grid of 2 mm intervals and to calculate the average value.

The use of noncontact specular microscopy does not require anesthetic agents, and the acquired corneal endothelial cell image is automatically interpreted. Therefore, the frequency of use is gradually increasing recently. However, if corneal stromal or epithelial edema is severe, it is difficult to observe endothelial cells. The contact type is not often used because of the proficiency of the examiner and the necessity of anesthesia in the eye, but contact type is more useful in measuring the corneal endothelial cell density in the peripheral cornea. Most of the light is transmitted through the corneal epithelium, while 0.02% of the light is reflected between the anterior aqueous fluid and the corneal endothelial cells, which is collected on the lens to obtain the image of the endothelium.

Specular microscope is useful in assessing the extent of endothelial damage after cataract surgery and intraocular lens implantation and may be useful in assessing the status of the donor cornea in corneal transplantation. It is helpful to observe the disappearance or change of endothelial cells even after corneal refractive surgery, or ocular trauma, before or after intraocular surgery or corneal endothelial degeneration.

9.6.1 Method

Place the center of the cornea in the center of the instrument and adjust the patient's jaw height.

After focusing on the corneal endothelial cells using an autofocusing device, images are taken.

In the corneal endothelial cell image displayed on the video screen, about 50–100 endothelial cells in the central cornea are selected and analyzed through an image analysis program. The analysis included the mean corneal endothelial cell density, endothelial cell area, cell surface area coefficient of variation, and endothelial cell polymorphism (ratio of hexagonal cells).

After analyzing the image displayed on the video screen, the analysis result is output.

9.6.2 Judgment

When the specimen is observed under a specular microscope, the following values are obtained as the test results, and the average values are shown in Table 9.5.

9.6.2.1 Endothelial Cell Density

The density of corneal endothelial cells decreases with age. In addition, long-term use of contact lenses, anterior segment diseases such as acute glaucomatous attack, trauma, and surgery are also factors contributing to corneal endothelial cell loss. In the keratoanalyzer for donor corneas, the endothelial cells in the central cornea are measured in principle, but in the case when the central portion is difficult to measure, the measurement is performed in the periphery of the cornea. Measuring and averaging at multiple sites can more accurately measure the condition of the donor cornea. The lower limit of endothelial cell density for corneal grafts may vary depending on the medical standard or the surgeon, but in general, the lower limit is 2000 cells/mm^2, and if it is less than 2000 cells/mm^2, it is used only for superficial kieratoplasty. When the number of cells is less than 500 cells/mm^2, corneal decompensation increases the incidence of bullous keratopathy.

9.6.2.2 Average Volume of Endothelium

Basically, when the density of the corneal endothelial cells is high, the cell area becomes small. When the density is low, the cell area becomes large. The standard deviation shown on the data screen is the limit of the variation of the corneal endothelial cell area, MAX is the maximum cell area and MIN is the minimum cell area. The normal cell area is about 300 μm^2 in adults.

Table 9.5 Mean value of normal corneal endothelial cells

Cell density	2777–3410 cells/mm^2
Average cell area	296–367 μm^2
Hexagonality	Over 55–67%
Coefficient of variation	Under 0.26–0.40

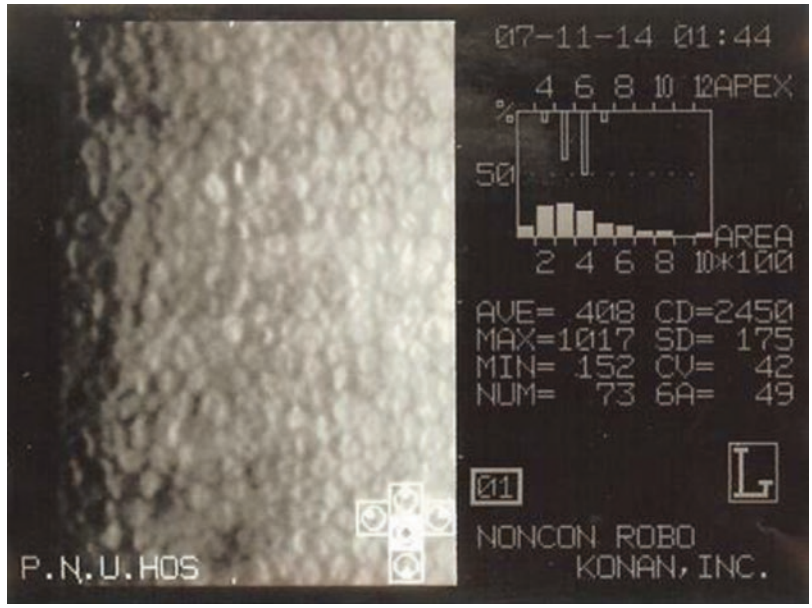

Fig. 9.12 Corneal endothelial cell findings by specular microscopy

9.6.2.3 Coefficient of Variation (CV)

It is the value of the standard deviation of cell areas/mean cell area (SD/AVE), indicating the degree of cell polymegathism. That is, as the CV of the corneal endothelial cell increases, the polymegathism of endothelial cell increases, and this can be interpreted as a recovery process by stimulation. In the normal subjects, CV is about 0.25 in the 20 s and about 0.3 in the 60 s and when the coefficient of variation is 0.35 or more are considered abnormal values.

9.6.2.4 Hexagonality

Hexagonality is the ratio of the number of hexagonal cells in the number of corneal endothelial cells, and healthy corneal endothelial cells are usually hexagonal in shape and almost uniform in size. However, when the corneal endothelial cell disorder occurs, the corneal endothelial cell death or dislocation causes peripheral corneal endothelial cells to migrate or enlarge. Consequently the size and shape of the cells become uneven, and the occurrence rate of hexagonal cells is decreased.

Hexagonality is used as an indicator of pleomorphism, which indicates the presence or absence of stress on corneal endothelial cells, as well as the coefficient of variation. In the normal subject, if it is less than 60%, it is regarded as an abnormal finding (Fig. 9.12).

The results of the examination of the left eye by specular microscope showed that a total of 73 cells were counted (NUM) and the results were interpreted. The average cell area (AVE) is 408 μm^2, the maximum cell area (MAX) is 1017 μm^2, the minimum cell area (MIN) is 152 μm^2, and the standard deviation (SD) is 175 μm^2. The corneal endothelial cell density (CD) was 2450 cells/mm^2, the coefficient of variation (CV) was 0.42, and the incidence of hexagonal cells (6A) was 49%.

9.7 Corneal Sensitivity Test

The cornea is rich in nasociliary nerve in the first branch of the trigeminal nerve, and it plays an important role in maintenance of corneal epithelial and endothelial cell. Corneal is sensitive to corneal center 5 mm, horizontal, vertical, and peripheral area. Therefore, if corneal sensitivity of these areas is decreased, it should be considered pathological change except for changes due to aging process.

The cornea distribution of the nasociliary nerve of the trigeminal nerve is examined for the aging process, herpes simplex, herpes zos-

ter, corneal disease caused by adenovirus, corneal degeneration, soft contact lens user, cerebellar plexus tumor, and diabetic keratitis. It is possible to confirm the degree of corneal perception when there is corneal ulcer and corneal degeneration and to know how hard the cornea is attached after transplantation. When the long-term contact lens is used, the sensitivity can decrease.

Corneal perception is reduced in normal aging, herpes simplex, herpes zoster, corneal disease caused by adenovirus, corneal degeneration, soft contact lens user, and cerebellar plexus tumor.

9.7.1 Method

9.7.1.1 Using a Cotton Swab

Let the patient look at the front and gently touch the cornea to instantly blink. At this time, be careful not to touch the eyelashes, and it should be approached from the side of patient to avoid seeing the cotton swab.

Spread the cotton at the end of the swab thinly and long.

Let the patient's eye see the opposite of the eye being examined.

The patient's eyelids are spread apart by the tester's fingers.

Place the end of the swab horizontally from the outside of the eye to be examined.

Check the eyelid closure reflex, epiphora, and foreign body sensation.

9.7.1.2 Using a Corneal Perception Meter

It is used to evaluate the sensation of the cornea by adjusting the length of the nylon thread (5–60 mm).

The longer the length, the more sensitive the sensation (Fig. 9.13).

Hold the instrument like a pencil. Rotate the knob attached to the instrument, and pull the nylon thread long. Press the cornea vertically until the patient is able to feel the nylon thread touching the cornea and shorten the thread. When the patient starts to feel the end of the nylon thread, measure the length of the nylon thread.

Fig. 9.13 Corneal perception meter

9.8 Keratometry

In addition to measuring the curvature of the cornea, we can measure the quality of the surface of the cornea.

The corneal reflex of the keratometry can be determined by measuring the curvature radius of the corneal surface that corresponds to the 3.0–3.5 mm diameter corneal center rather than the entire cornea. The principle of the test is to measure the corneal reflex images on two optical time tables attached to the telescope while using a short focus lens with a low depth of focus. This test is indicated by the radius of curvature (mm) of the cornea and the refractive index (D) of the cornea.

It is used for measurement radius curvature of the cornea, astigmatism, basic curvature when prescribing contact lenses, and lens dioptric power when inserting an intraocular lens during cataract surgery.

There are two types of curvature measurements currently in use, manual and automatic (see Chap. 2).

9.9 Corneal Topography

This is to observe and record the surface morphology of the cornea in astigmatism and keratoconus. The light is reflected on the cornea, and the degree of deformation of the cornea is photographed with a video camera, analyzed by computer software, and the curvature of each part of the cornea is displayed in various colors. This is called the topography of the cornea. The basic quad map of the corneal topography consists of

Table 9.6 Point of judgment and indication of measuring device of corneal disease

	Video keratoscope	Slit type	Point of judgment
Corneal transplantation	Good	Good	Is there any reduction in corrected visual acuity due to irregular astigmatism?
Excimer laser keratectomy	Good	Good	Is there any asymmetry in corneal thickness or curvature?
Pterygium	Good	Considerable	What is the range and degree of corneal shape change?
Corneal suture stitch out	Good	Considerable	What is the degree of mire distortion? What is the interpretation of asymmetric and regular astigmatism components?

an anterior elevation map, a posterior elevation map, a pachymetry map, and an axial map. The steep face is a red color with a warm color, and the flat face is a blue or in green color. In order to measure the corneal topography accurately, the condition of the ocular surface, tear film status, the patient's ability to watch, and the proficiency of the examiner are important.

It is measured in eyes with keratoconus, penetrating keratoplasty, corneal trauma, Terrien marginal degeneration, pellucid marginal degeneration, irregular astigmatism, and before and after corneal refractive surgery. It is performed to evaluate the changes of corneal morphology according to the time course.

9.9.1 Types of Corneal Topography

Currently, the measurement principle of the corneal topography analyzer is divided into two types.

One is computerized video keratoscopy, which is interpreted by digitizing the reflection image based on placido disc, and the other is slit-scanning device (slit type). The corneal topography with a placido-based device has a cone or hemispherical illumination device that produces a ring-shaped light. The camera attached to the computer manually or automatically obtains an annular image that is reflected at about 10 mm from the center of the cornea.

The plaque-based method is easy to measure because of the short inspection time and high reproducibility of results. The height measurement by the slit-scanning method can be used to analyze the front and back of the cornea by synthesizing a three-dimensional slit-scanning image and to measure the thickness of the cornea effectively and with high reproducibility. However, since scanning is performed continuously for several seconds, it is necessary to pay special attention to decrease of reproducibility due to movement of the subject during the measurement. Therefore, it is recommended to use the slit-scanning method when information on the corneal thickness or the shape of the corneal posterior surface is required. Otherwise, computerized video keratoscopy should be used (Table 9.6).

9.9.2 Method

Place the center of the cornea in the center of the instrument and adjust the patient's jaw height.

To measure the patient's right eye first, a concentric plate is placed on the cornea of the patient, and the monitor shows the entire cornea of the patient.

The examiner identifies the concentric circles reflected on the cornea through the hole in the center of the plate.

The focus of the corneal reflex is photographed, and the computer displays the curvature of each part in multiple colors.

9.9.3 Judgment

Corneal topography is helpful in the case of keratoconus, which is difficult to diagnose clinically and refractive status due to astigmatism can be seen in normal eye. Diagnosis of keratoconus using corneal topography may vary depending on

the type of measuring machine; the following sections are useful for clinical use. The video corneal topography can be diagnosed as keratoconus if the average simulated keratometry (SimK) is 45.7D, the central corneal curvature is 47.2D, and the inferior corneal I-S value is 1.4D or higher. It can be diagnosed as keratoconus if the central corneal curvature is greater than 47D, the central corneal curvature differs more than 1D from the opposite eye, and the inferior corneal steepness is more than 3D. Pentacam shows that the central corneal curvature is more than 47.2D, the steepness of the inferior cornea is more than 1.2D, SimK astigmatism is more than 1.5D, and skewed radial axes (SRAX) is greater than 21, and it can be diagnosed as keratoconus (Fig. 9.14).

9.9.3.1 Quantification of Regular and Irregular Astigmatism

It is necessary to evaluate the optical performance of the cornea by corneal topography before surgery in keratoconus. When the corneal abnormality is so severe that the distortion of the mire is too large or the evaluation in the color code map is difficult, it is preferable to refer to the image data of the mire or to evaluate the corneal status using a photokeratoscope. After surgery, it is advisable to partially stitch out by reevaluating the shape of the cornea due to the suture effect.

9.9.3.2 Corneal Thickness

A slit-type examination is required to measure corneal thickness. In order to prevent keratoectasia by excimer laser surgery, it is recommended to check whether there is any asymmetry in the shape of the posterior surface of cornea or the corneal thickness distribution by automatic diagnostic program with built-in video keratoscope.

9.9.3.3 Corneal Refractive Power

When excimer laser surgery is performed, the curvature of the anteroposterior surface of the cornea changes, and corneal irregular astigmatism occurs. Therefore, it is not possible to accurately evaluate the corneal refractive power only by measuring the automatic corneal refractometer. In this case, it is better to measure the anteroposterior surface of the cornea using a slit method and then determine the lens power after measuring the anterior chamber depth.

9.9.3.4 Evaluation of Smoothness of Corneal Surface

Corneal epithelial defect or corneal dystrophy is inaccurate in corneal surface reflections. Therefore, it is impossible to properly evaluate the smoothness of the corneal surface due to the mires distortion. If the mires distortion is detected, it is necessary to identify the cause and treat it accordingly.

9.10 Wavefront Aberrometry

The wavefront aberrometer is an automated, objective instrument that measures the imperfection of an ocular optical system more precisely than the wavelength of light. We expected good visual outcome after correcting refractive error. But, although refractive errors are minor after refractive surgery or cataract surgery, patients present with complaints of glare, halo, light stretching, and poor visual quality due to monocular diplopia. The concept that can explain this is wavefront aberration. When the rays from one point do not gather at one point, the image is blurred and distorted, and the top surface is not flat, which means aberration. The aberration is divided into chromatic aberration and monochromatic aberration. Currently commercially available wavefront aberration was developed to measure monochromatic aberrations. Wavefront aberrations consist of lower-order aberrations corrected with spherical or cylindrical lenses, such as myopia, hyperopia, and astigmatism, and higher-order aberrations that are not corrected.

Depending on the method of measuring the wavefront aberration, there are several types (Table 9.7).

The Hartmann-Shack method is an analyzing light reflected from the center of the retina. Tscherning, ray tracing, and OPD scan methods are analyzing the image pattern on the retina itself.

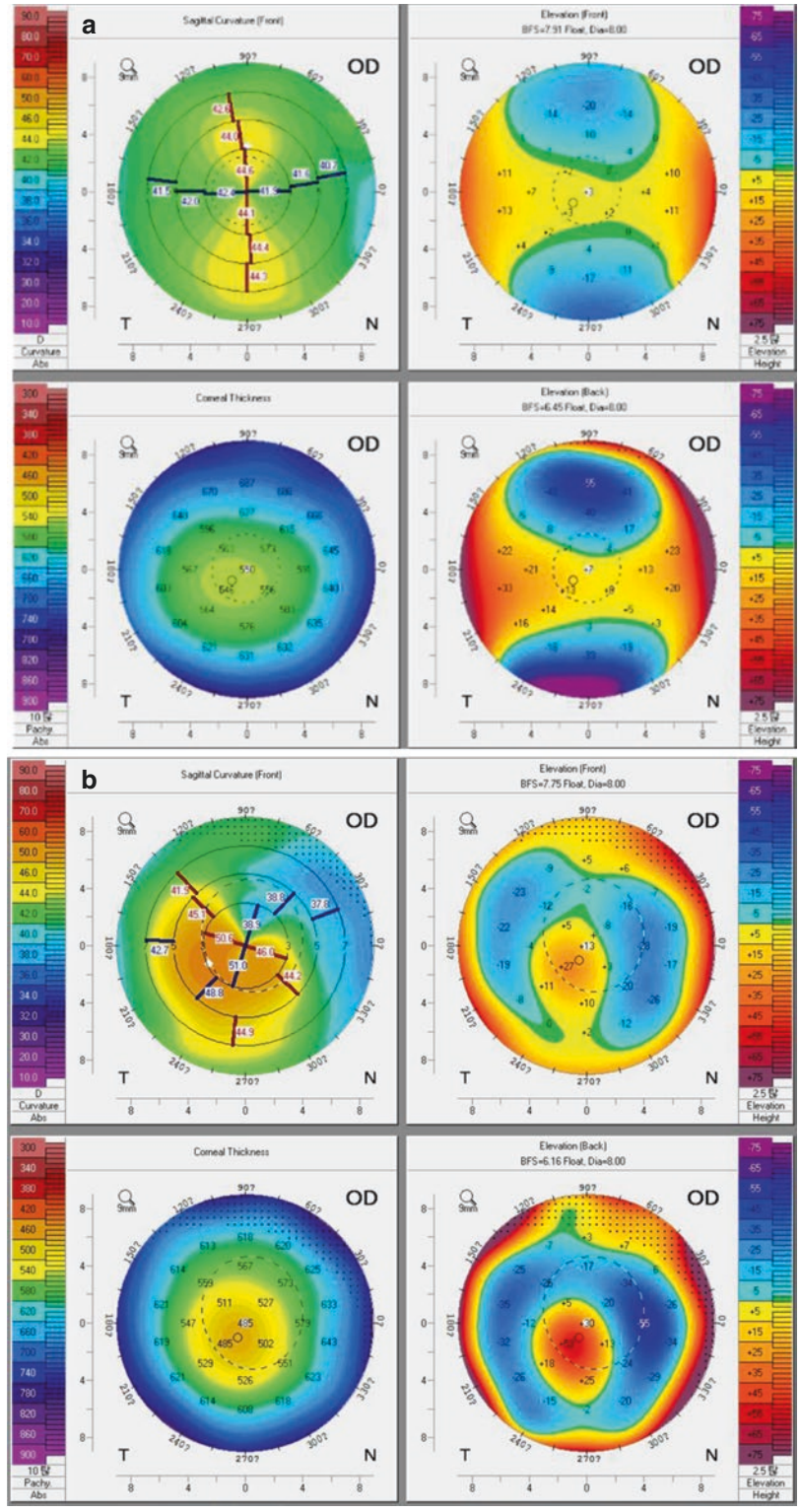

Fig. 9.14 Corneal topographic quadrant maps. Sagittal curvature, elevation (front and back), corneal thickness map. **a** is normal cornea, **b** shows keratoconus with posterior elevation

Table 9.7 Wavefront aberrometry according to measurement principle

Type	Product name	Manufacture company
Hartmann-Shack	KR-1 W®	Topcon
	WaveScan™	Abbott
Tscherning	WaveLight®	Alcon
Ray tracing	i-trace®	Tracey Technology
	Galilei™G6	Zeimer
OPD scan	OPD scan III®	Nidek

9.10.1 Method

Place the center of the cornea in the center of the instrument, and adjust the patient's jaw height.

Let the patient look at the red light in the center of the laser. Scan the eye by projecting 256 lasers.

We analyze wavefront aberration considering color code, Zernike polynomial aberration, root mean square, retinal image quality, and pupil size.

9.10.2 Judgment

The third and fifth orders in the high-order aberration are asymmetric aberrations, and the fourth order and sixth order are symmetric aberrations. The third-order coma aberration and the fourth-order spherical aberration can be checked first, and the remaining aberrations can be referred to.

9.10.2.1 Interpretation of Color Code Map

It is useful to know the meaning of color in the wavefront aberration map such as the various colors provide information to one eye in corneal topography. The main aberration of the eye, that is, the refractive power, can be known through the total wavefront aberration map. The blue color is myopia, the color of the red is hyperopia, and the color of green is close to the emmetropia.

9.10.2.2 Zernike Polynomials and Naming of Aberrations

It is a polynomial introduced to efficiently express the wavefront aberration and a standard form of wavefront aberration using a function. It is designed to correspond well with the previously known order aberrations with special functions. There are three ways to refer to each Zernike polynomial, denoted by order, name, and number (Fig. 9.15).

The wavefront aberration is classified into piston, tilt, defocus, astigmatism, coma, and spherical aberration. The piston is a zero-order aberration with a constant phase shift, and tilt is tilted with respect to the *x*- and *y*-axes as the first-order aberration. Defocus and astigmatism correspond to the second-order aberration with the least aberration of the actual aberrations and can be corrected with spherical and cylindrical lenses. Higher-order aberrations are called higher orders, coma and trefoil corresponding to the third-order aberrations, and spherical aberration, quatrefoil, and secondary astigmatism corresponding to the fourth-order aberrations.

9.10.2.3 Zernike Coefficients and RMS (Root Mean Square)

We use the Zernike coefficient and the root mean square (RMS) as a measure of order intensity. In the case of defocus and astigmatism as second-order aberrations, the intensity is expressed using diopter. The unit for the third-order higher-order aberration is the root mean square (RMS) associated with the Zernike coefficient.

9.11 Confocal Microscopy

It has a high resolution of about 1.4 times higher than that of conventional optical microscopes, has a deep focal depth, and is capable of various images processing using a computer. Usually, the reason why the image is blurred in the optical microscope is that the light other than the focal plane is not processed by the illumination process. However, the confocal microscope is capable of three-dimensional observations of relatively thick materials and living cells that were difficult to observe with conventional microscopes until now.

Light from the light source is emitted and compressed by the objective lens and then irradiated onto the sample. At this time, the laser light is compressed to a small point through the objective lens again by the reflected light coming from

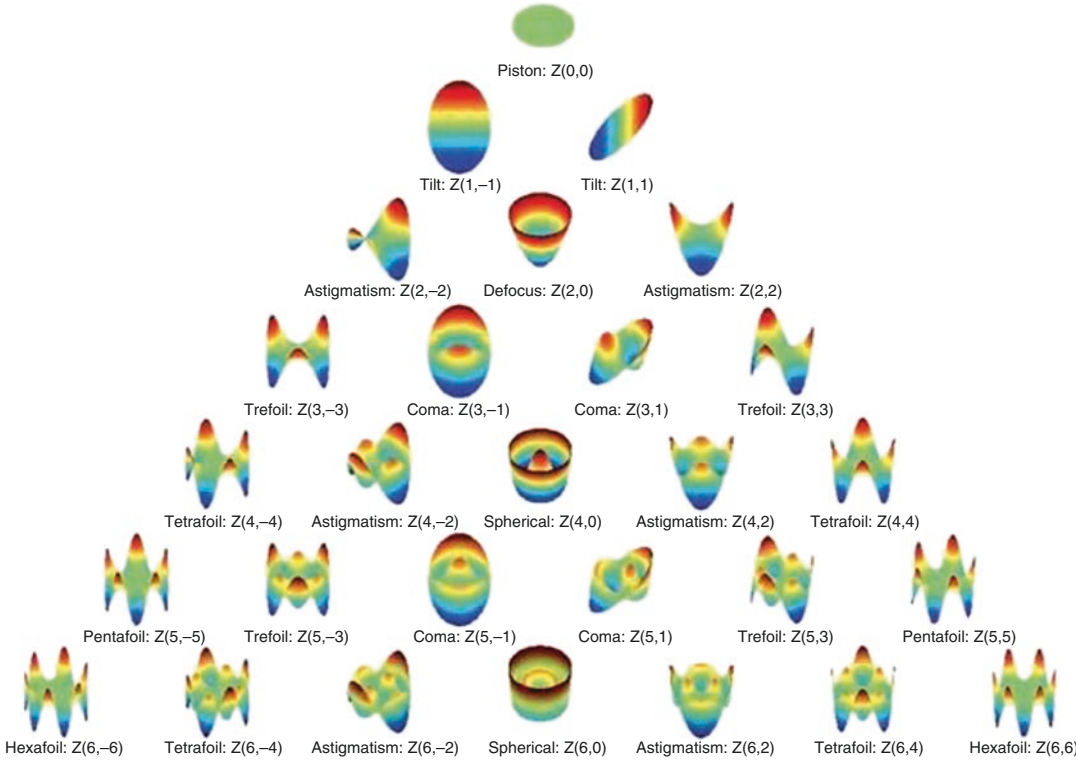

Fig. 9.15 Zernike Pyramid Periodic Table. Each Zernike polynomial is denoted by order, name, and number

the sample in the compression focus, only the light of the face that is exactly in focus is passed through the position. Since the image is electrically signalized, image processing such as image quantification by a computer, stereoscopic reconstruction such as contrast, and overlapping of images can be facilitated. It mainly consists of a light source, a microscope, a computer for control analysis, and a monitor.

It is useful to diagnose normal corneal structure, wound healing process after corneal refractive surgery, effect of contact lens, abnormality of tear film, keratoconus, corneal dystrophy, acanthamoeba keratitis, herpes keratitis, corneal trauma, and drug toxicity to the cornea.

9.11.1 Method

Place the center of the cornea in the center of the instrument, and adjust the patient's jaw height.

First, 2% proparacaine is applied to the eyes, and immersion gel is applied to the end of the tip to contact the cornea. Automatically moving the epithelium and endothelial layer of the cornea and imaging the tissue 3–4 times. The shape of the cell can be known through the necessary images or information. Using a Z-scan, the thickness of the cornea can be measured by focusing on the whole cornea.

9.11.2 Judgment

In the corneal epithelium of normal subjects, epithelial surface cells with bright nuclei (Fig. 9.16) (a), wing cells with constant cell boundaries (b), and nerve plexus under the epithelial layer (c) were observed. In Bowman's membrane, there is a wrinkle-like shade.

The anterior part of the corneal stromal cell layer shows a nuclear morphology of the polygon. In the middle region, the distribution of nerves appears (d). The closer to the endothelial cell layer, the more prominent a nucleus in the parenchymal layer of the posterior cornea. The endothelial cell layer has a hexagonal monolayer of endothelial cells (e).

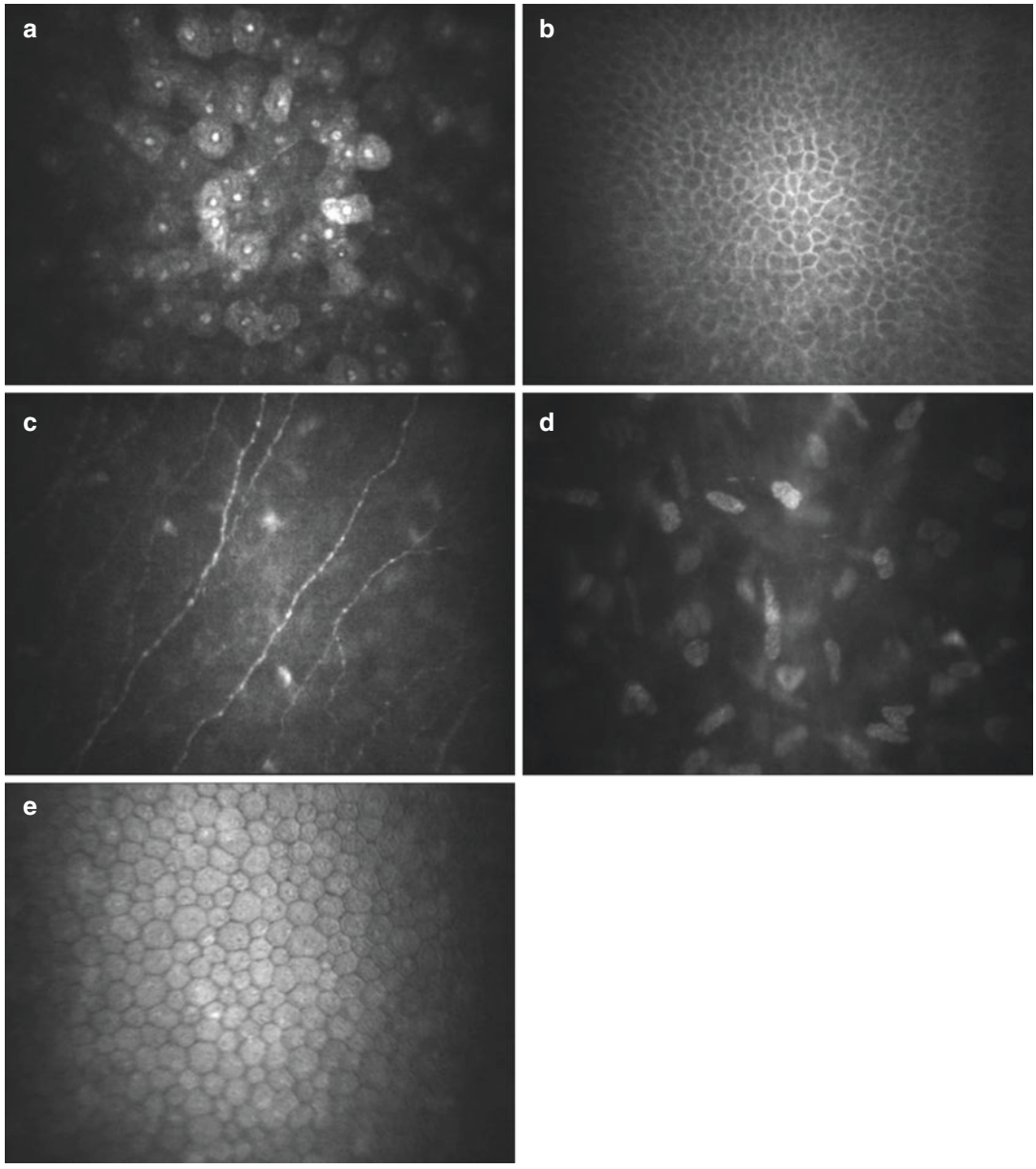

Fig. 9.16 Confocal microscopy of normal cornea. (**a**) Corneal epithelium surface layer. (**b**) Wing cell layer. (**c**) Subepithelial nerve plexus. (**d**) Corneal stroma. (**e**) Corneal endothelial layer

In the case of posterior polymorphous corneal dystrophy, abnormalities of the Descemet's membrane and corneal endothelial layer of the cornea are the main lesions. A band- or blister-like hyporeflective image with a diameter of 6–159 μm is observed in the posterior part of the corneal tissue. Band-like lesions on adjacent corneal endothelial cells (Fig. 9.17a) and the lesion behind the stromal layer (Fig. 9.17b) can be seen. The nerve plexus distributed in the corneal tissue is thickened. In the case of corneal endothelial cells, pleomorphism is not a typical form, but polymegathism is a common confocal microscopic finding.

In Fuchs' corneal dystrophy, the lesion is the corneal endothelial cell layer, and abnormal

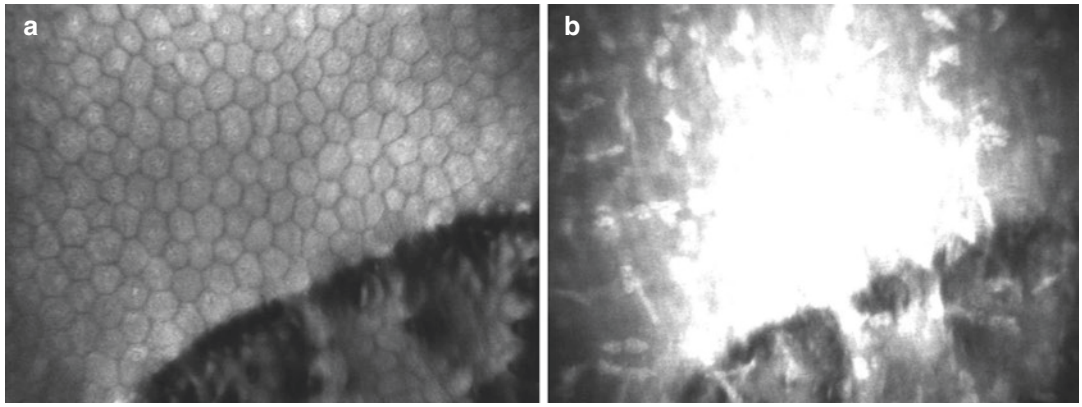

Fig. 9.17 Confocal microscopy of posterior polymorphic corneal dystrophy. (**a**) Corneal endothelial layer. (**b**) Posterior corneal stroma

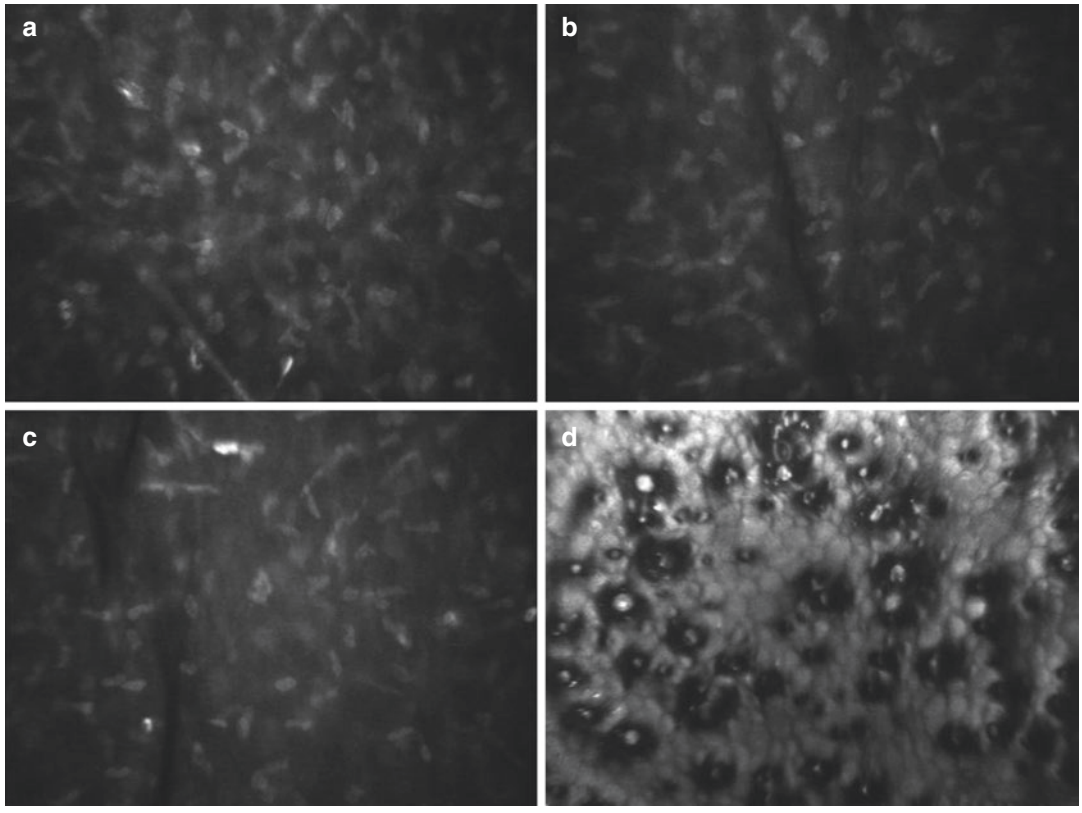

Fig. 9.18 Confocal microscopy in Fuchs' corneal dystrophy. (**a**) Subepithelial nerve plexus. (**b**) Anterior corneal stroma. (**c**) Posterior corneal stroma. (**d**) Guttata of corneal endothelium

findings are observed mainly in the corneal posterior pole and endothelial cell layer. Corneal epithelium is normal finding, but nerve plexus of anterior portion of the corneal stroma is thicker than normal (Fig. 9.18a), dense granular form was observed sporadically, and a wrinkled form on the vertical line was observed in some cases (b). The corrugation shape becomes

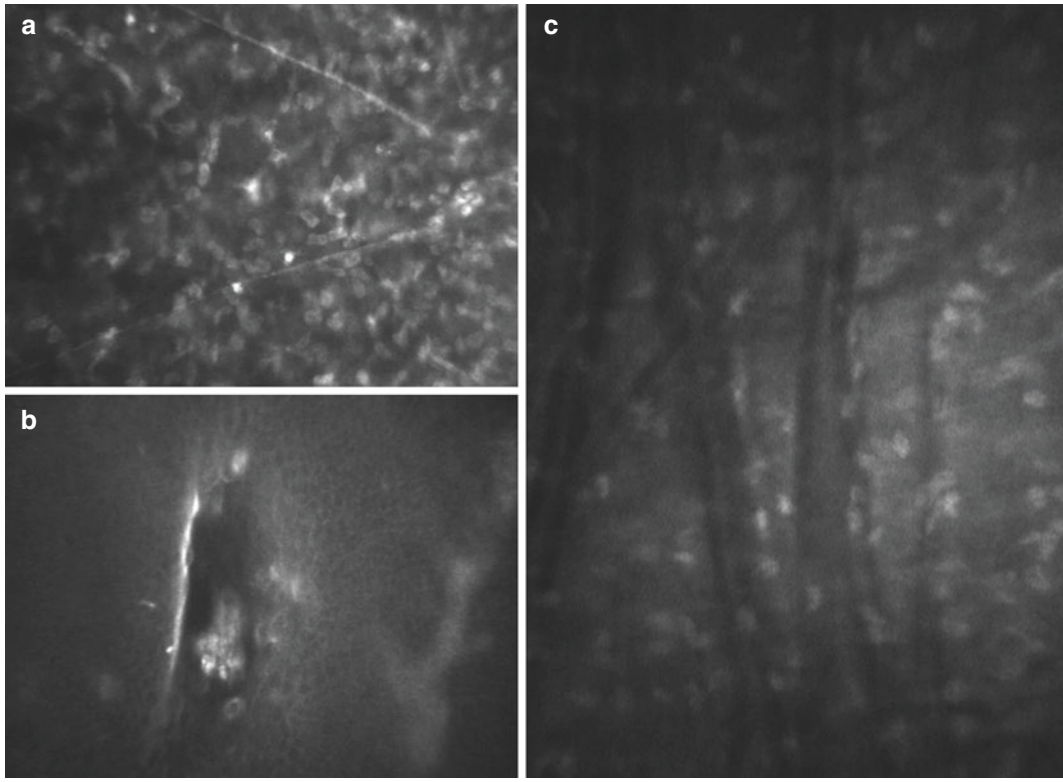

Fig. 9.19 Confocal microscopy of keratoconus. (**a**) Subepithelial nerve plexus. (**b**) Bowman membrane. (**c**) Corneal stroma near the Descemet's membrane

clearer toward the posterior pole of the corneal stroma (c), and corneal endothelium shows guttata (d).

Confocal microscopic findings of the keratoconus show that the surface of the corneal epithelium is somewhat obscure and elongated shape, and the nerves subepithelial layer of the wing cell layer are somewhat thicker than normal (Fig. 9.19a). Bowman's membrane shows a dark shadow of larger shape than a normal wrinkled structure. That is, the ruptured form of the Bowman's membrane (b). In the corneal parenchymal cells, near the epithelial layer, the shade of the nucleus increases, the cell boundary becomes unclear, and the reflectivity increases in the parenchyma area. The shape of the nucleus becomes clearer toward the deep part, while as the number of cells decreases, vertical line of Vogt's striae are observed around the Descemet membrane (c). However, the endothelial cell layer maintains a normal hexagonal mosaic shape without any significant change, and no unusual changes are seen.

9.12 Fluorophotometry

In the case of using a fluorophotometry, it is possible to measure the degree of damage to the functional barrier function of corneal endothelial cells which cannot be observed by clinical examination or a specular microscope. That is, the endothelial cell damage and recovery process, which is not correlation to morphological or functional damage, may be determined by measuring the permeability of the corneal endothelial cells. The method of evaluating corneal permeability with a fluorophotometry using a fluorescent material is highly reliable and can provide quantitative measurement of the function of the tight junction between the corneal endothelial cells, thus providing valuable information related to the corneal layer. However, the spatial resolution for distinguishing the fluorescence of the cornea and the tear layer is insufficient and takes a long time for measurement. There is also a disadvantage that the change in barrier function of the periphery of

the cornea cannot be measured. In addition, depending on the amount of tear film or concentration of fluorescent material, which varies from person to person, the measured value according to the corneal permeability increases, resulting in a large standard deviation. For those with low permeability, it is advisable to increase the concentration of the fluorescent eye drops to increase the fluorescence of the cornea to a measurable extent.

This is useful for confirming changes in barrier function of corneal epithelium and endothelium following wound healing process after corneal refractive surgery, changes in blood aqueous barrier after cataract surgery, follow-up of intraocular surgery, and response of blood aqueous barrier to drugs for inflammation treatment.

To measure the endothelial permeability of the cornea, 50 μl of 10% fluorescent material was applied to the lower conjunctival sac four times at intervals of 5 min, and the fluorescence intensity of the corneal stroma and the anterior chamber was measured using a fluorophotometry. To measure the permeability of the epithelium layer, 20 μl of 2% fluorescence was applied to the lower conjunctival sac, and the corneal fluorescence was measured 45 minutes later.

This is a method of examining the permeability of corneal endothelial cells by measuring the exchange of fluorescent materials between the cornea and the aqueous humor; the mean corneal endothelium permeability was measured as 3.48×10^{-3}/min in normal and 3.75×10^{-3}/min in the presence of diabetes. The corneal endothelium permeability measured at 4 days post-cataract surgery increased by 61.88% in normal subjects but increased by 118.13% in patients with diabetes, and the corneal permeability was significantly increased in diabetic patients.

9.12.1 Meibomian Gland Dysfunction (MGD) Assessment

Meibomian glands secrete oily components called meibum that form the lipid layer of the tear film. The lipid layer of the tear film prevents evaporation of the tear fluid, and thus meibomian gland dysfunction (MGD) mainly causes evaporative dry eye. So It is important to adequate evaluate the morphology and function of meibomian glands.

9.12.1.1 Lid Margin Telangiectasia (LMT) Score

There are about 30–40 glands in upper lid margin and fewer (20–40) in the lower lid margin, and the vascular zone, which can be observed with telangiectasia, is the zone from the mucocutaneous junction near the meibomian gland orifice to the eyelash root. It is easier to observe the telangiectasia in the upper because the vascular zone in the upper eyelid is wider than in the lower eyelid. The LMT was scored based on the degree of telangiectasia at the upper eyelid margin, with 0 point in the absence of capillary dilatation, 1 point in the case of mild capillary dilatation, 2 points in the case of moderate capillary dilatation, and severe capillary dilatation defined as 3 points (Fig. 9.20).

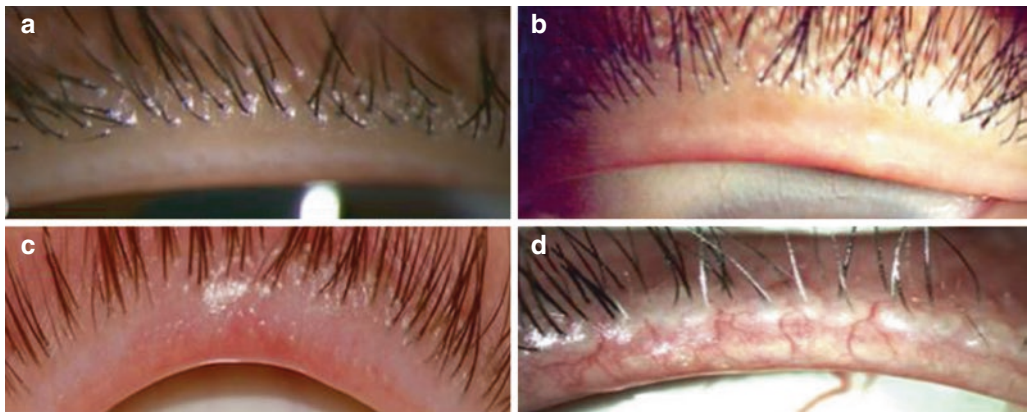

Fig. 9.20 Upper lid margin telangiectasia score. **a** shows no capillary dilatation as 0 point. **b** shows 1 point in the case of mild capillary dilatation. **c** shows moderate capillary dilatation as 2 points. **d** shows severe capillary dilatation as 3 points

9.12.1.2 Meibomian Gland Secretion (MGS) Score

For measurement of MGS, we pressed softly skin and palpable conjunctiva near the center of upper lid margin using a sterilized cotton swab. MGS is defined as 0 point for secretion of clear secretion, 1 point for turbid secretion, 2 points for granular secretion, and 3 points for solid form secretion from meibomian orifice (Fig. 9.21).

9.12.1.3 Meibography

Meibography is a technique that uses transillumination biomicroscopy of the everted eyelid with infrared imaging. This noninvasive meibography system enabled us to observe the entire meibomian gland, from the nasal part to the temporal part of the upper and lower eyelids within 1 min. A slit-lamp microscope equipped with a charge-coupled device camera and infrared-pass filter visualized the meibomian gland as a bright area. The normal appearance of the meibomian glands using this technique is shown in Fig. 9.22.

This system clearly evaluates various morphological changes in meibomian glands such as dropout, truncation, dilation, or distortion related to ocular surface diseases (Fig. 9.23). It can be classified, so-called meiboscore, according to whether it is partial or complete loss of meibomian glands for each eyelid. In patients with MGD, the meiboscore was useful for diagnosing MGD.

9.12.1.4 Interferometry

Interferometry of the tear film lipid layer is useful in screening and evaluating dry eye. It allows noninvasive grading of the tear film lipid layer and estimation of its thickness on the basis of the observed interference colors.

The LipiView Interferometer compensates for lid thickness variations providing a normalized and uniform brightness across the surface. It is a highly accurate instrument initially developed to precisely measure tear lipid layer thickness. Then it calculated on a frame-by-frame basis and plotted for ~1 billion data points per eye. The results are then displayed and are available for printout (Fig. 9.24).

It also enables practitioners to evaluate blink characteristics such as blink rate and the presence of incomplete blink. The most recent version of the system has added a high-resolution infrared meibography component. Although most often used in combination with the therapeutic LipiFlow system, LipiView is now available as a

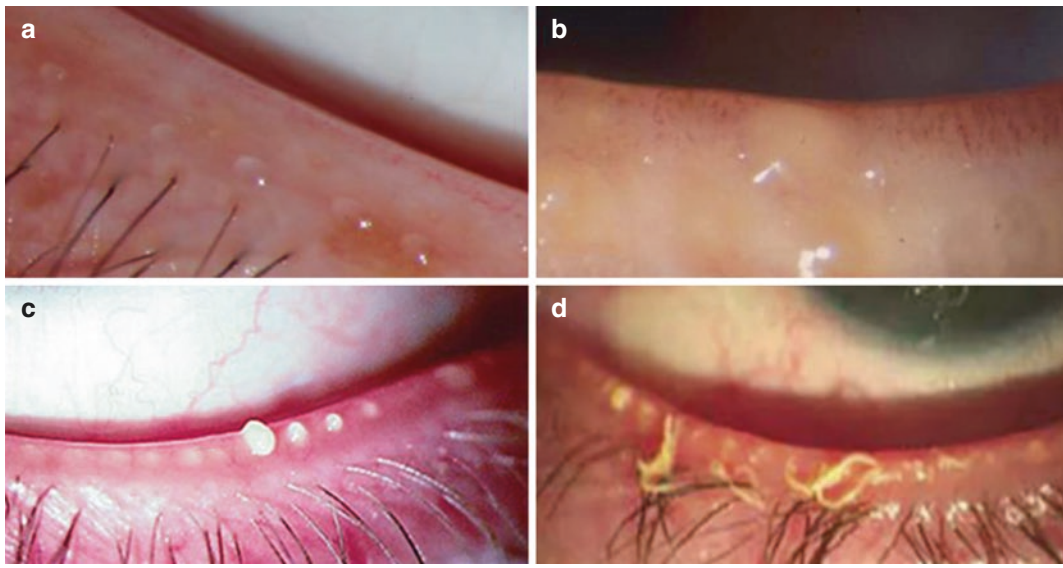

Fig. 9.21 **a** is clear meibum secretion which is defined as 0 point. **b** shows turbid meibum secretion as 1 point. **c** is 2 points for granular secretion. **d** shows 3 points for solid, tooth paste-type meibum secretion

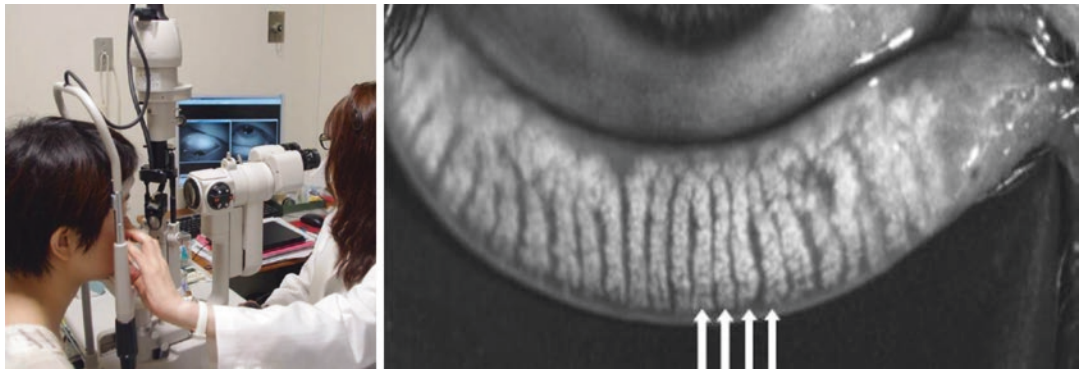

Fig. 9.22 The meibography system and normal appearance of the meibomian glands of lower lid using noninvasive meibography (white arrows)

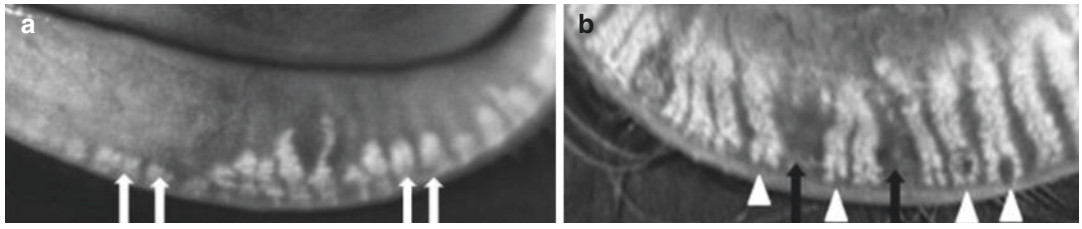

Fig. 9.23 **a** shows meibomian glands dropout (white arrows) and **b** shows gland truncation (black arrows) with duct dilatation (white arrows head)

Fig. 9.24 LipiView results are displayed in a frame-by-frame graphical representation that shows fluctuations in lipid thickness measurements between each blink

standalone diagnostic instrument. The system utilizes interferometry to measure lipid layer thickness down to the submicron level of accuracy. It further incorporates what the manufacturer terms dynamic meibomian imaging (DMI) to produce detailed images of the meibomian glands in order to demonstrate ductal gland dilation plus gland atrophy and dropout, which are common to MGD.

Dynamic changes in the interference pattern have also been studied. Figure 9.25 illustrates the interferometric patterns recorded using the tear interferometer. These techniques have been used to measure tear lipid film thickness in nor-

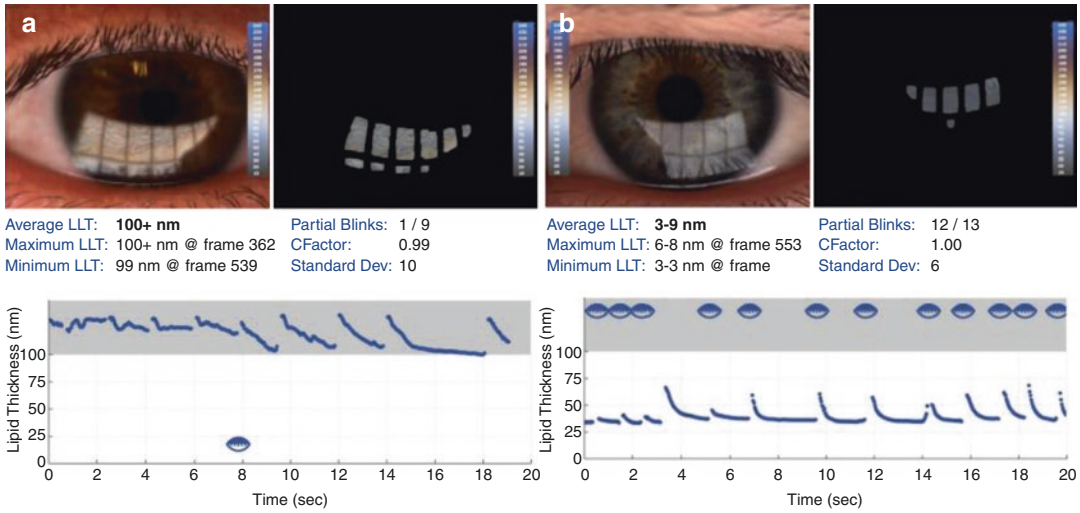

Fig. 9.25 Tear lipid layer thickness patterns as seen with interferometry. **a** is normal tear film lipid thickness that is over 100 nm. **b** shows lack of lipid layer, its lipid thickness under 40 nm

mal subjects and in disease, with fairly good agreement between investigators. The simplicity and noninvasiveness of interferometry and its direct relationship to the amount of lipid on the tear film make it an attractive technique that may offer opportunities to relate lipid thickness to evaporation. The tear interferometer patterns are characterized by lack of the aqueous layer, lack of both the aqueous and lipid layers, and a lack of the lipid layers. Therefore, the evaluation of the function using them is considered to be more reliable than the simple lipid layer thickness.

Suggested Reading

Arita R, Suehiro J, Haraguchi T, et al. Topical diquafosol for patients with obstructive meibomian gland dysfunction. Br J Ophthalmol. 2013;97(6):725–9.

Benson WH, Lanier JD. Comparison of techniques for culturing corneal ulcers. Ophthalmology. 1992;99:800–4.

Bourne WM, Kaufman HE. Specular microscopy of human corneal endothelium in vivo. Am J Ophthalmol. 1976;81(3):319–23.

Cavanagh HD, Shields W, Jester JV, et al. Confocal microscopy of the living eye. CLAO J. 1990;16:65–73.

Dingeldein SA, Klyce SD. The topography of normal corneas. Arch Ophthalmol. 1989;107:512.

Feenstr RPG, Tseng SCG. Comparison of fluorescein and rose Bengal staining. Ophthalmology. 1992;99:605–17.

Foulks GN, Bron AJ. Meibomian gland dysfunction: a clinical scheme for description, diagnosis, classification, and grading. Ocul Surf. 2003;1(3):107–26.

Kim J, Foulks GN. Evaluation of the effect of lissamine green and rose Bengal on human corneal epithelial cells. Cornea. 1999;18(3):328–32.

Kitzmann AS, Winter EJ, Nau CB, et al. Comparison of corneal endothelial cell images from a noncontact specular microscope and a scanning confocal microscope. Cornea. 2005;24(8):980–4.

Klais CM, Buhren J, Kohnen T. Comparison of endothelial cell count using confocal and contact specular microscopy. Ophthalmologica. 2003;217:99–103.

Langston DP, Foulk GN. Cornea and external disease. Boston: Little Brown; 1991.

Maeda N, Klyce SD, Smolek MK, et al. Automated keratoconus screening with corneal topography analysis. Invest Ophthalmol Vis Sci. 1994;35:2749–57.

Mannis MJ, Holland EJ. Cornea. 4th ed. Philadelphia: Elsevier; 2005.

Mathers WD, Daley T, Verdick R. Video imaging of the meibomian gland [letter]. Arch Ophthalmol. 1994;112(4):448–9.

Mishima S. Corneal thickness. Surv Ophthalmol. 1968;13:57–96.

Nemoto Y, Arita R, Mizota A, et al. Differentiation between chalazion and sebaceous carcinoma by noninvasive meibography. Clin Ophthalmol. 2014;8:1869–75.

Spencer W, Zimmerman L. Conjunctiva. Philadelphia: WB Saunders; 1985.

Swartz T, Marten L, Wang M. Measuring the cornea: the latest developments in corneal topography. Curr Opin Ophthalmol. 2007;18:325–33.

Wise RJ, Sobel RK, Allen RC. Meibography: a review of techniques and technologies. Saudi J Ophthalmol. 2012;26(4):349–56.

Pupil Exam

10

Jae Ho Jung

Pupil light reflex is a reflex that controls the diameter of the pupil, in response to light stimulus. A higher intensity of light makes miosis (pupil constriction), whereas a lower intensity makes mydriasis (pupil dilatation). Neural pathwau of pupil reflex is composed of afferent fibers from the retina to the Edinger-Westphal (EW) nucleus of the oculomotor nucleus and efferent fibers from the EW nucleus to the pupillary sphincter. The afferent fibers travel through the retina, optic nerve, optic chiasm, and optic radiation and are separated before lateral geniculate nucleus and connected to EW nucleus in the dorsomedial side of the oculomotor nucleus complex.

Efferent fibers are divided into parasympathetic pathways and sympathetic pathways. The parasympathetic pathway starts from the EW nucleus and travels along with the oculomotor nerve fibers, and after making a synapse at ciliary ganglion, it becomes a short posterior ciliary nerve and distributes to the pupil sphincter and ciliary muscle which are responsible for inducing pupil contraction. The sympathetic pathway started from the hypothalamus and goes down to the level of the eighth cervical vertebrae and the second thoracic vertebrae along the spinal cord through the midbrain, pons, medulla, and lateral tegmentum. And it goes up again to the superior cervical ganglion and travels along the internal carotid artery; finally, it reaches into the cavernosu sinus. It travels along the abducens nerve in the cavernous sinus and next travels along the nasociliary nerve which is the first branch of the trigeminal nerve. Then, it becomes the long ciliary nerve and distributes to the pupil dilator muscle and induces pupil dilation (Fig. 10.1).

Before testing pupils, the patient should be instructed to remove patient's glasses. Examiner has to make a relexed and comportable enviroment. A distant, non-accommodative target two to three lines larger than the patient's uncorrected visual acuity should be used as target. If a target is too small for the patient might use accommodation, with assocaited with pupillary constriction. This accommodation may contaminate test results.

10.1 Examination of Pupil Shape, Size, and Location

10.1.1 Methods

- First, the red reflex provided by from the direct ophthlamopscope can be useful when comparing the two eyes, also helpful evaluate general shape, size and location of pupil.
- Although pupil testing using direct ophthalmoscope or pupillometer provides gross

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observations, the slit lamp cab ne hlepful to exmine the pupil and iris in more detail.

- Measurment of pupil size should be under normal room light conditions to the nearest 0.5 mm using a millimeter ruler or Haab pupillometer (Fig. 10.2). To avoid stimulating accommodative pupil constriction, the pupillometer should be held away from the visual axis of the patient.

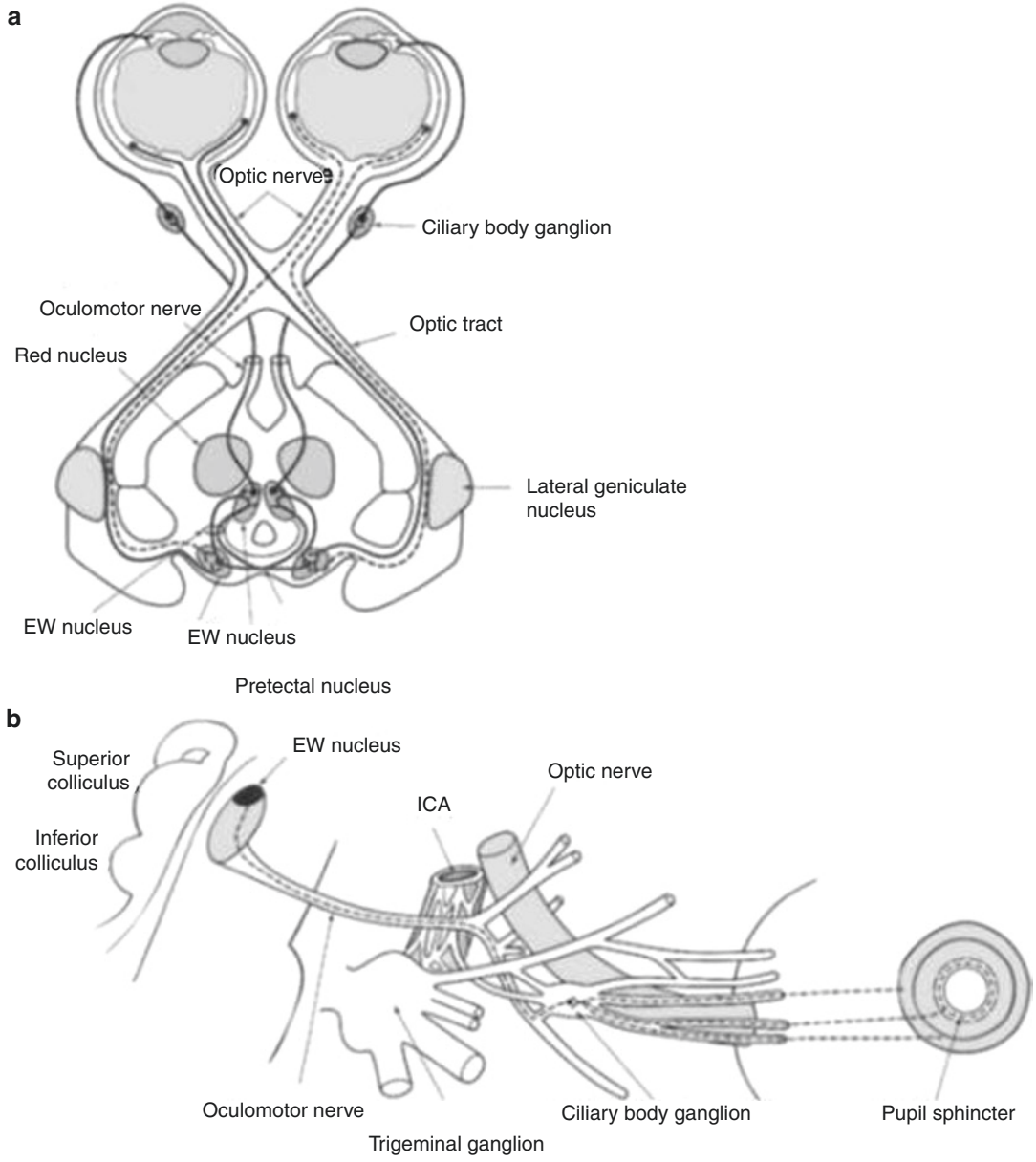

Fig. 10.1 Pupil light reflex pathway. (**a**) Pupil light reflex. (**b**) Parasympathetic pathway of the pupil sphincter. (**c**) Sympathetic pathway of the pupil dilator

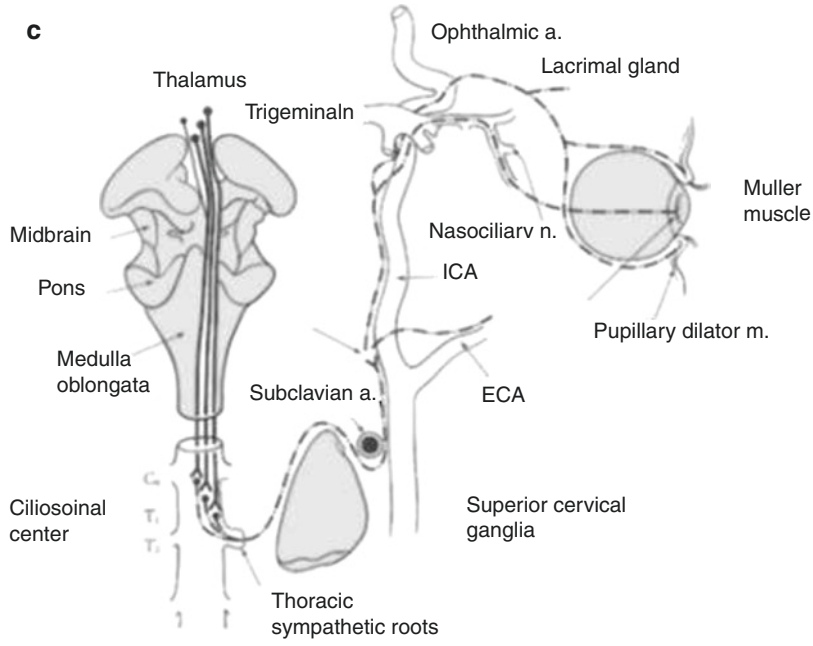

Fig. 10.1 (continued)

Fig. 10.2 Haab pupillometer

10.1.2 Results

The normal pupil diameter is 2–4 mm, and it is defined as anisocoria when the pupil diameter is 4 mm or more and the pupil contraction is 2 mm or less. The difference between both pupils is within 1.0 mm. The iris (iris crypt) or iris collarette should be clearly visible and should be suspected of corneal opacity, anterior inflammation, and iris atrophy if not visible. If the color of the bilateral iris is different, the congenital anomalies of the dilated muscles such as heterochromia of iris, uveitis, tumor, or congenital Horner's syndrome should be suspected. When the foreign substance with iron is in the iris, the color turns into brown.

10.2 Pupillary Reaction Test

10.2.1 Anisocoria test

Observing the difference in pupil size between the two eyes under dim light and bright light.

10.2.1.1 Methods

- Let the patient see the distant target under normal room light.

- Change room light intensity, and observe any puil size difference occur under dim light or bright light.

10.2.1.2 Results

20 percent of normal had physiologic pupil size difference, the difference less than 1.0 mm. However, the different pupil size should be addressed pathologic in nature or pharmacologic etiology. If the amount of anisocoria is the same in both the bright light and the dim light, then the anisocoria os physiologic. If there is greater anisocoria in the bright light, the larger pupil is not constrict, examiner should consider parasympathetic pupil proble. However, there is a greater amount of anisocoria in the dim light, possible causes should be address syspathetic nerve issue, such as Horner's syndrome. Each disease has characteristic pupil changes according to illumination (Fig. 10.3, Table 10.1).

10.2.2 Pupillary reaction to light test

The pupillary light reflex consists of both an afferent and efferent pathway. Under normal conditions, when light is placed into one eye, pupil will constrict and a consensual pupil constriction in the oppsite eye.

10.2.2.1 Methods

Direct pupillary reaction to light. Observing a pupil's direct and consensual responses to light, the test should be performed under normal to dim illumination with fixing the distance non-accommodative target.

Indirect pupillary reaction to lgiht. Evaluate consensual response of pupil constriction in the oppsitie eye. Direct and indirect pupillary light reaction (Fig. 10.4).

- Each procedures should be repeated several times and in the other eye, while observing and grading the magnitude of changes and rapidity of change. The responses are recorded as grade 4 (prompt response) to 1 (delayed response sluggish) and observing whether the degree of pupil contraction is complete or incomplete.

10.2.2.2 Results

By the pupil's reaction, we can see whether the disorder of visual pathway is afferent or efferent. The normal response is when the light is shined, the pupil is contracted, and then the pupil dilates slowly. In the presence of an afferent pupillary movement disorder, if the light is reflected in the eye with disorder, the pupil contraction does not occur due to the disappear-

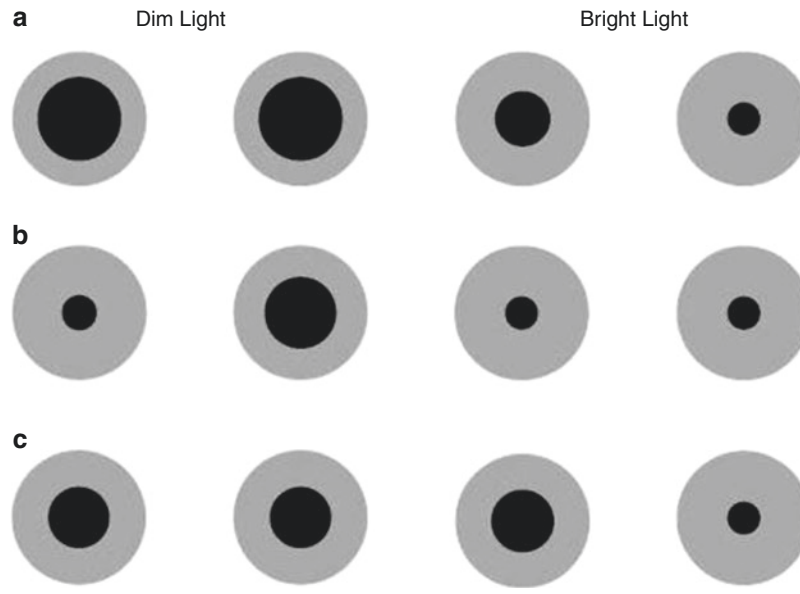

Fig. 10.3 Pupil anisocoria in dim and bright light condition. (**a**) Physiologic. (**b**) Horner's syndrome on the right eye. (**c**) Third nerve palsy on the right eye

Table 10.1 Common causes of anisocoria and its differential diagnosis

	Pupillary dilator	Tonic pupil (early)	Third nerve palsy	Horner's syndrome
In normal light				
Dim light				
Bright light				
Accommodation				
Pilocarpine	2% pilocarpine	Delay response 0.125% pilocarpine	2% pilocarpine	
Other features		Pupillary spasm Loss of tendon reflex	Exotropia ptosis pain (sometimes)	Partial ptosis

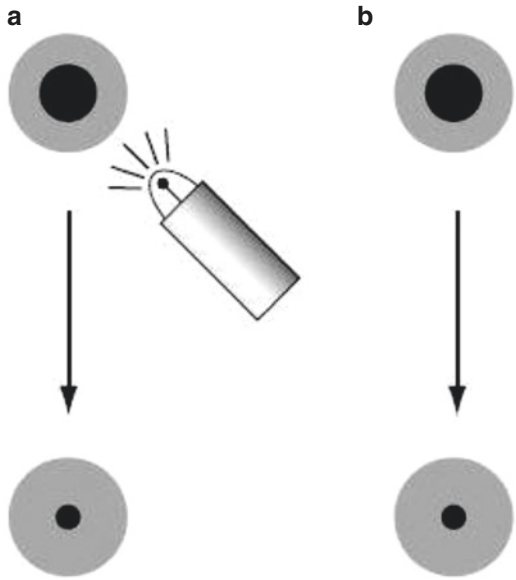

Fig. 10.4 Test Method of pupillary reaction to light. (**a**) Direct light reflex. (**b**) Indirect light reflex

ance of the direct and indirect reflex. But direct and indirect reflexes of the pupil occur when the light reflects in the normal eye. In these cases, one eye suspects extensive retinal disease or optic nerve disease. In the presence of an efferent pupil movement disorder, both direct and indirect reflexes within the eye with disorder are lost or reduced (Fig. 10.5).

10.2.3 Swinging Flashlight Test

The purpose of the swinging flashlight test is to compare the strength of the direct pupillary response with that of the consensual response in the same eye.

10.2.3.1 Methods

- In a half-dark room, let the patient watch over a distance non-accommodative target.
- The light beam is directed in the right eye and held for two ~ three seconds, then qucikly moved to the left eye and held for two ~ three seconds. This procedure should be repetaed for at least three to four cycles. When moving the light beam between the eyes, use a slight u-shaped motion, making sure to avoid the transilluminator crossing the patient's visual axis, which may stimulate accommodation. It is critical that the magnitude, angle and duration of the light be kept the equal for each eye (Fig. 10.6).

10.2.3.2 Results

It is an objective and sensitive test that can detect the difference of afferent visual transduction between the left eye and the right eye. A relative afferent pupillary movement disorder is defined as a pupillary escape in which abnormal

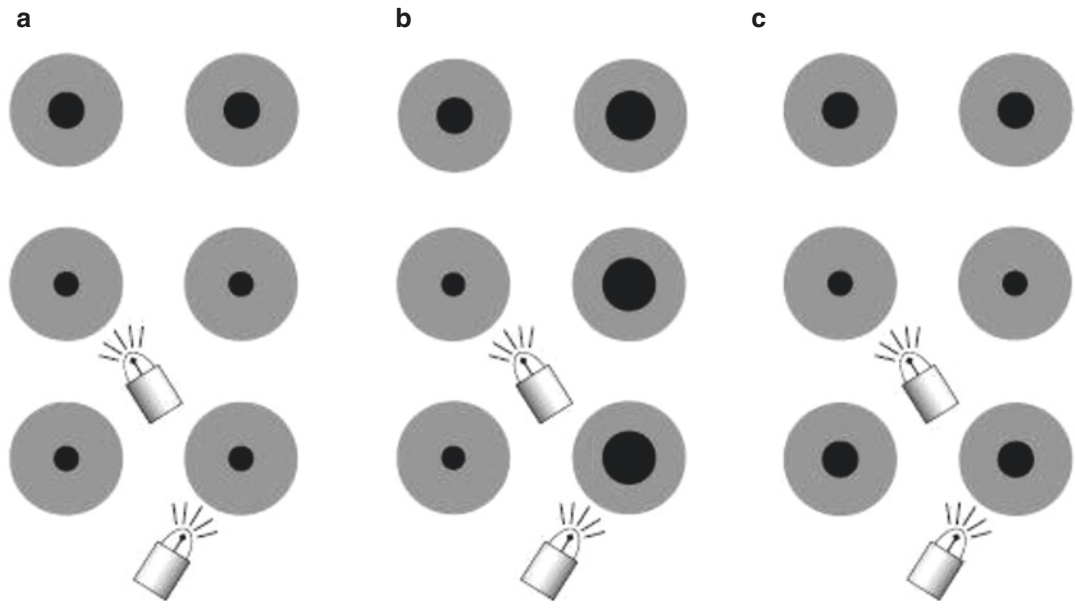

Fig. 10.5 Interpretation of the light reflex test. (**a**) Normal. (**b**) Abnormal efferent pupil movement (left eye). (**c**) Abnormal afferent pupil movement (left eye)

pupil dilation occurs when an abnormal pupil is alternately illuminated within the normal pupil. It is important to observe pupillary reaction time and compare the difference in pupillary reaction between the two eyes. At this time, the abnormal eye is denoted by RAPD (+). In this case, visual pathway disturbance before the lateral geniculate nucleus is strongly suspected, and sometimes it can be observed even in a variety of retinal disorders or amblyopia.

Among the quantitative evaluation methods of relative afferent pupillary movement disorder, there is a method using neutral density filters. After the diagnosis of relative afferent pupillary movement disorder by alternate light test, the neutral filter was sequentially added to the normal eye by 0.3 log unit neutral density (ND filter), and alternate light test is performed until the relative afferent pupillary movement disorder disappeared. Observe whether there is a defect.

A neutral filter between 0.1 log unit and 2.0 log unit is most useful. The use of a neutral filter allows quantification of afferent pupillary dysfunction and is consistent with the results of visual field tests. Therefore, it is possible to compare the progress in patients who are not able to perform visual field tests or in patients who are being treated. In addition, amblyopia patients with RAPD with 0.6 log units or more are more likely to have underlying disease and are useful in distinguishing ischemic or nonischemic central retinal vein occlusion. Another way is to use ten neutral density filters arranged in a circle on a plastic sheet. A patient's visual acuity is not necessarily correlate with the degree of RAPD, however it has correlation with visual field. RAPD do not cause anisocoria.

10.3 Near Reflex and Accommodation

Convergence, accommodation, and pupil constriction occur together when we look at the near object. So we can observe the pupil shape with this principle. The test method is to observe whether pupil contraction occurs or not when the patient first looks at distant object and then looks at the near 20 cm object (Table 10.2). This is rarely added to routine pupil test becuase the near reflex is always present when the direct light

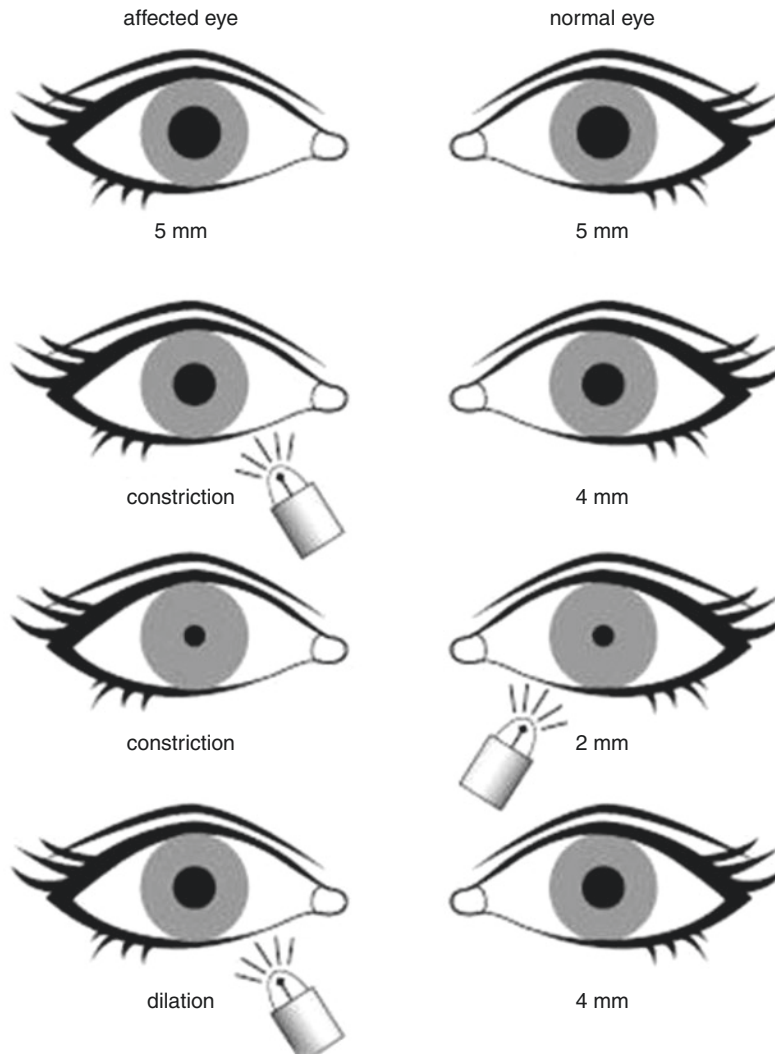

Fig. 10.6 Swinging flashlight test

Table 10.2 Causes of light near dissociation

Cause	Location	Mechanism
Loss of afferent light reflex	Anterior optic tract (the retina, optic nerve, optic chiasm)	Damage of the retina or optic tract
Loss of light reflex to the pretectal area of EW nucleus	Midbrain tectum	Infection (Argyll-Robertson pupil)
Tonic pupil	Ciliary ganglion	Aberrant regeneration of pupillary sphincter by control neuron
PRP, cryotherapy, orbital surgery	Short ciliary nerve, post-ciliary ganglion	Aberrant regeneration after damage of the short ciliary nerve or post-ciliary nerve
Third nerve aberrant regeneration	Third nerve tract	Aberrant regeneration of pupillary sphincter by control neuron or EOM neuron
Peripheral neuropathy	Short ciliary nerve, post-ciliary nerve, ciliary ganglion	Axonal loss

reflex is intact. In other words, if a normal direct reaction to light is observed, then there is no need to checl the near response. Light-near dissociation is a phenomenon in which pupil contraction occurs more strongly in the near reflex than in the light reflex, because the reflex nerve is located more ventral than the reflex nerve.

10.3.1 Methods

Have the patient look at distant places at normal brightness.

Have the patient watch closely the target (pencil or examiner's fingers), slightly below the examiner's eye level, toward the patient. Or pull the patient's fingers forward from a distance to observe the rate and degree of pupil contraction. Do not use lights at this time.

It is inspected and recorded several times. If it is difficult to judge the contraction of the pupil, observe the process of returning to the pupil enlargement by moving the gaze to the distant target after watching the near distance.

10.3.2 Results

Light-near dissociation can be observed in the tonic pupil, Parinaud's syndrome, pineal gland tumors, and Argyll-Robertson pupil, and all the light and near reflex will disappear in diabetes, Miller Fisher syndrome, Botox, paraneoplastic syndrome, etc.

10.4 Drug Test

10.4.1 0.1% Pilocarpine

It is used to diagnose Adie's tonic pupil and pupil contraction. When examined 30 min after administration, the pupil contraction does not occur in the normal eye, but the pupil contraction occurs in the tonic pupil. This is due to an oversensitivity of the eye by the parasympathetic stimulant.

10.4.2 10% Cocaine

It is used for the diagnosis of Horner's syndrome. It enlarges the pupil in the normal state but does not enlarge the pupil in Horner's syndrome. The mechanism is that 90% of norepinephrine (NE) is reabsorbed in neuronal synapses, and cocaine increases this reabsorption and induces pupil dilation.

10.4.3 1% Hydroxyamphetamine

It is used to differentiate between preganglionic and postganglionic cause of Horner's syndrome. Pupil enlargement occurs in Horner's syndrome with preganglionic cause. There is no pupillary response in Horner's syndrome with postganglionic cause. The norepinephrine in the preganglionic nerve secretion induced by 1% hydroxyamphetamine leads to pupil dilation. The pupil enlarges in Horner's syndrome with preganglionic because neurotransmission is possible.

10.4.4 0.5% Apraclonidine (Iopidine)

The alpha 2 antagonist apraclonidine can be used for the diagnosis of Horner's syndrome. It helps to diagnose by using alpha 1 receptor antagonistic effect rather than alpha 2 antagonistic effect.

It has a similar positive rate to that of cocaine test, and reaction occurs in the patients with Horner's syndrome. When 0.5% apraclonidine is administered, the pupil contracted by Horner's syndrome becomes larger than the pupil size of the normal contralateral eye. In addition, the ptosis disappears, and the inversion phenomenon occurs which the abnormal eyelid height becomes higher than that of the normal eye. It has become a standard test for the diagnosis of Horner's syndrome and is also used as a medication for Horner's syndrome. However, do not use into newborns or patients allergic to clonidine drugs (Table 10.3).

Table 10.3 Anisocoria diagnosis

Clinical diagnosis	General characteristics	Neuroanatomy	Response to the light and near reflex	Anisocoria	Response to the pupil dilator	Response to the pupil constrictor	Response to other drugs
Pysiologic anisocoria	Round and regular	Positive, normal	Both	No change	Dilation	Constriction	Normal
Traumatic iris	Irregular pupil margin, iris atrophy	Pupil sphincter muscle	Vary depending on the degree of damage	Dilated by the light	Dilation	Various degree of constriction may occure	NA
RAPD	Round and regular, + on swinging flashlight test	Anterior visula pathway disease	More consensual to the light and near reflex	No response	Dilation	Constriction	Normal
Dorsal midbrain syndrome	Intermediate dilation on both eye	Dorsal midbrain	Less on light, more on near reflex	No response	Dilation	Constriction	NA
Tonic pupil (Adie's pupil)	Insidious pupil dilation and finally constriction (sector pupil palsy, vermiform movement)	Ciliary ganglion	No light reflex, tonic to near, tonic redilation	Increased in bright light	Dilation	Constriction	Constriction on 0.125% pilocarpine
Dilated by the drugs	Unilateral, very large, and round	Pupil sphincter	Fixated to 8–9 mm	Increased in bright light	Already fully dilated	No constriction	No constriction on 0.5~2% pilocarpine
Oculomotor nerve palsy	Unilateral intermediate dilation (5–7 mm), various ptosis	Parasympathetic nerve in Third cranial nerve	Fixated	Increased in birght light	Dilation	Constriction	Constriction on 0.5~2% pilocarpine
Horner's syndrome	Unilateral small and round pupil, mild ptosis	Sympathetic tract	Response all	Increased in dark light	Dilation	Constriction	Cocaine 4–10% or apraclonidine test is usefull for dianogsis
Argyll-Robertson pupil	Both small and irregular	Midbrain	Response to near reflex	No response in dark light	Poor reflex	Constriction	NA

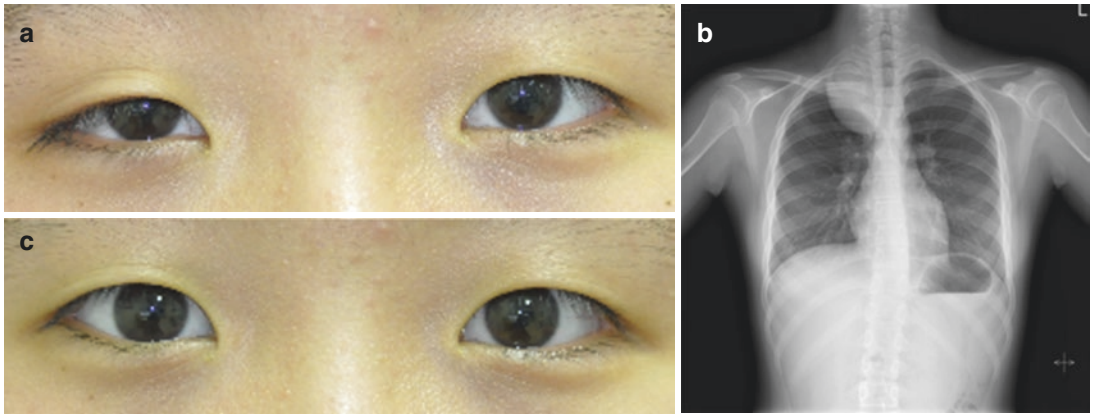

Fig. 10.7 Change of ptosis after apraclonidine instillation in Horner's syndrome. (**a**) Horner's syndrome. (**b**) Benign mass at the lung apex. (**c**) Loss of ptosis after applying of apraclonidine eye drops

10.5 Slit Lamp Examination

It is necessary to observe the iris structure precisely through slit lamp examination. If iris atrophy or sphincter abnormality is observed, it is necessary to confirm the past history of ocular trauma. If pupil is dilated, it is helpful to diagnose the tonic pupil when the partial iris shrinkage or wormlike movement is observed under light stimulus (Fig. 10.7).

10.6 Differential Diagnosis of Pupillary Abnormalities

By examining the pupil size and response, we can know the function of the optic nerve. We can examine the functions of pupil constrictor and dilator to differentiate the central nervous system and peripheral nervous system lesions (Fig. 10.8).

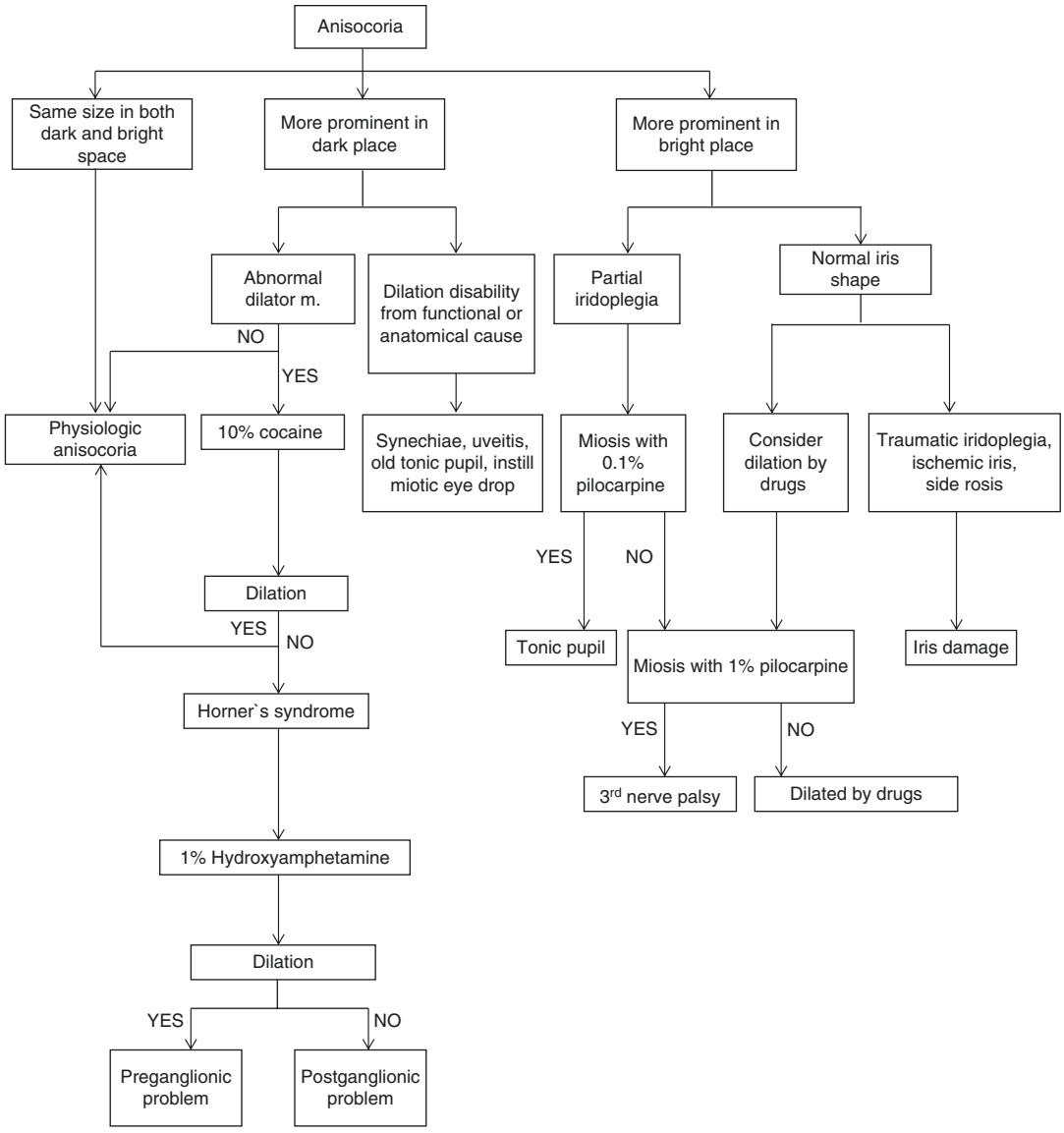

Fig. 10.8 Decision-making in anisocoria

Suggested Reading

Bell RA, Thompson HS. Optic tract lesions and relative afferent pupillary defect. In: Thompson HS, editor. Topics in neuro-ophthalmology. Baltimore: Williams and Wilkins; 1979. p. 164–5.

Bremver FD, Smith SE. Pupil abnormalities in selected autonomic neuropathies. J Neuroophthalmol. 2006;26:209–19.

Bremner FD, Smith SE. Bilateral tonic pupils: Holmes Adie syndrome or generalized neuropathy? Br J Ophthalmol. 2007;91:1620–3.

Bremner FD, Booth A, Smith SE. Benign alternating anisocoria. Neuro-Ophthalmology. 2004;28:129–35.

Bruno MK, Winterkorn JMS, Edgar MA, et al. Unilateral Adie pupil as sole ophthalmic sign of anti-Hu paraneoplastic syndrome. J Neuroophthalmol. 2000;20:248–9.

Burde RM, Loewy AD. Central origin of oculomotor parasympathetic neurons in the monkey. Brain Res. 1980;198:434–9.

Chen PL, Chen JT, Lu DW, et al. Comparing efficacies of 0.5% apraclonidine with 4% cocaine in the diagnosis of Horner syndrome in pediatric patients. J Ocul Pharmacol Ther. 2006;22:182–7.

Dacey DM, Liao HW, Peterson BB, et al. Melanopsin-expressing ganglion cells in primate retina signal colour and irradiance and project to the LGN. Nature. 2005;433:749–54.

Fotiou DF, Brozou CG, Tsiptsios DJ, et al. Effect of age on pupillary light reflex: evaluation of pupil mobility for clinical practice and research. Electromyogr Clin Neurophysiol. 2007;47:11–22.

Jacobson DM, Vierkant RA. Comparison of cholinergic supersensitivity in third nerve palsy and Adie's syndrome. J Neuroophthalmol. 1998;18:171–5.

Karden RH, Haupert CL, Thompson HS. The relationship between static perimetry and the relative afferent pupillary defect. Am J Ophthalmol. 1993;115:351–6.

Koc F, Kavuncu S, Kansu T, et al. The sensitivity and specificity of 0.5% apraclonidine in the diagnosis of oculosympathetic paresis. Br J Ophthalmol. 2005;89:1442–4.

Papageorgiou E, Ticini LF, Hardiess G, et al. The pupillary light reflex pathway. Neurology. 2008;70:956–63.

Sadun AA, Bassi CJ, Lessell S. Why cataracts do not produce afferent pupillary defects. Am J Ophthalmol. 1990;110:712–4.

Thompson HS, Mensher JH. Hydroxyamphetamine test in Horner's syndrome. Reply. Am J Ophthalmol. 1975;79:525–6.

Wilhelm H, Wilhelm B, Mildenberger I. Primary aberrant regeneration of abducens nerve fibers into the pupillary pathway. Neuroophthalmology. 1994;14:85–9.

Young RS, Kimura E. Pupillary correlates of light-evoked melanopsin activity in humans. Vis Res. 2008;48:862–71.

Tonometry

11

Jong-Hoon Shin

Tonometry is a routine procedure in ophthalmological examination; it is performed for diagnosing not only ocular hypertension and glaucoma but also ocular hypotension caused by eye trauma, retinal detachment, or intraocular inflammation following intraocular surgery for corneal, lenticular, and vitreoretinal diseases. Tonometry is a basic procedure performed on nearly all outpatients in ophthalmology, except those who visit with an eye infection. Normal intraocular pressure (IOP) is 10–21 mmHg, with a mean value of approximately 15.5 mmHg and standard deviation of approximately 2.6 mmHg.

The statistical distribution of IOP values is similar to a Gaussian curve, but it tends to be asymmetric toward the side with higher IOPs. Statistically, adding twice the value of the standard deviation to the mean yields an IOP of 20.7 mmHg, which is described as the upper limit of normal IOP. However, considering the asymmetry in the IOP distribution and the fact that optic nerve impairment occurs at IOPs less than 21 mmHg, the upper limit of normal IOP cannot actually be 21 mmHg. In Korea, IOP measurements on all residents (age, 40 years) of Namil-myeon, Geumsan-gun, yielded a mean IOP of 13.5 mmHg, with a standard deviation of 2.9 mmHg. Normal IOP is defined arbitrarily, and glaucoma cannot be diagnosed through tonometry alone.

11.1 Goldmann Applanation Tonometer

The Goldmann applanation tonometer, attached to a slit lamp, is used to measure IOP in the sitting position and is widely applied in clinical settings. The method is based on the principle of measuring the force required to flatten a round corneal surface with a diameter of 3.06 mm. Briefly, it uses the Imbert–Fick law, explained by the eq. $W = \mathrm{Pt} \times A$, where W is the applanation force, Pt is the internal pressure, and A is the area of the surface being flattened. If A is constant, Pt can be derived by measuring W (Fig. 11.1). This law assumes that the cornea is completely round, its thickness is infinitesimal, and it is dry and completely flexible. Therefore, it does not apply to actual situations. The presented equation has been modified according to the characteristics of the cornea, and it is actually applied to the eyeball. The force that resists corneal applanation does have an effect, but if the diameter of the surface being applanated is set to 3.06 mm, tear surface tension and corneal resistance offset each other, allowing the law to be applied. Unlike the Schiotz tonometer, this tonometer does not need to account for scleral rigidity, which makes it the most clinically accurate IOP measurement device.

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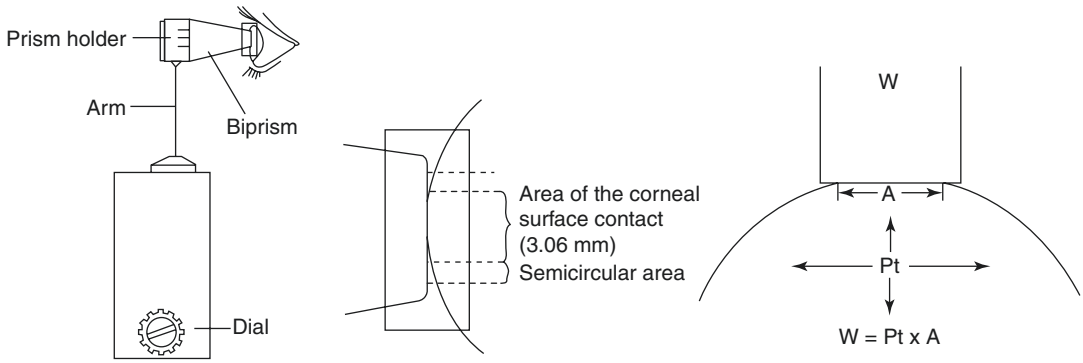

Fig. 11.1 Principle behind measurement using Goldmann applanation tonometer (Imbert–Fick law). (**a**) Goldmann applanation tonometer, (**b**) Imbert–Fick law

11.1.1 Structure

- Biprism: The part that directly contacts the cornea. Internally, two prisms, one on top and one on the bottom, facing in opposite directions, form two divided semicircles. It is designed such that the inner margins of the semicircles align when the diameter of the applanation surface is 3.06 mm.
- Connecting rod: It attaches the biprism to the body.
- Adjustment knob: The knob that adjusts the applanation force. Turning the knob clockwise increases the applanation force. By multiplying the value displayed on the scale (in units of g) by 10, after the inner margins of the semicircles are aligned, the value is converted to units of mmHg.

11.1.2 Method

The 0 mark on the biprism knob is first lined up with the white line on the sleeve. For cases involving corneal regular astigmatism of ±3 diopters or more, the line with the weakest corneal curvature of astigmatism is aligned with the red line on the sleeve. For sterilization before measurement, the tip of the biprism should be cleaned with 70% alcohol and allowed to dry. After topical anesthesia, a fluorescein-impregnated paper strip is used to stain the lacrimal layer. Just as in an anterior segment examination, a slit-lamp microscope is fixed in front of the face, and the patient is instructed to look straight while making sure the patient is calm. The room is darkened, and the patient is instructed to keep the eyes open, making sure the eyelashes or eyelids do not touch each other. The line on the adjustment knob is set to 1 g, and the slit-lamp beam is directed toward the tip of the biprism through a cobalt blue filter. The angle between the biprism and light beam should be ≥60°. While looking at the biprism from the side, it is adjusted in the up-and-down and left-and-right directions to approach the center of the cornea. When it gets sufficiently close to the cornea, it is viewed through the eyepiece of the slit-lamp microscope at a low magnification of ≤10×. As soon as the tip of the biprism touches the cornea, green semicircles form on the top and bottom. The position of the biprism is adjusted to bring the equal-sized semicircles to the upper left- and lower right-hand sides of the horizontal plane. The adjustment knob is turned to align the inner margins of the top and bottom semicircles (Fig. 11.2). If the semicircles pulsate, the inner margins are aligned to the center of the pulsation range. The scale of the adjustment knob is multiplied by 10 to obtain the IOP in units of mmHg, which is recorded, in addition to the measurement time.

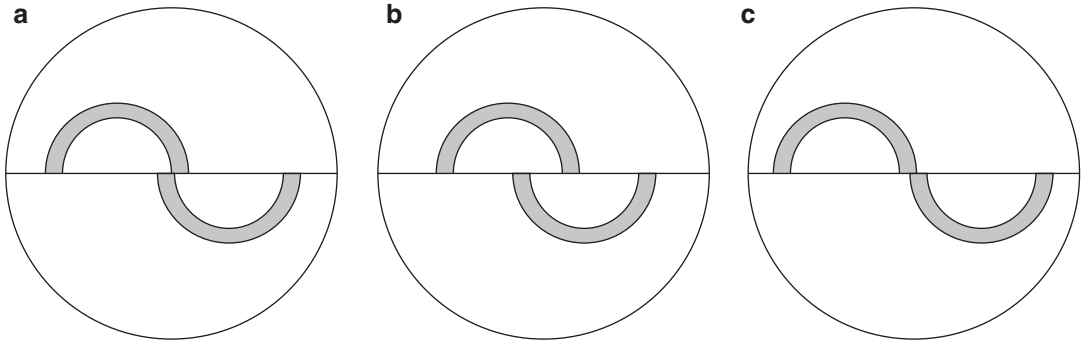

Fig. 11.2 Formation of semicircles by Goldmann applanation tonometer. (**a**) Appropriate, (**b**) low IOP, (**c**) high IOP

If the measurement was difficult or other inaccurate factors were present, the results are recorded with a side note to repeat at a later time. If IOP measurement is performed on a patient with adenovirus or herpes virus infection, hepatitis B, or acquired immunodeficiency, the biprism is washed in running water immediately afterward and soaked in 10% sodium hypochlorite solution, 3% hydrogen peroxide, or 70% isopropyl alcohol for 5 min to prevent the transmission of infection.

11.1.3 Precautions

Sometimes, IOP measurement may result in damage to the corneal epithelium; therefore, it should be performed in the last stage before the pupils are dilated. The tip of the biprism coming in contact with an eyelash or eyelid or pressure applied to the eyeball when the eyelid is opened may cause a measurement error. Therefore, greater attention should be paid when the gap between the eyelids is narrow, and the examination should be performed using the fingers to press down and fix the eyelids against the upper and lower orbital edges. Moreover, the width of a semicircle may be measured as larger than its actual size due to tearing. In such cases, the measurement should be performed again after cleaning the tip of the biprism. The appropriate width of the semicircle is 0.25–0.3 mm (approximately 1/10th of the applanation diameter).

11.1.4 Calibration

If possible, the device should be calibrated before each examination, but if not, it is necessary to have it calibrated at least once every 1–2 months. A balance rod, an accessory part, and a support for it are used. The line in the center of the balance rod represents 0 g, the next line represents 2 g, and the line farthest from the center represents 6 g. If problems are detected during calibration, the device should be sent for repair.

11.1.4.1 Operational Check on the 0-g Position

After setting the tonometer to its operational position, the balance rod, with the support fixed at the 0-g line, is inserted into the tonometer. The adjustment knob is turned to align with the 0-g position, and the balance rod is checked to see if it moves with light force. Check to ensure that when the adjustment knob is turned to −0.1 g, it tilts toward the examiner and when it is turned to +0.1 g, it tilts toward the patient.

11.1.4.2 Operational Check for the 2-g Position

The balance rod, with the support fixed at the 2-g line, is inserted into the tonometer. The 900 model has the longer end of the balance rod toward the examiner, whereas the 870 model is longer at the patient end. The adjustment knob is turned to align with 2 g, and just as with the

method used for 0 g, ensure that when the adjustment knob is turned to +1.9 g, it tilts toward the examiner and when it is turned to +2.1 g, it tilts toward the patient.

11.1.4.3 Operational Check for the 6-g Position

The balance rod, with the support fixed at the 6-g line, is inserted into the tonometer. After turning the adjustment knob to align with 6 g, ensure that turning to +5.9 g results in the balance rod tilting toward the examiner and turning to +6.1 g results in the balance rod tilting toward the patient (Fig. 11.3).

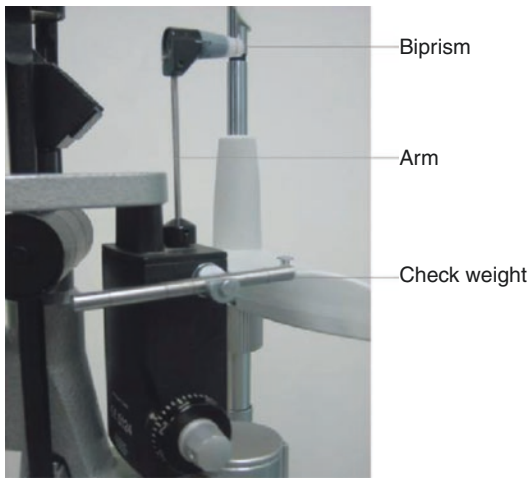

Fig. 11.3 Calibration of Goldmann applanation tonometer

11.2 Perkins Tonometer

This is a portable tonometer that uses a prism in a manner similar to the Goldmann applanation tonometer, but it is used on patients who cannot walk, such as infants, and those who cannot sit up for a slit-lamp examination as well as during surgery and inpatient examination.

11.2.1 Methods

After topical anesthesia in a dark room, a fluorescein paper strip is used to stain the lacrimal layer. When the adjustment knob is turned higher than 0 mmHg, the internal light source sends out a light beam through a cobalt blue filter. With the eyelids of the patient are open sufficiently wide, the biprism is placed adjacent to the cornea, without touching the eyelid margin or eyelashes. As soon as a contact is made with the cornea, the top and bottom semicircles are observed through the eyepiece. The adjustment knob is turned until the inner margins of the top and bottom semicircles line up, thereby adjusting to the applanation force. When aligned semicircles are seen, the value at that point is read, and this measurement is repeated approximately three times (Fig. 11.4).

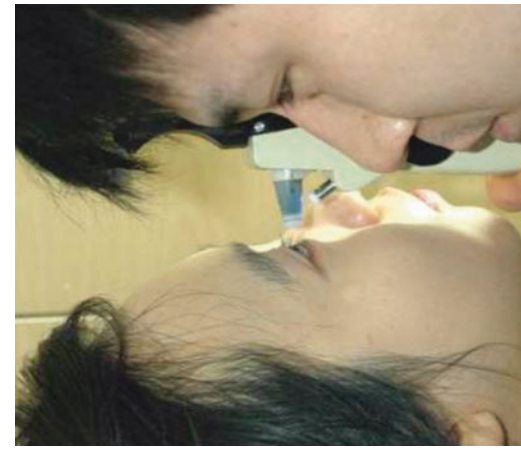

Fig. 11.4 Perkins tonometer

11.2.2 Precautions

This device can be used to examine a patient in the sitting or lying position, and the measured IOP has high precision. Moreover, because the duration of contact of the device with the cornea is short, it can easily be used to measure children who are asleep. However, the measurement position is unstable, and a certain level of expertise is required to appropriately use the device. Repeated measurements can reduce the IOP because of a massage effect, and attention should be paid to this possibility.

Notably, measurements in the lying position tend to yield results that are 2–3 mmHg higher than those obtained in the sitting position.

11.3 Tono-Pen Tonometer

This is a portable electric applanation tonometer based on the Mackay–Marg principle. It has an outer shell (diameter, 3 mm) at the tip of the probe, which contains a 1 mm plunger. As the tip of the probe lightly contacts the cornea, every small movement of the plunger is detected as an electrical impulse. The results are provided as mean IOP and percentage variability, based on 4–10 repeated measurements. It is a battery-operated device and can measure IOP in the sitting or lying position in a relatively easy manner.

Because the area of corneal surface needed for the measurement is small, this device can be used eve n if there is an anomaly in the cornea. It is particularly useful for cases involving heavy tearing or a narrow gap between the eyelids (Fig. 11.5).

11.3.1 Structure

- Probe tip: This is the part that comes into direct contact with the cornea. It has a plunger (diameter, 1 mm), located in the center of an outer shell (diameter, 3 mm).
- Activation button: This is a button used to switch the tonometer on and for calibration.
- Liquid crystal display: This displays various information during calibration. It also indicates the measurement status of the tonometer and ultimately displays the measured IOP and its variation.

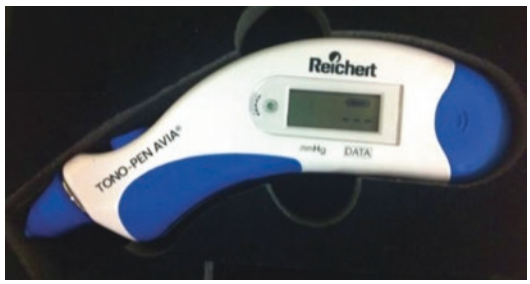

Fig. 11.5 Tono-Pen

11.3.2 Methods

With the batteries loaded, a rubber cover is fitted on the plunger, ensuring it is not very loose for air to enter. The activation button on the body is pressed, after which two horizontal lines appear on the display, at the top and bottom, indicating that the device is ready for measurement. After topical anesthesia, the patient is instructed to look straight. The tonometer is lined up at a right angle to the cornea and brought in contact with it, quickly and softly, without pressing down on the cornea. The measurement is completed when a short "beep" is heard. Once 4–10 measurements are recorded, the mean value is calculated automatically and displayed, accompanied by a continuous beeping sound. Variability is displayed as a short horizontal line on the bottom of the screen, indicating 5%, 10%, 20%, or >20%. If the value is ≥10%, the measurement must be repeated until a value of 5% is obtained. To accomplish this, when the plunger comes in contact with the cornea, it must not press down on the cornea. Calibration should be performed daily before use, when unexpected measurement values are observed, when the batteries are replaced, and when calibration was not performed properly the previous time. With the plunger facing vertically downward, the activation button is pressed twice in rapid succession. The word "CAL" will appear on the screen, and after maintaining this state for approximately 15 s, the word "UP" will appear. At this time, the plunger is turned to face upward, and when the word "Good" appears shortly thereafter, the calibration is successfully completed. If the word "Bad" appears, the calibration must be performed again.

11.3.3 Precautions

The center of the cornea should be measured whenever possible, but if the corneal surface is uneven because of corneal erosion or degeneration, a smooth surface as close as possible to the center should be measured. The measured values are approximately the same as those from a Goldmann applanation tonometer,

but the results may appear slightly higher when the IOP is low and slightly lower when the IOP is high. At IOP ≥20 mmHg, the accuracy drops slightly.

11.4 Noncontact Tonometer

The noncontact tonometer (NCT), developed by Grolman in 1972, can measure IOP without directly contacting the eyeball of the patient. Corneal applanation is performed instantaneously by an air puff. The device comprises three major components: an air-jet sprayer, an optical applanation detector, and a positioner to accurately aim the air-jet toward the corneal surface. In the instant that the air-jet is sprayed toward the cornea, the optical applanation detector on the left and right sides measure the corneal distortion, and the time required to flatten a certain amount of area or the air pressure needed for flattening is converted to an IOP value. The latest model is equipped with an automatic air sprayer, which allows the air to be sprayed automatically when the corneal apex and spray nozzle are accurately aligned (Fig. 11.6).

Because this device does not require topical anesthesia and poses no concerns about possible infection due to contact, it is often used for general IOP screening.

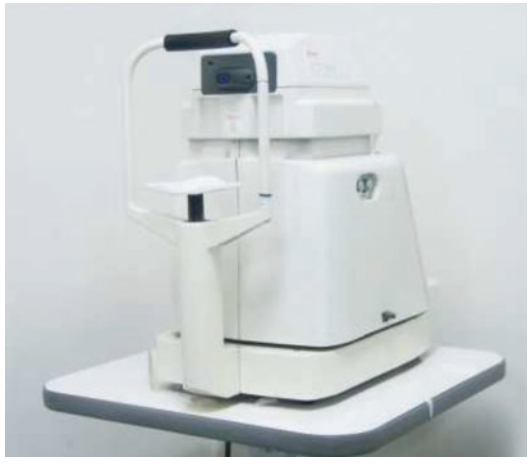

Fig. 11.6 Noncontact tonometer, NCT

11.4.1 Structure

- Air-jet sprayer: This component sprays the air needed for corneal applanation, with the applanation force increasing over time.
- Optical applanation detector: This component detects the condition in which the maximum amount of light is reflected from the corneal surface that has been flattened by the air-jet.
- Positioner: This component is used to position the air-jet such that the air is directed toward the center of the cornea.

11.4.2 Methods

When the power switch is turned on, a recharging mark should appear on the upper portion of the monitor. The height of the device is adjusted such that the patient can rest his or her chin on the chin support without any problem. The patients are given advance notice that a short burst of air will be sprayed into the eye during the measurement but that the procedure will be painless. The position is adjusted until the monitor shows accurate air-jet aiming at the cornea. After correct positioning, an indication is provided that the device is ready for measurement. Once the air-spray button is pressed, part of the cornea is flattened by the air, which causes changes in the specular reflection on the monitor. The change in light intensity caused by this specular reflection is converted to an IOP value and displayed on the screen.

11.4.3 Precautions

A single measurement of IOP by using an NCT is very brief (1–3 ms). Consequently, the measured values may fluctuate significantly depending on whether the measured value represents the maximum or minimum value of IOP fluctuations caused by the heartbeat. In particular, glaucomatous eyes, for which IOP has greater significance, tend to show greater fluctuations. Therefore, the values measured by NCT would also show large fluctuations. Therefore, at least

three IOP measurements should be taken with NCT, and the average of those measurements should be used. The standard range of fluctuation is <3 mmHg.

NCT is known to have a tendency to produce low results when the actual IOP is lower than normal and high results when it is higher than normal. Therefore, it is necessary to use the Goldmann applanation tonometer for IOP ≥18 mmHg. If there is dust buildup in the device, especially the air sprayer, dust can enter the eyes of the patient as the air is sprayed. Moreover, when measurements are recorded on a patient with a contagious eye disease, such as epidemic keratoconjunctivitis, tears from the patient can be blown onto the device by the air spray, which can cause infection in the next patient who is measured. Therefore, precautions should be taken against these possibilities.

When the device is installed for the first time, an eye model is used for calibration, but if measured IOP values are suspicious, the device should be recalibrated.

11.5 Pulsair Tonometer

This device is based on the same principle as the NCT, in that the air pressure required to flatten a certain amount of corneal area by air spray is measured and converted to IOP. Because it uses a noncontact method, it does not require topical anesthesia, and the risk of infection transmitted by tears is also low (Fig. 11.7). Because the measuring unit is handheld, the device can be used without any restrictions based on the position or posture of the patient. However, because the working unit of the power pump is connected to a large tube, the movement is not completely free. The device does not come directly in contact with the eye. Therefore, it presents less of a fear factor, which makes it convenient for use on children. In cases involving the patient not being able to open the eyelids, poor corneal exposure, or an uneven corneal surface because of corneal erosion or transplantation, measurement may be difficult, or the reliability of the results may be compromised.

Fig. 11.7 Pulsair tonometer

11.5.1 Methods

While the examiner looks through the eyepiece, the measuring unit is placed very close to the cornea of the patient, but not actually touching it. Once the measuring unit gets close enough to the patient's eye, a green light appears, and when the unit is moved even closer, a cross-shaped light appears for focusing. After the distance is adjusted by focusing, the air is sprayed automatically, and the IOP is measured.

11.6 Ocular Response Analyzer

The recently introduced Ocular Response Analyzer (ORA; Reichert Corporation, New York, USA) is a type of noncontact tonometer that uses air to analyze the dynamic aspects of corneal deformation. When a time-varying airstream strikes the cornea, the time of applanation is determined not only by the air pressure but also by the rate at which it is increasing or decreasing. The relationship between pressure and its rate of change is determined by the stiffness of the cornea. In the ORA, the air pressure increases, reaches its peak, and then decreases. The function of the ORA is to measure the corneal applanation force when the air pressure is increasing

("force-in" applanation, P1) and the applanation force when the air pressure is decreasing ("force-out" applanation, P2). The difference between these forces is called corneal hysteresis (CH) (Fig. 11.8). The variables shown as measurement results include the corneal-compensated IOP, CH, corneal resistance factor, and Goldmann-correlated IOP. It is believed that CH, in addition to central corneal thickness, influences IOP. IOP measured by this tonometer is less affected by corneal thickness. Although the results are highly correlated with IOP measured with a Goldmann applanation tonometer, the ORA tends to yield results that are a few mmHg higher. High CH is associated with the progression of glaucoma, but additional studies on this topic must be monitored.

11.6.1 Methods

The patient should be seated comfortably in front of the device. Soft contact lenses should be removed, and the necktie should be loosened, if one is worn. The patient is instructed to keep the eyes open and is explained that a slight air puff will be felt. The patient is instructed to stare at a green light surrounded by red light and to place the forehead vertically against the forehead support. After the patient is instructed to blink, the measurement button is pressed. The resulting data are displayed on a computer screen (Fig. 11.9).

11.7 Rebound Tonometer (Icare)

Recently, the Icare tonometer, a rebound tonometer, was developed. An advantage of this device is that it does not require corneal anesthesia. IOP measurement with this device is based on the principle of a small plastic probe of the tonometer, grounded on the forehead of the patient, coming in contact with the corneal surface and rebounding. Because the probe is very small, topical anesthesia of the cornea is not required, just as with pneumatic tonometers. The Icare tonometer can be used on adults and children because it is readily portable and convenient to use. Its accuracy is known to be similar to that of the Tono-Pen and Goldmann applanation tonometers. The fact that it does not require topical anesthesia of the cornea enables the potential application of this device at home to measure IOP.

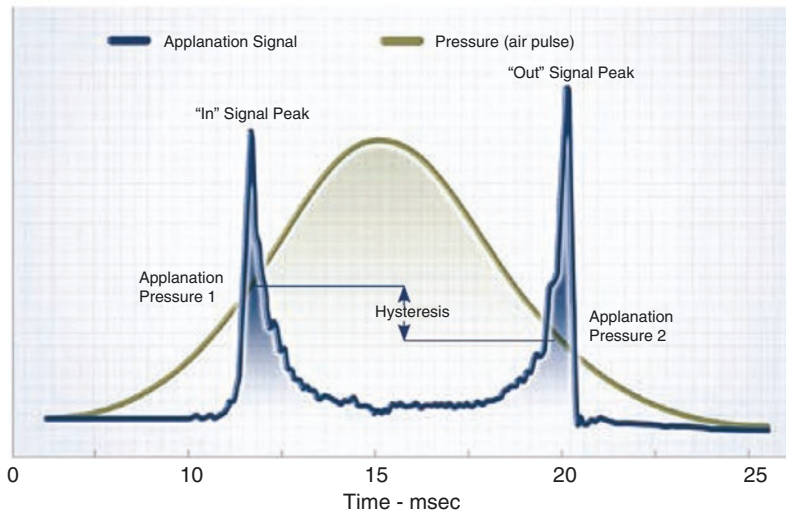

Fig. 11.8 Applanation signal and air pressure. Corneal hysteresis = applanation pressure 1 − applanation pressure 2. (Copyright 2004 Reichert Inc.)

11.7.1 Methods

The patient is instructed to relax and look straight. The tonometer is placed in front of the patient's eye; at this time, the central groove must be in the horizontal position. The Icare tonometer probe must be positioned at 90° to the corneal surface, with the probe tip and corneal surface at a distance of 4–8 mm. The measurement button is pressed gently, such that the tonometer does not shake. After six measurements, the resulting IOP is displayed on the screen (Fig. 11.10).

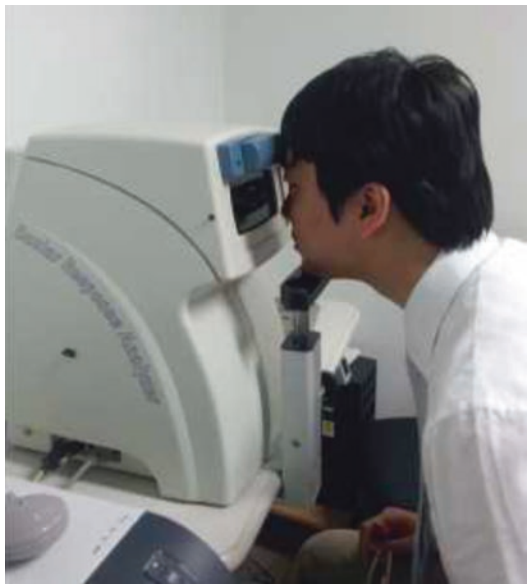

Fig. 11.9 IOP and CH being measured with ORA

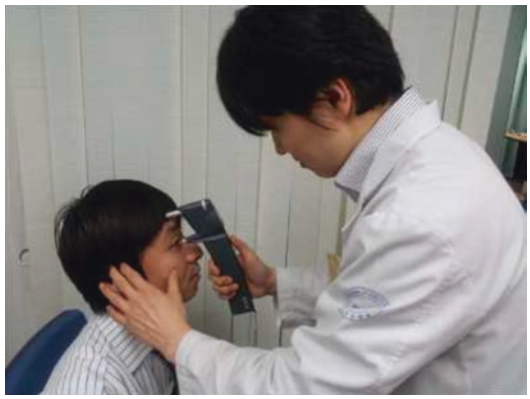

Fig. 11.10 IOP being measured with Icare tonometer

11.8 Dynamic Contour Tonometry

As with the Goldmann tonometer, this type of device is designed to be fixed on a slit lamp for measurements. The tonometer has a concave detecting unit with a contact surface at the end that fits the corneal surface, with a diameter of 10.5 mm. In the center, there is a piezoelectric pressure sensor (size, 1.2 mm) that converts the IOP to an electrical signal. The pressure signal is altered by pulsatile intraocular blood flow and is measured for approximately 5 s, after which the diastolic IOP is displayed on the LCD screen of the tonometer. The difference in IOP between the systolic and diastolic phases of the heartbeat is expressed as the ocular pulse amplitude (OPA), which is approximately 1.5–3 mmHg in healthy people (Fig. 11.11).

IOP measured through dynamic contour tonometry is less affected by central corneal

Fig. 11.11 Pascal tonometer

thickness than is that measured by a Goldmann tonometer. Therefore, it is believed to be useful for measuring IOP after refractive surgery. Because the measurement requires at least 5 s of contact with the corneal surface, the measured values may not be accurate when used on patients with nystagmus or those who are uncooperative.

11.8.1 Methods

After topical anesthesia, a silicone tip is attached to the tonometer, and contact is made with the cornea. Contact must be maintained for at least five cardiac cycles. The tonometer makes a sound when the contact period has been sufficiently long. When the measurement is performed appropriately, IOP, OPA, and a quality score appear on the display. The results are considered reliable if the quality score is 1 or 2.

11.9 Schiotz Tonometer (Indentation Tonometer)

When the tonometer is placed on the center of the cornea, the plunger causes the cornea to become indented to a certain degree. The degree of corneal indentation is expressed on the scale by the movement of the needle. Each line on the scale represents an indentation of 0.05 mm caused by the plunger, and the result is converted to IOP on the basis of the weight used and the scale. Because the cornea and sclera are elastic, placing the tonometer increases the IOP and stretches the eyeball. This elasticity is referred to as the coefficient of ocular rigidity (OR). Eyes with weak elasticity are said to have a high coefficient of OR. The Schiotz tonometer is affected by the radius of corneal curvature and coefficient of OR.

The conversion table is based on the average radius of corneal curvature (7.8 mm) and coefficient of OR (0.0215). Because of this factor, measurement by the Schiotz tonometer produces results that are higher than the actual IOP when the coefficient of OR is higher than average or the radius of corneal curvature is lower than average; these results are lower than the actual IOP when the coefficient of OR is lower than average. Abnormally high coefficients of OR may be found in cases involving hyperopia, chronic glaucoma, or vasoconstriction therapy, whereas abnormally low coefficients of OR may be seen in cases involving myopia, miotic therapy, vasodilation therapy, or retinal detachment (Fig. 11.12).

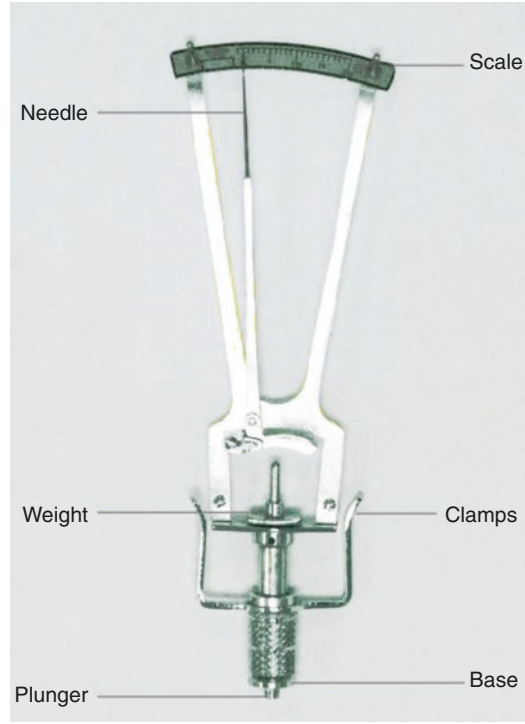

Fig. 11.12 Schiotz tonometer

11.9.1 Structure

- Scale: This contains lines numbered from 0 to 20, in 1 mm increments. A movement of 0.05 mm by the plunger is represented by a change of one line on the scale.
- Needle: This magnifies the movement of the plunger by a factor of 20 and indicates the result on the scale.
- Clamps: These hold the tonometer during IOP measurement.

- Weight: Weights of 5.5, 7.5, and 10 g can be used. If the measured value with a 5.5 g weight is <4, a 7.5 or 10 g weight is used for the measurement.
- Base: This is the area that comes in direct contact with the cornea and has the plunger located in the center.
- Plunger: This protrudes from the center of the base and has a rod shape (diameter, 3 mm). When the cornea causes it to move by 0.05 mm, the result is shown on the scale as a movement by one line.

11.9.2 Methods

After loading a 5.5 g weight, the tonometer is placed vertically on the test block, ensuring that the needle is pointing exactly at 0. After topical anesthesia, the patient is placed in the supine position and instructed to look straight at a specific point on the ceiling, light source, or the tip of a finger, while a pillow is used to adjust the head such that the face is horizontal. It would be ideal to have the patient open the eyes voluntarily, but if it is difficult to do so, the examiner should use the thumb and forefinger or the forefinger and middle finger to gently pull back the upper or lower eyelid in the horizontal direction. The fingers must be fixed on the edges of the upper and lower eye sockets to ensure no pressure is applied to the eyeball. While holding the handle of the tonometer with two fingers, the tonometer base is brought to the center of the cornea and placed vertically erect. The position of the tonometer needle on the scale is read. If the pressure pulsates strongly, the middle of the pulse is used as the value. If the tonometer needle points to a value of <4, a 7.5 or 10 g weight is placed on the tonometer, and measurement is recorded using the same method. If the values measured using a 5.5 and 10 g weight show a difference of ≥3 mmHg, the coefficient of OR would be considered to be abnormal, requiring IOP correction. The procedure is repeated until three consecutive measurements show differences on the scale that are no more than 0.5. The device should be sterilized thoroughly before and after use.

11.9.3 Precautions

The weight placed on the tonometer (5.5, 7.5, or 10 g) and the scale reading are used as the numerator and denominator to express the results as fractions (i.e., 6/5.5 and 7/7.5), or such fractions can be converted to mmHg based on the conversion table. Although this device was once widely used because of its convenience, it is not used as much currently due to errors associated with the coefficient of OR.

11.10 Other Tonometers

For the diagnosis and treatment of glaucoma, it is necessary to continuously measure IOP over a set period of time or number of days. A continuous IOP monitoring device has been developed for this purpose, while efforts are ongoing to develop other types of tonometers. In addition, there is a phosphene tonometer that can be used for self-measurement.

11.11 Glaucoma Provocative Test

A provocative test is performed in cases where glaucoma is suspected, but not confirmed, based on IOP, optic disk, and visual field findings at a stage before the onset of clear visual impairment. Briefly, a provocative test is aimed to assist in early determination of glaucoma. If a significant increase in IOP is found in a provocative test, such cases may be diagnosed as open-angle glaucoma or chronic closed-angle glaucoma, not normal tension glaucoma. Because provocative tests do not yield false-positive and false-negative results, a positive provocative test result should be viewed as merely suggesting glaucoma and indicating the need for stricter care. Because of its high false-positive and false-negative rates, this type of test is not commonly used today.

Provocative tests can be divided into tests performed when open-angle or closed-angle glaucoma is suspected.

11.11.1 Open-Angle Glaucoma

11.11.1.1 Water Provocative or Hemodilution Test

The water provocative test is the most commonly used provocative test for glaucoma. The patient is instructed in advance to discontinue the use of any drugs that may affect IOP and to fast for at least 8 h before the test. It is best to perform the test in the morning on an empty stomach.

The patient is instructed to drink water that is slightly colder than room temperature: 1 L for adults and 14 mL per kilogram for children, within 5 min. The IOP is measured before drinking the water, at 5-min intervals for the first 15 min after drinking the water and at 15-min intervals thereafter for up to 1 h. If there is a tendency for elevated IOP even 1 h after drinking the water, measurements are continued at 15-min intervals until elevated IOP is no longer observed. The peak IOP typically appears between 10 and 30 min after drinking the water. Cases wherein the IOP is elevated by at least 8 mmHg, compared with that before drinking the water, are defined to show a positive provocative test result.

The degree of increase in IOP is influenced by the IOP level at the time of drinking the water. If the level is high at that time, the subsequent increase in IOP will be much greater. Therefore, determination by a water provocative test does not look at the absolute value of how much IOP has been elevated but is based on whether the elevation in level after drinking the water represents an increase of at least 30%. The results of water provocative tests are of a limited diagnostic value because of their high false-positive rate.

11.11.1.2 Bulbar Compression Test

After applying 50 g of force on the insertion area of the external rectus muscle for 4 min, a decline of ≤30% in IOP is considered a positive result.

11.11.1.3 Steroid Eyedrop Test

If clear results could not be obtained through a water provocative test, a steroid eyedrop test may be used. This method involves obtaining a baseline IOP based on several measurements and measuring IOP after continued use of 0.1% betamethasone eyedrops, four times a day for 4–6 weeks. According to the classification used by Becker et al., after the administration of 0.1% betamethasone for four times a day for 6 weeks, those who show an IOP of <20, 20–31, and ≥32 mmHg are classified as poor, intermediate, and high responders, respectively. However, there are cases in which the IOP increases rapidly over a short period of time, as well as those in which the elevated IOP does not decrease. Therefore, it is safer to avoid using the steroid eyedrop method, if possible. If it is necessary, sufficient explanation should be given to the patient.

11.11.2 Angle Closure Glaucoma

11.11.2.1 Dark-Room Test

The dark-room test is a relatively physiological examination, as well as a safe examination. First, after measuring the baseline IOP, the patient is placed in a dark room. Being placed in a dark room may cause the patient to feel drowsy. However, because sleep can cause miosis, it is necessary for the examiner to periodically ensure that the patient is awake. After 60–90 min, the IOP should be measured immediately in a dark place, while the anterior chamber angle is also observed. Compared with the baseline IOP, if there is an increase of ≥8 mmHg in the IOP or the anterior chamber angle is completely closed, such cases are determined as positive cases, which would require immediate initiation of treatment for closed-angle glaucoma. Even if the result is negative, closed-angle glaucoma cannot be ruled out.

11.11.2.2 Mydriatic Test

The mydriatic test is used for measuring the IOP and anterior change angle after dilating the pupil with a mydriatic. This method has a higher probability of yielding a positive result than does the dark-room test, but it should be performed on only one eye due to the risks involved. The test uses mydriatics with short efficacy, such as 3% eucatropine hydrochloride or 0.5% tropicamide.

The IOP and anterior chamber angle are examined when the pupil has dilated by approximately 5–7 mm, 5–10 min after the eyedrop application. Subsequently, the test is repeated every 15 min, up to a total of 1 h.

The result is considered positive if the IOP has increased by ≥8 mmHg or the anterior chamber angle is completely closed. Upon completion of the test, a mild mydriatic, 0.5–1% pilocarpine, is administered topically. This test may be performed when the results from a prone-position test in a dark room are inconclusive.

11.11.2.3 Prone-Position Test

The IOP is measured after the patient stays in the prone position for 1 h. If the IOP has increased by ≥8 mmHg, the result is considered positive. This test is often performed together with the dark-room test.

11.12 Aqueous Outflow Rate Test (Tonography)

The IOP is usually determined by the balance between aqueous production in the ciliary epithelium and aqueous outflow from the anterior chamber angle. Therefore, the IOP may increase because of overproduction of aqueous humor or obstruction or impairment of aqueous outflow pathways. Clinically, however, most cases of elevated IOP involve impairment of aqueous outflow. In rare cases, glaucoma may be caused by elevated upper scleral venous pressure. The aqueous humor plays a role in maintaining the IOP and supplying nutrients to and removing metabolites from the cornea and lens (Fig. 11.13).

This is a useful method for investigating the aqueous humor circulation in glaucoma and identifying the mechanism of antiglaucoma drugs. This test can determine aqueous outflow impairment, the primary cause of elevated IOP, from the amount of aqueous outflow. If obstruction of the aqueous outflow pathways is present, the rate of decrease in IOP becomes slower, and the overall level of decrease becomes lower as well. Clinically, this test is used for predicting the onset of primary open-angle glaucoma, assessing the validity of antiglaucoma therapy, discovering extensive diurnal variation in IOP, diagnosing closed-angle glaucoma, and discovering myasthenia gravis.

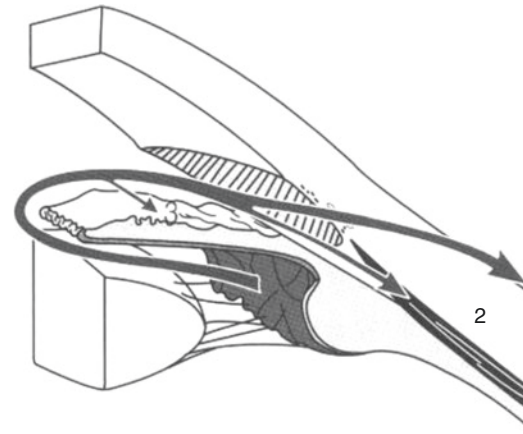

Fig. 11.13 Aqueous outflow pathways. (1) Trabecular meshwork in the Schlemm's canal pathway. (2) Uveal–scleral pathway. (3) Iris pathway

11.12.1 Methods

After topical anesthesia, the Goldmann applanation tonometer is used to measure the baseline IOP. Subsequently, the patient is placed in the supine position, and a Schiotz tonometer is placed on the surface of the cornea for 4 min. The weight of the tonometer causes the IOP to increase and the rate of aqueous outflow to increase above the normal rate. The IOP gradually decreases, whereas the production and outflow of aqueous humor reach an equilibrium after a certain amount of time. The tonometer is connected to a recording device that continuously measures the gradual decrease in IOP. The observed changes in IOP are used to measure the amount of aqueous humor that has moved from the eyeball by using the Friedenwald table. The equation for the coefficient of aqueous outflow is as follows: $C = \Delta V/T\Delta P$ (C average coefficient of aqueous outflow, ΔV change in the amount of aqueous humor, T set time, ΔP difference in IOP).

11.12.2 Determination

The average coefficient of the aqueous outflow in normal eyes is 0.28 μL/min/mmHg (normal, 0.20 μL/min/mmHg).

Suggested Reading

Allingham RR, Damji KF, Freedman SF, Moroi SE, Rhee DJ. Shields textbook of glaucoma. 6th ed. Philadelphia: Lippincott Williams & Wilkins; 2010.

Gabelt BT, Kaufman PL. Changes in aqueous humor dynamics with age and glaucoma. Prog Retin Eye Res. 2005;24(5):612–37.

Gedde SJ. Curbside consultation in glaucoma: 49 clinical questions. 2nd ed. Thorofare: Slack; 2015.

Kaufmann C, Bachmann LM, Thiel MA. Comparison of dynamic contour tonometry with Goldmann applanation tonometry. Invest Ophthalmol Vis Sci. 2004;45(9):3118–21.

Lowe RF. Primary angle-closure glaucoma. A review of provocative tests. Br J Ophthalmol. 1967;51(11):727–32.

Schacknow PN, Samples JR. The glaucoma book: a practical, evidence-based approach to patient care. New York: Springer; 2010.

Shaarawy TM, Sherwood MB, Hitchings RA, Crowston JG. Glaucoma. 2nd ed: Elsevier; 2014.

Shin J, Lee JW, Kim EA, Caprioli J. The effect of corneal biomechanical properties on rebound tonometer in patients with normal-tension glaucoma. Am J Ophthalmol. 2015;159(1):144–54.

Stamper RL, Lieberman MF, Drake MV. Becker-Shaffer's diagnosis and therapy of the glaucomas. 8th ed. Edinburgh (Scotland): Mosby; 2009.

Tonnu PA, Ho T, Sharma K, White E, Bunce C, Garway-Heath D. A comparison of four methods of tonometry: method agreement and interobserver variability. Br J Ophthalmol. 2005;89(7):847–50.

Anterior Chamber Angle Exam

12

Keun-Heung Park

12.1 Gonioscopy

It is used to diagnose and differentiate various lesions such as glaucoma, inflammation of the anterior segment, congenital anomaly, eye trauma, ischemic ocular disease, laser treatment, before and after eye surgery, anterior chamber angle tumor, or foreign body. It is performed for the exact diagnosis and classification of glaucoma, the degree of occlusion of the anterior chamber angle due to peripheral anterior synehiae (PAS), the prediction of IOP control, and the selection of treatment modalities. It is also helpful in diagnosing and determining the degree of inflammation in uveitis. It is also performed to evaluate the adequacy of eye solution before and after surgery, such as goniotomy and laser trabeculoplasty. It can be used to diagnose various diseases at the periphery of the iris such as tumor, cysts, perforation, foreign body at the periphery of the iris, traumatic iridodialysis, laceration of Descemet's membrane, or ocular disease near the base of the vitreous.

12.1.1 Principle

Because of the curvature of the cornea and the difference in refractive index between the cornea and air, the light from the angle of the anterior chamber cannot be visualized directly because the light is reflected from the corneal surface and returned to the anterior chamber. Therefore, goniolens, a suitable contact lens, is attached to the surface of the cornea to change the path of the light so that a frontal angle can be observed (Fig. 12.1).

The anterior angle examination is important in confirming the normal anatomical structure of the angle, the degree to which the angle is open, the pigmentation of angle, and the presence of abnormality of the angle. However, functional evaluation cannot be performed in the gonioscopic examination. Therefore, it cannot be said that aqueous humor is normally flowing out even if it is normal gonioscopy test.

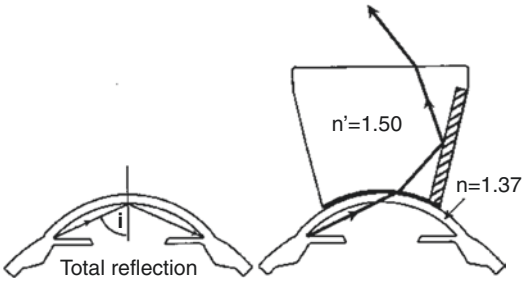

Fig. 12.1 Optical principle of gonioscopy (n, refractive index; i, incident angle)

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J.-S. Lee (ed.), *Primary Eye Examination*, https://doi.org/10.1007/978-981-10-6940-6_12

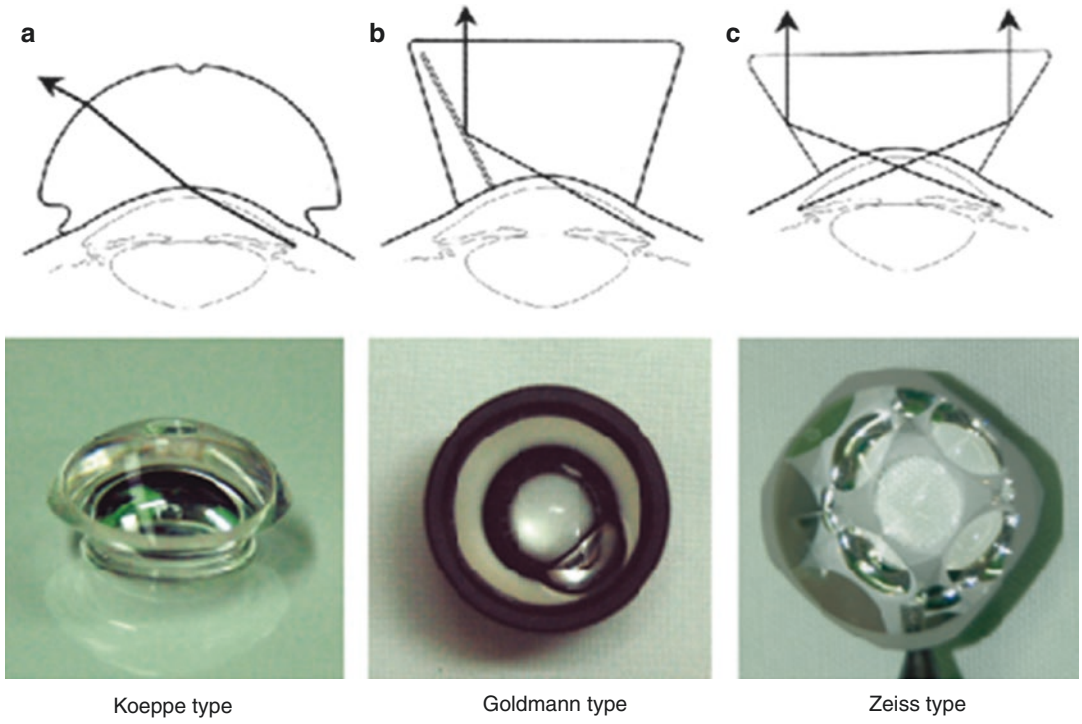

Fig. 12.2 Various gonioscopy lenses. (**a**) Koeppe type. (**b**) Goldmann type. (**c**) Zeiss type

12.1.2 Types and Methods

There are two types of gonioscopy, a direct gonioscopy and an indirect gonioscopy, according to the characteristics of the lens (Fig. 12.2). Observation can be started from any direction, but the lower anterior chamber angle is the largest, so it is easy to understand the structure of the anterior chamber. Pigment and inflammation substances are likely to accumulate here. In general, the lower anterior chamber angle is observed first (Table 12.1).

12.1.2.1 Direct Gonioscopy

The gonioscopy is applied to the cornea with the patient lying down, and the anterior chamber is observed directly with a loupe or portable slit lamp, which is used for goniotomy or preoperative diagnosis (Fig. 12.3). The most commonly used direct gonioscopy lens is the Koeppe type, a 50D semicircular gonioscopy. Compared with indirect gonioscopy, the equipment is somewhat complicated and requires skill, but this lens does not make angle of the anterior chamber deformed and has a wide range of view.

Method

The patient is laid down and topical anesthesia is performed, and the corneal surface of the lens is filled with methylcellulose. Then, the lens is first inserted into the lower conjunctival sac and then inserted into the upper conjunctival sac. After the nasal side of the lens is slightly raised, saline is filled between the lens and the cornea. Take a portable slit lamp and observe the entire anterior chamber angle while changing the observation direction.

12.1.2.2 Indirect Gonioscopy

The patient is placed in front of a slit lamp microscope, and using a contact lens with a built-in reflector, anterior chamber angle is observed indirectly. When the reflector is above, the lower anterior chamber angle is observed, and when the reflector is low, the upper anterior chamber angle

Table 12.1 Comparison of gonioscopy types

Direct gonioscopy	Indirect gonioscopy
Requires surgical microscope or portable slit lamp microscope	Slit lamp microscope required
Observe in a lying position	Observe in sitting position
Since it is an actual image, the positional relationship is clear	Observation with mirror requires skills
Easy to observe the whole anterior chamber angle	Accurate anterior chamber angle observation is possible
Both eyes can be examined at the same time, so the two eyes can be compared	The location of the Schwalbe line is easy to see, so it is useful to determine the height of PAS
Useful for anterior chamber angle surgery	Cannot use for surgery of anterior chamber angle but laser treatment is possible
Difficult to see when corneal opacity is present or angle is closed	Even if the corneal opacity is present, the angle is observable to some degree
A bed and a large examination room are required	It is necessary to rotate the lens to observe the entire anterior chamber angle

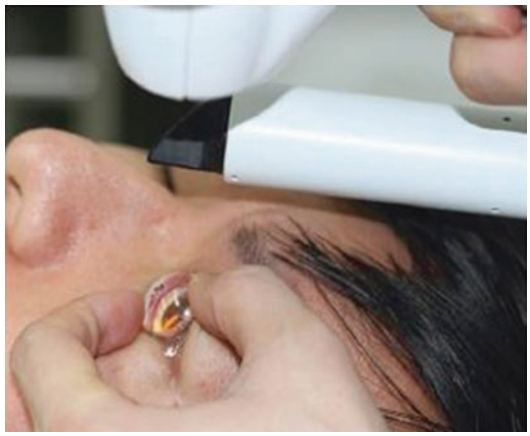

Fig. 12.3 Direct gonioscopy

is observed. Although it is difficult to observe the anterior chamber angle in the ear and nose directions compared to the up and down directions, observation can be easier when the slit lamp light is turned horizontally and the angle between the microscope and the slit lamp light is minimized. If corneal edema is severe, apply 75–100% glycerine solution to the cornea or remove the corneal epithelium and then observe.

Goldmann Gonioscopy Lens

There are one or two mirrors, so the lens should be rotated to the opposite side of the anterior chamber angle to see. Since the curvature of the lens is smaller than the curvature of the cornea, the lens will not be detached from the eye without pressing the lens. Excessive pressure can cause wrinkles in the cornea, resulting in poor visibility. Depending on the gonioscopy, the position, height, and angle of the mirror are different, and the angle of anterior chamber can be seen differently. For example, Goldmann's one-sided view shows angle of anterior chamber higher than that of Goldman's three-sided view. Therefore, it is easy to observe the eye with narrow angle of anterior chamber, which is difficult to see all the way to the bottom of the angle due to iris root. In addition, Goldman's three-sided view shows an anterior chamber angle in a more horizontal direction than Goldmann's one-sided view, so that the width of the trabecular meshwork is shown widely and the anterior chamber angle is easy to observe when it is the opening angle. Understand the characteristics of this gonioscopy and use appropriate gonioscopy.

Method

After topical anesthesia, fill the concave portion of the lens with methylcellulose. Have the patient look up, then place the lens on the lower eyelid, lift the upper eyelid with the other hand, place the lens on the upper eyelid, and lightly press. Let the mirror go to the 12 o'clock position, observe the widest 6 o'clock angle, then rotate the lens, and observe the anterior chamber angle in each direction. Trabecular meshwork looks slightly narrower than it actually is because it is slightly tilted with respect to the mirror. When the anterior chamber angle is narrow, tilt the lens toward the anterior chamber angle you want to look at (dive bomber view), or let the patient see the mirror (Fig. 12.4). If the anterior chamber angle is wide and deep, let the patient's eye slightly pointed to the opposite side of the mirror (cruise missile view), and then the trabecular meshwork will become parallel to the mirror and can be observed without deformation. With this tech-

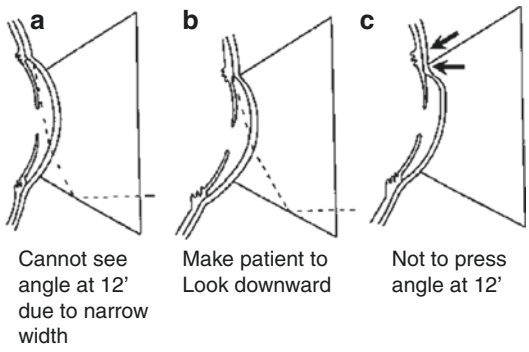

Fig. 12.4 Dive bomber view. (**a**) Cannot see angle at 12′ due to narrow width. (**b**) Make patient to look downward. (**c**) Not to press angle at 12′

nique, laser trabeculoplasty can be performed without changing the size of the laser beam.

Zeiss Gonioscopy

There are four mirrors, so you can observe 360° anterior chamber angle without rotating the lens. Because the curvature of the lens is similar to the curvature of the cornea, methylcellulose is not necessary. However, care should be taken not to push the eyeball at the time of examination, and it may be advantageous to perform indentation gonioscopy.

Method

After topical anesthesia, place the lens on the patient's eye in the same manner as the Goldmann gonioscopy. Gently place the lens on the cornea without pressing. The lens is better placed in a square shape rather than a diamond shape. Observe first from the angle of 6 o'clock and observe the other angle. If necessary, indentation gonioscopy is performed.

Indentation Gonioscopy

If the anterior chamber angle is narrow or closed and the anterior chamber angle structure cannot be seen, the indentation gonioscopy (Fig. 12.5) is necessary. If the central cornea is pressed, the surrounding iris moves backward, and the anterior chamber angle is widened due

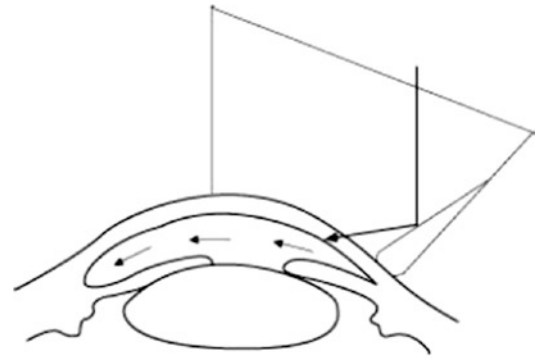

Fig. 12.5 Indentation gonioscopy

Fig. 12.6 Sussman 4 mirror lens

to the movement of the aqueous humor. In this way, it is possible to distinguish whether the anterior chamber angle closure is a simple contact state or closure due to adhesion. If the angle is simply contacting, it can be reopened with this technique. The lenses that can be used for the indentation gonioscopy are Zeiss-type goniolens, Iwata-Ricky lens, and Ocular Sussman mirror lens (Fig. 12.6).

Method

Let the patient see the opposite direction of the anterior chamber angle to be seen and press the lens toward the direction of the anterior chamber angle to be seen. Be careful not to slip the lens, press carefully, and observe; because if Descemet's membrane wrinkles are formed, the visualization of the angle is worsened (Fig. 12.7).

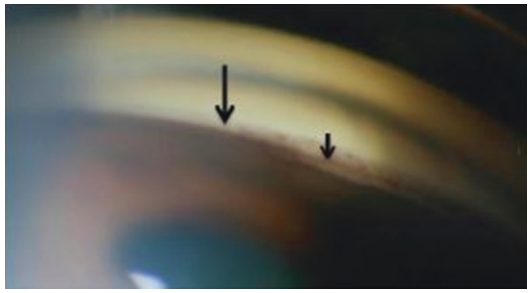

Fig. 12.7 A 55-year-old woman with primary angle-closure glaucoma. When the Sussman 4 mirror lens is pressed against the cornea, the trabecular meshwork hidden by the iris (small arrow) becomes observed. If trabecular meshwork is still not visible, the peripheral iris has adhesion (large arrow) to the trabecular meshwork. The point at which the open angle changes to the closed angle is clearly observable

12.1.3 Normal Anterior Chamber Angle and Normal Gonioscopy (Figs. 12.8 and 12.9)

12.1.3.1 Ciliary Body

A part of the anterior surface of the ciliary body is visible. In the case of colored people, it looks darker than the iris. At the angle recession glaucoma after trauma, the width of the ciliary body band is irregularly widened.

12.1.3.2 Scleral Spur

It is a grayish white line, the point of attachment of the fibers of the trabecular meshwork and ciliary muscle.

12.1.3.3 Trabecular Meshwork

This is a light gray band between the scleral spur and the Schwalbe line, with brown deposits as the age increases.

12.1.3.4 Schwalbe Line

Anatomically, it is the thickened end of the Descemet's membrane of the cornea. An indirect gonioscopy examination reveals that the parallelepiped lines of the cornea produced by the slit lamp light meet at this point (Fig. 12.10). Because the curvature of the cornea is steeper than the curvature of the sclera and the rough trabecular meshwork starts at this point, the pigment is piled up like dust on the shelf (Sampaolesi's line). Axenfeld-Rieger syndrome has an anteriorly displaced Schwalbe line (posterior embryotoxon).

12.1.4 Angle Grading

12.1.4.1 Becker-Shaffer Classification

1. Fourth degree: The anterior chamber angle is 45° wide, the front of the ciliary body is visible, and the anterior chamber angle is in a normal state without occlusion.
2. Third degree: The anterior chamber angle is 20°–45° in normal condition.
3. Second degree: The anterior chamber angle is moderately narrowed to 20°, and there is a possibility of occlusion.
4. First degree: The anterior chamber angle is 10°, the anterior chamber is narrowed, and the possibility of occlusion is high.
5. Slit: The width of the anterior chamber angle is less than 10°, and the possibility of closure is very high.
6. Zero degree: The anterior chamber angle is fully closed (Fig. 12.11).

12.1.4.2 Spaeth Classification

In addition to the Shaffer classification, the approximated area and shape of the iris were also classified to include the width of the anterior chamber angle as well as the shape of the anterior chamber angle (Fig. 12.12). Record the approximated area of the iris as A to E. Perform indentation gonioscopy and, if the approximated site is different after indentation, record it in parentheses. The shape of the anterior chamber angle can be determined by the area between trabecular meshwork surface and a hypothetical line drawn at the 1/3 peripheral portion of the iris, and record the shape as steep (s), regular (r), and queer (q) (Table 12.2, Fig. 12.13).

(C) D20s: 12 o'clock direction anterior chamber recordings are bulging of the peripheral iris.

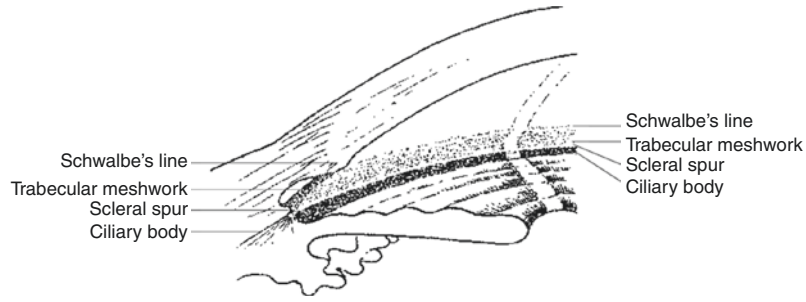

Fig. 12.8 Structure of anterior chamber angle

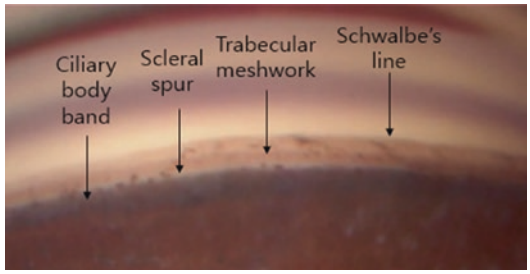

Fig. 12.9 Actual gonioscopy findings

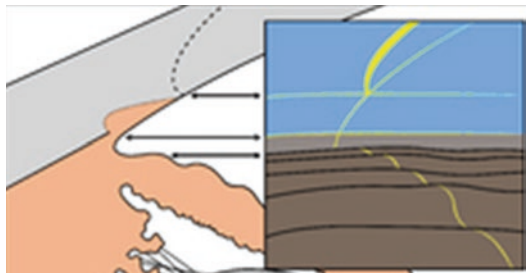

Fig. 12.10 Examination of corneal parallelepiped test. You can check the location of the Schwalbe line

If the iris is not pressed, the iris attaches to the scleral spur. When it is compressed, trabecular meshwork is seen and there is no pigmentation.

D20r +: 3 o'clock and 6 o'clock direction anterior chamber recordings have flat peripheral iris, trabecular meshwork, and pigmentation.

A10s: At 9 o'clock direction, the anterior chamber record shows that the peripheral iris is bulging, and the iris is attached to the anterior part of the trabecular meshwork, and the trabecular meshwork is not visible.

In addition, recession of the anterior chamber angle is observed at 2 to 4 o'clock position, and peripheral anterior synehiae (PAS) is observed from 7 to 10 o'clock.

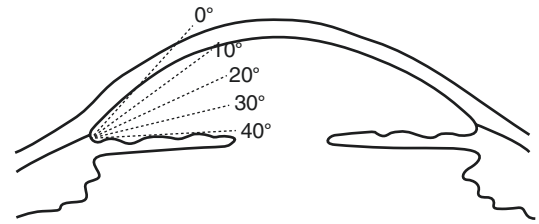

Fig. 12.11 Measurement of anterior chamber angle width by Becker-Shaffer classification

12.1.4.3 Scheie's Classification: Pigmentation of Trabecular Meshwork

As age increases, the degree of pigmentation of the trabecular meshwork also increases. After surgery or by disease, pigmentation can be increased.

12.2 Anterior Chamber Depth Test

12.2.1 Anterior Chamber Depth Test Using Slit Lamp Microscope

12.2.1.1 Van Herick Technique

The center and peripheral anterior chamber depth can be measured using a slit lamp microscope.

Method

Make the slit beam thin and illuminate it at the angle of 45–60° from the temporal side and observe the eye from the front. Evaluate the anterior chamber depth of the center. How many times the distance from the back of the cornea to the front of the lens to the corneal thickness is compared and evaluated roughly.

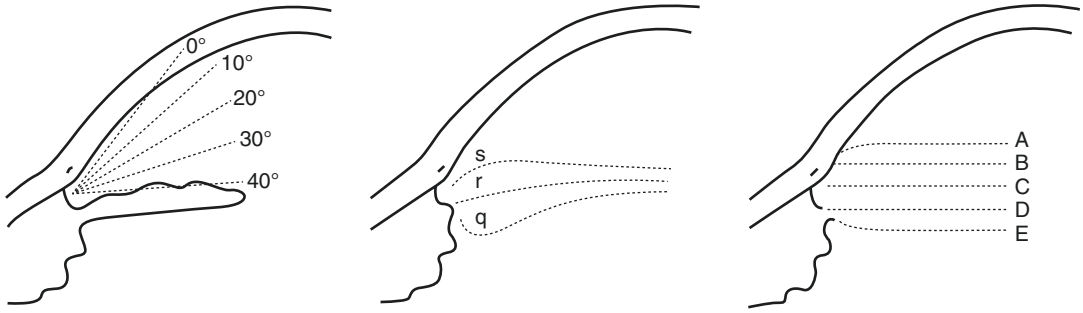

Fig. 12.12 Spaeth's anterior chamber angle classification

Table 12.2 Spaeth grading system

Angle width	The curvature of the peripheral iris	The iris insertion
10	q – queer, concave	A – anterior to meshwork
20	r – regularly flat	B – behind Schwalbe line
30	s – steeply convex	C – centered at scleral spur
40	s – very steep and convex	D – deep angle width visible face of the ciliary body
		E – extremely deep angle

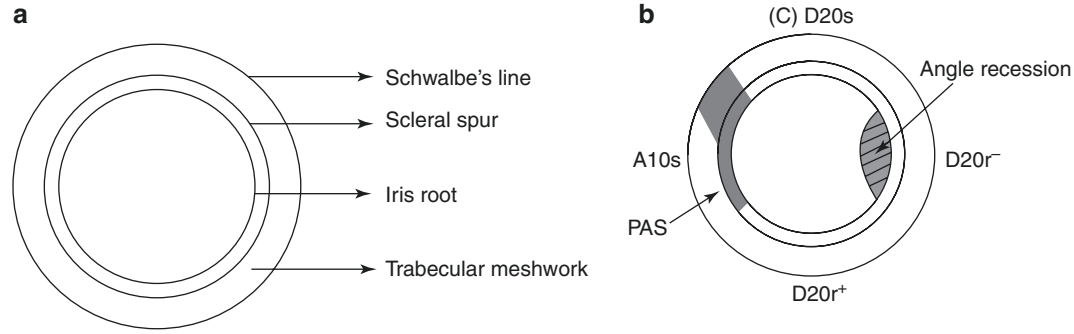

Fig. 12.13 Anterior chamber angle examination ((**a**) picture, (**b**) record)

Generally, if it is 6 times or more, it is deeper, 4–5 times is moderate, and 3 times or less is shallower. Assess the peripheral chamber depth. Project the slit beam at 60° from the front (perpendicular to the cornea) to the temporal limbus of the cornea and evaluate in the same manner as in the central anterior chamber. If the anterior chamber depth of the periphery is less than 1/4 of the corneal thickness, the possibility of the anterior chamber angle occlusion is high (Fig. 12.14).

12.2.2 Haag-Streit Anterior Chamber Depth Measuring Instrument

Anterior chamber depth can be accurately observed by the Haag-Streit slit lamp microscope attaching an accessory device using a prism.

Method

Place an anterior chamber depth-measuring instrument on the upper rod of a Haag-Streit slit lamp microscope and make the slit beam as thin

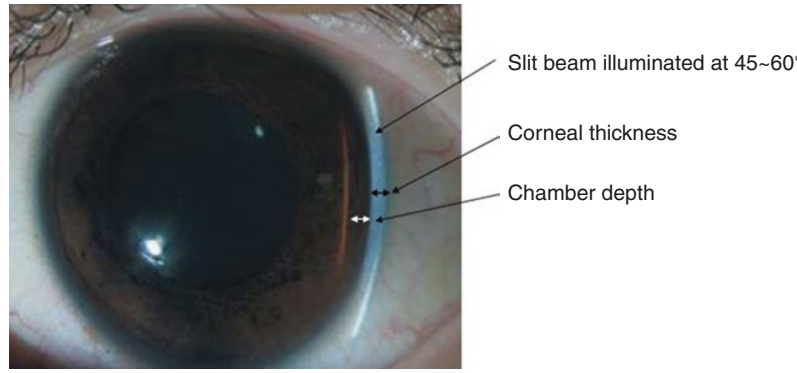

Fig. 12.14 Anterior chamber depth measurement using a slit lamp microscope, Van Herick technique

as possible through the gap in the plate attached to the anterior chamber depth-measuring instrument. Replace the right eyepiece of the slit lamp microscope with the eyepiece provided with the instrument. Turn the eyepiece so that the gap in the eyepiece is facing horizontally. The light source is illuminated from the front of the cornea, and observe the eye from the left side of the patient. When the examinee observes with his or her right eye, an optical slice of slit beam is divided into two segments (upper and lower). Move the upper scale of the anterior chamber depth-measuring instrument to align the two divided beams of the back of the cornea with the front of the lens and then read the scale to obtain the anterior chamber depth (mm).

12.2.3 Ultrasound Biomicroscopy

(See Chap. 17)

It is a noninvasive method to observe the anterior segment structures using high-frequency ultrasound.

Method

Place the ultrasonic probe vertically on the surface of the cornea on the axis. Measure the anterior chamber depth several times while taking care not to press the cornea.

12.2.4 Scheimpflug Camera Test

It is possible to perform objective evaluation by measuring anterior segment in the photo using computer after taking an image of anterior segment. It is good in accuracy and reproducibility.

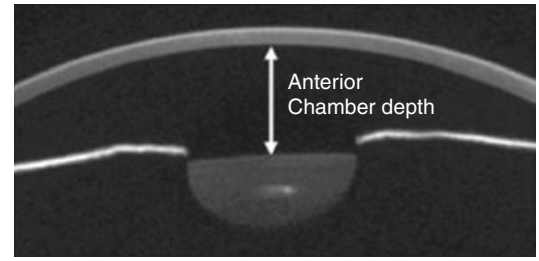

Fig. 12.15 Scheimpflug camera image shows anterior chamber depth

Method

Use a Scheimpflug camera (Pentacam®, Oculus) to photograph the anterior segment, with caution not to press the eyeball. Use the computer to measure the depth of the anterior chamber. Draw a vertical line between the back of the cornea and the front of the lens and then measure the distance between the back of the cornea and the front of the lens (Fig. 12.15).

12.2.5 Anterior Segment Optical Coherence Tomography

The Zeiss Visante OCT, the Cirrus HD-OCT 5000, and the Heidelberg Spectralis OCT with anterior segment module can be used to obtain anterior chamber angle image and to determine whether anterior chamber angle is open or closed. The anterior chamber angle and the anterior opening distance can be quantitatively measured

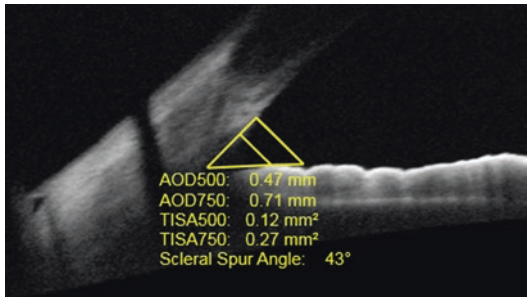

Fig. 12.16 Anterior chamber angle image of Cirrus HD-OCT 5000 shows angle opening distance (AOD 500/750), trabecular iris space area (TISA 500/750), and scleral spur angle

by drawing the lines between the scleral spur, the inner side of the cornea, the iris surface, and the angle recess (Fig. 12.16).

Suggested Reading

Balidis MO, Bunce C, Sandy CJ, Wormald RPL, Miller MH. Iris configuration in accommodation in pigment dispersion syndrome. Eye (Lond). 2002;16(6):694–700. https://doi.org/10.1038/sj.eye.6700115.

Bruno CA, Alward WLM. Gonioscopy in primary angle closure glaucoma. Semin Ophthalmol. 2002;17(2):59–68. https://doi.org/10.1076/soph.17.2.59.14721.

Fellman R. Gonioscopy. Atlas of Glaucoma. https://doi.org/10.3109/9780203007204-11.

Forbes M. Gonioscopy with corneal indentation: a method for distinguishing between appositional closure and synechial closure. Arch Ophthalmol. 1966;76(4):488–92. https://doi.org/10.1001/archopht.1966.03850010490005.

Foster PJ, Devereux JG, Alsbirk PH, et al. Detection of gonioscopically occludable angles and primary angle closure glaucoma by estimation of limbal chamber depth in Asians: modified grading scheme. Br J Ophthalmol. 2000;84(2):186–92.

Gazzard G, Friedman DS, Devereux JG, Chew P, Seah SKL. A prospective ultrasound biomicroscopy evaluation of changes in anterior segment morphology after laser iridotomy in Asian eyes. Ophthalmology. 2003;110(3):630–8. https://doi.org/10.1016/S0161-6420(02)01893-6.

Jensen PK, Nissen O, Kessing SV. Exercise and reversed pupillary block in pigmentary Glaucoma. Am J Ophthalmol. 1995;120(1):110–2. https://doi.org/10.1016/S0002-9394(14)73767-5.

Sakata LM, Lavanya R, Friedman DS, et al. Comparison of gonioscopy and anterior segment ocular coherence tomography in detecting angle closure in different quadrants of the anterior chamber angle. Ophthalmology. 2008;115(5):769–74. https://doi.org/10.1016/j.ophtha.2007.06.030.

Scheie HG. Width and pigmentation of the angle of the anterior chamber: a system of grading by gonioscopy. AMA Arch Ophthalmol. 1957;58(4):510–2. https://doi.org/10.1001/archopht.1957.00940010526005.

Singh P, Tyagi M, Kumar Y, Kuldeep K, Sharma PD. Gonioscopy: a review. Open J Ophthalmol. 2013;3(04):118–21. https://doi.org/10.4236/ojoph.2013.34025.

Thomas R, Thomas S, Chandrashekar G. Gonioscopy. Indian J Ophthalmol. 1998;46(4):255.

Troncoso MU. Gonioscopy and its clinical applications. Am J Ophthalmol. 1925;8(6):432b. https://doi.org/10.1016/S0002-9394(25)90063-3.

13 Optic Nerve Head and Retinal Nerve Fiber Exam

Keun-Heung Park

13.1 Optic Nerve Head Examination

13.1.1 Funduscopy

Ophthalmoscopy to observe lesions of the optic nerve head is important in diagnosing glaucoma and assessing progression of the disease. Observe and record the shape, size, and depth of the optic nerve head cupping, the color of optic nerve head, the running of the blood vessels, and the presence of small bleeding around the optic nerve head. Also, if you record the optic nerve head with your fundus camera longitudinally, it will help you to know whether the glaucoma is progressing or not.

13.1.1.1 Direct Ophthalmoscopy

The width of the slit beam is 1/3–1/2 of the width of the optic nerve head. Determine the neural rim using the shadow that is produced by moving the direct ophthalmoscope up, down, left, and right. Identify the edge of the neural rim in one place. Observe the circle and width of the neural rim along the circumference of the optic nerve head.

13.1.1.2 Binocular Ophthalmoscopy

You can inspect the optic nerve head three-dimensionally by slit lamp microscopy with Goldmann three-mirror lens, Hruby lens, or Volk lens. Use a green light to examine the retinal nerve fiber layer.

13.1.2 Result

13.1.2.1 Normal Finding

The size of the optic nerve head cupping is expressed as the ratio of the horizontal diameter of the cupping to the horizontal diameter of the disc (C/D ratio), but sometimes it is also evaluated in the vertical direction. The C/D ratio of a normal person is 0.4 or less, the difference of the binocular C/D ratio is 0.2 or less, and the C/D ratio is rarely more than 0.6.

13.1.2.2 Optic Nerve Head Change

Initially, optic nerve head cupping may not be evident, but if high intraocular pressure persists, optic nerve head cupping will proceed from the top to bottom and then to the temporal side. At the same time, the blood vessels on the optic nerve head are deflected and bent toward the nasal side. The base of the optic nerve head cupping is free from blood vessels and pale, and the cribriform plate is visible. In ophthalmoscopy, when the difference between the two eyes in the C/D ratio is greater than 0.2; the C/D ratio is greater than 0.5; the vertical oval cup is present, or local or peripapillary atrophy, or neural rim notch; or bleeding from the optic nerve head is visible, glaucoma is suspected (Fig. 13.1).

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Optic Nerve Head Cupping

The boundaries of the optic nerve head cupping should be measured not at the pale hue in the optic nerve head but at the bending point of the blood vessel going from the cupping to the edge of the optic nerve head. In the early period of chronic glaucoma, the vertical diameter is enlarged before the horizontal diameter, so pay attention to the vertical C/D ratio.

Neural Rim

If the IOP is consistently high, the boundary between the neural rim and the cupping becomes clearer, and a notch develops in the neural rim. The blood vessels on the optic nerve head are displaced to the nasal side.

Retinal Nerve Fiber Layer

If the fundus is examined with green light, a defect of the retinal nerve fiber layer may be found locally. Reflexes in the retina with loss of nerve fibers are less than those seen in normal retinal tissues.

13.1.3 Photograph of the Optic Nerve Head

The most convenient and inexpensive method for objectively monitoring the optic nerve head status of a patient is to photograph and compare the optic nerve head. The optic nerve head pallor and optic nerve head cupping ratio can be calculated directly from the photograph. The most important advantage is that you can record the state of the neural rim. The disadvantage is that the accuracy of optic nerve head cupping boundary is lower than that of stereoscopic photography.

13.1.4 Optic Nerve Stereoscopic Photography

In two-dimensional images, it is sometimes difficult to accurately determine the boundaries of optic nerve head cupping. A fundus camera is used to photograph two consecutive photographs at different angles in a horizontal direction. This method requires a lot of training to obtain a good image and has a disadvantage of poor reproducibility. Therefore, it is difficult to follow up the depth change of the optic nerve head cupping. Presently, a prism is adopted in the camera, and a method of taking two three-dimensional photographs at the same time is widely used because it is possible to obtain a highly reproducible stereoscopic image and digital analysis of the retina around the optic nerve head and the optic nerve head.

Method

A method of obtaining a stereoscopic image using a fundus camera is as follows. Enlarge the pupil as much as possible. Turn the lever for stereoscopic photography to make the camera in the semifixed status. This will limit the range in which the camera moves when you move the camera handle to the left or right, to the range

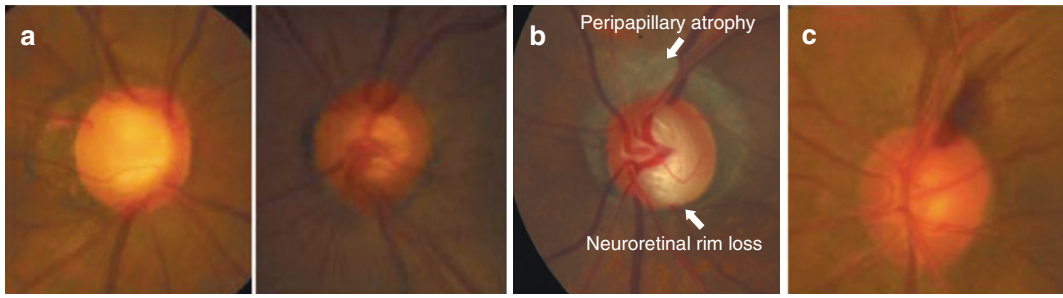

Fig. 13.1 Glaucomatous optic nerve head change. (**a**) The difference between the two eyes in the C/D ratio is greater than 0.2. (**b**) The C/D ratio is greater than 0.5, or the vertical oval cup is present, or local or peripapillary atrophy, or neural rim notch. (**c**) Bleeding from the optic nerve head is visible; glaucoma is suspected. (**b** Peripapillary atrophy (upper), neuroretinal rim loss (lower))

used for stereoscopic photography. Take a picture of the optic nerve head with the camera knob to the left and shoot it again to the right. The larger this range, the better the stereoscopic effect can be obtained. Move within the appropriate range in order not to be covered by pupil, which may affect the image quality.

13.1.5 Optic Nerve Head Analysis

This is for quantitative analysis of information on neural rims, optic nerve head cupping, and other optic nerve heads.

13.1.5.1 Stereophotogrammetry

In addition to the first developed PAR IS 2000 (Topcon ImageNet®), there are Rodenstock Optic Nerve Head Analyzer®, Humphrey Retinal Analyzer®, and Glaucoma-Scope®. These analytical instruments analyze the information using a digitally recorded stereoscopic fundus photograph or a 35 mm photograph taken with a digitizer. The boundary of optic nerve head cupping is set by the examiner, or the machine itself sets the vertical and horizontal optic nerve head cupping ratio, the area of the optic nerve head cupping area, the area ratio of the optic nerve head, and the volume of the optic nerve head cupping. Reproducibility is low, pupil dilation is necessary, and it is difficult to obtain a good image if the ocular medium has turbidity.

13.1.5.2 Confocal Laser Scanning

After confocal laser scanning was first developed, Heidelberg retina tomograph (HRT, Heidelberg Engineering, Heidelberg, Germany) was commercialized. HRT 3 can be used to construct a 3D image of the optic nerve using a 670 micron diode laser with 64 cross sections with 1/16 mm intervals (Fig. 13.2). The depth of each of the 64 sections is 4 mm, and each section has 384 × 384 points, and each of the points has the horizontal, vertical, and height values. When the image is obtained, the examiner displays the optic nerve head contour and sets the reference plane 50 μm behind the contour and the retinal surface (350–356°) on the papillomacular bundle to distinguish between neural rims and optic nerve head cupping. You can obtain various parameters including optic nerve head, optic nerve head cupping, and neural rim area and volume. You can also divide the optic nerve head into multiple zones and obtain index values in each zone. The thickness of the retinal nerve fiber layer is also obtained, and it helps to evaluate the minute changes over time (Fig. 13.3).

The index for the cup is represented by the linear cup/disc ratio and the cup shape measure. Indices for the neural rim appear as rim area and rim volume. Indices for RNFL are height variation contour and mean RNFL thickness. Each indicator is categorized as normal (green), border (yellow exclamation mark), abnormal (red mark), and displayed asymmetry of both eyes. Moorfields regression analysis (MRA) compares the rim area and volume values with normal values, taking the area and age of the optic nerve into consideration.

13.1.5.3 Optical Coherence Tomography, OCT

In the spectral domain OCT, Cirrus OCT (Carl Zeiss Meditec, Dublin, California), the edge of the optic nerve head is determined by the termination of Bruch's membrane. The neuroretinal rim area of the optic nerve head is determined by measuring the amount of nerve tissue in the optic nerve. This method differs from methods used in HRT that determines the cupping edge

Fig. 13.2 Heidelberg retina tomograph (HRT) 3

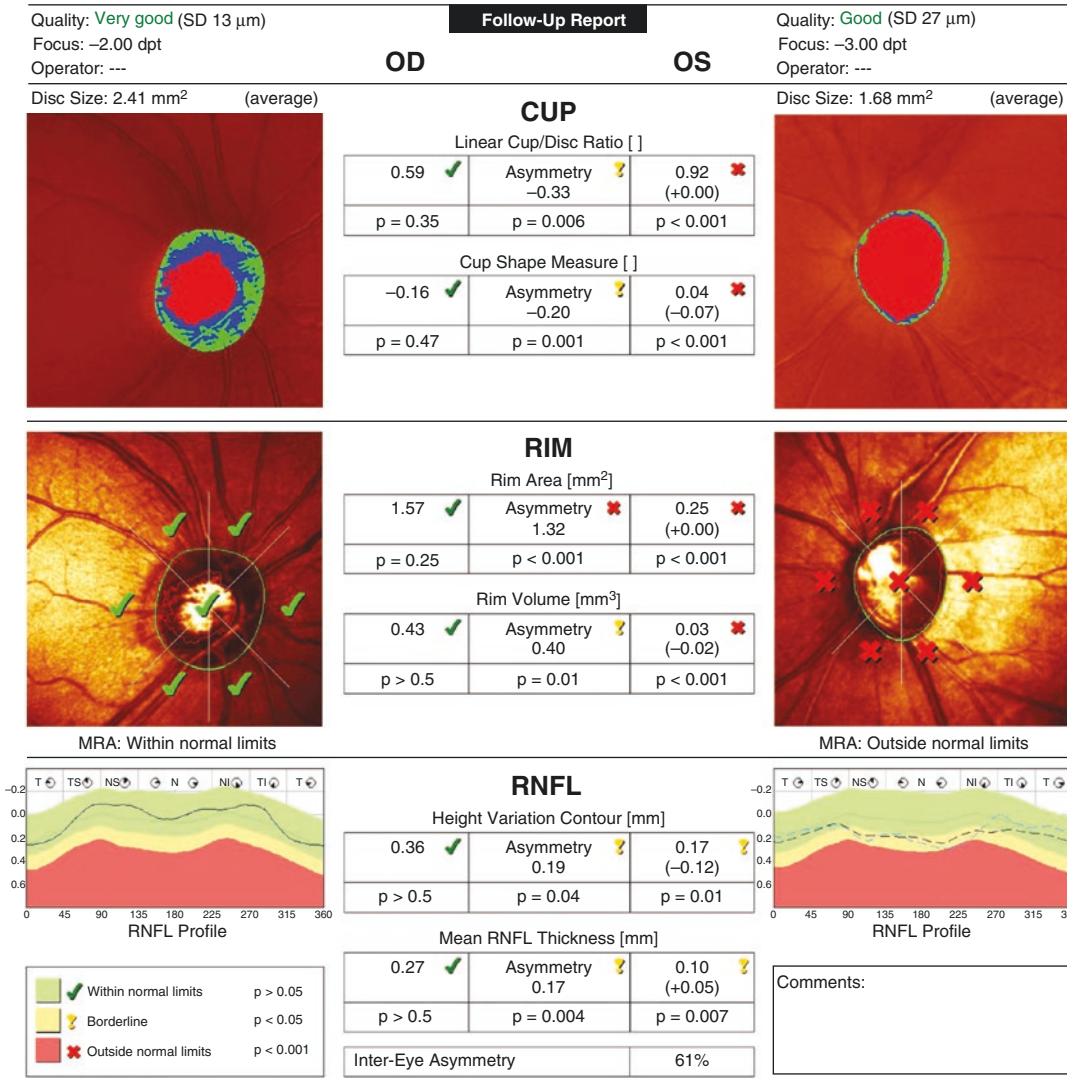

Fig. 13.3 Confocal laser scanning for optic nerve head and retinal nerve fiber layer

relative to the plane, intersecting the plane at a fixed distance above the optic nerve head (Fig. 13.4).

The neural rim area (mm^2) is a summary of the dark gray neural rim range shown at the top of the RNFL thickness map. The light gray range on the same map is the cupping area (mm^2), and the total area of the optic nerve head is the neural rim area plus the cupping area (mm^2). The average C/D ratio is given as the square root of the cupping area ratio to the optic nerve head area, and the vertical C/D ratio is the ratio of the cupping diameter to the optic nerve head diameter in the vertical meridian. The cupping volume is a 3D measurement defined as the volume between the plane generated by the cupping contour at the vitreous interface and the backside of the optic nerve head.

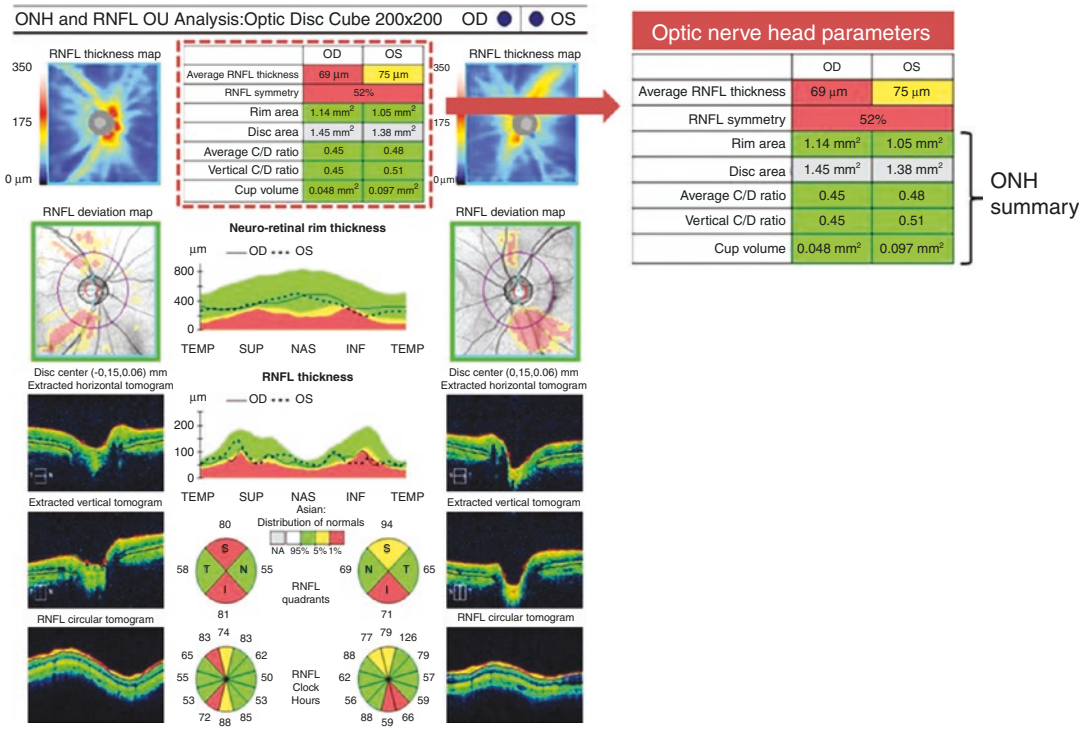

Fig. 13.4 Optic nerve head summary parameters

13.2 Evaluation of the Retinal Nerve Fiber Layer

The main cause of visual field defect in glaucoma is the loss of ganglion cells. The purpose of examining the retinal nerve fiber layer is to diagnose early glaucoma and progression of glaucoma changes early (Fig. 13.5). In addition to glaucoma, localized retinal nerve fiber layer defects can also be caused by optic nerve drusen, toxoplasma, retinochoroidal scars, and cotton-wool spots in ischemic retinal disease.

13.2.1 Retinal Nerve Fiber Layer Photograph

It is the easiest way to examine the retinal nerve fiber layer. The retinal nerve fibers are observed three-dimensionally through a slit lamp microscope using a contactless or noncontact lens while illuminating red or green light or photographed with a fundus camera.

13.2.2 Scanning Laser Polarimetry

The GDx variable corneal compensator (GDx VCC, Carl Zeiss Meditec, Dublin, Calif.) indirectly measures the thickness of the retinal nerve fiber layer by illuminating a 780 nm diode polarized laser onto the retina and analyzing the double refraction of the retinal nerve fiber layer with a polarimeter.

13.2.3 Optical Coherence Tomography, OCT

It is a noncontact, noninvasive method using near-infrared wavelengths of 830–843 nm. Although a high-resolution monolayer image can be obtained within 1 s, a pupil of about 5 mm or more is required (see Chap. 18).

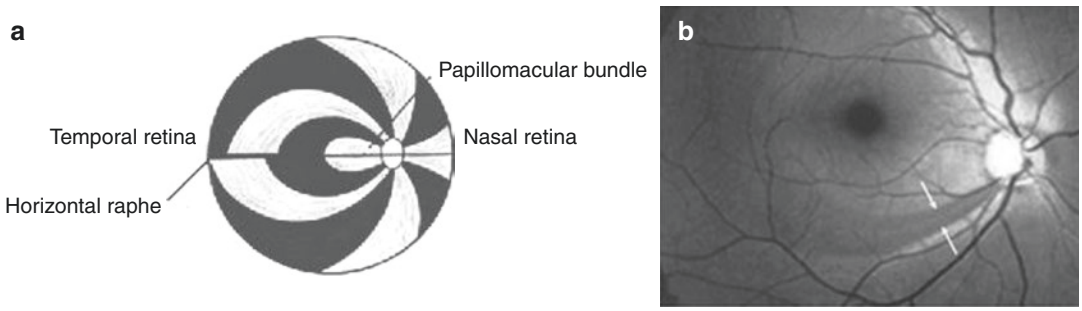

Fig. 13.5 The retinal nerve fiber layer. (**a**) A schematic diagram of direction of retinal nerve fiber coming from the optic nerve head. (**b**) Retinal nerve fiber layer defect

Suggested Reading

Airaksinen PJ, Drance SM. Neuroretinal rim area and retinal nerve fiber layer in glaucoma. Arch Ophthalmol. 1985;103(2):203–4.

Folio LS, Wollstein G, Schuman JS. Optical coherence tomography: future trends for imaging in glaucoma. Optom Vis Sci. 2012;89(5):E554.

Hawkins S, Osborne A, Schofield S, Pournaras D, Chester J. Improving the accuracy of self-assessment of practical clinical skills using video feedback–the importance of including benchmarks. Med Teach. 2012;34(4):279–84.

Hoyt WF, Frisen L, Newman NM. Fundoscopy of nerve fiber layer defects in glaucoma. Invest Ophthalmol Vis Sci. 1973;12(11):814–29.

Kong YXG, Coote MA, O'Neill EC, Gurria LU, Xie J, Garway-Heath D, Medeiros FA, Crowston JG. Glaucomatous optic neuropathy evaluation project: a standardized internet system for assessing skills in optic disc examination. Clin Exp Ophthalmol. 2011;39(4):308–17.

Mwanza J-C, Budenz DL. New developments in optical coherence tomography imaging for glaucoma. Curr Opin Ophthalmol. 2018;29(2):121–9.

Nicolela MT, Drance SM. Various glaucomatous optic nerve appearances: clinical correlations. Ophthalmology. 1996;103(4):640–9.

Quigley HA, Addicks EM. Quantitative studies of retinal nerve fiber layer defects. Arch Ophthalmol. 1982;100(5):807–14.

Reus NJ, Lemij HG, Garway-Heath DF, Airaksinen PJ, Anton A, Bron AM, Faschinger C, Holló G, Iester M, Jonas JB. Clinical assessment of stereoscopic optic disc photographs for glaucoma: the European Optic Disc Assessment Trial. Ophthalmology. 2010;117(4):717–23.

Sakata LM, DeLeon-Ortega J, Sakata V, Girkin CA. Optical coherence tomography of the retina and optic nerve–a review. Clin Exp Ophthalmol. 2009;37(1):90–9.

Stone RA, G-s Y, Pearson DJ, Bansal M, Puri M, Miller E, Alexander J, Piltz-Seymour J, Nyberg W, Maguire MG. Utility of digital stereo images for optic disc evaluation. Invest Ophthalmol Vis Sci. 2010;51(11):5667–74.

Swindale NV, Stjepanovic G, Chin A, Mikelberg FS. Automated analysis of normal and glaucomatous optic nerve head topography images. Invest Ophthalmol Vis Sci. 2000;41(7):1730–42.

Wollstein G, Garway-Heath DF, Hitchings RA. Identification of early glaucoma cases with the scanning laser ophthalmoscope. Ophthalmology. 1998;105(8):1557–63.

Yücel YH, Gupta N, Kalichman MW, Mizisin AP, Hare W, de Souza Lima M, Zangwill L, Weinreb RN. Relationship of optic disc topography to optic nerve fiber number in glaucoma. Arch Ophthalmol. 1998;116(4):493–7.

Zangwill LM, Chan K, Bowd C, Hao J, Lee T-W, Weinreb RN, Sejnowski TJ, Goldbaum MH. Heidelberg retina tomograph measurements of the optic disc and parapapillary retina for detecting glaucoma analyzed by machine learning classifiers. Invest Ophthalmol Vis Sci. 2004;45(9):3144–51.

Zupan M, Mikek K, Gruden S. Ophthalmoscopic evaluation of the optic nerve head. Slovenian Med J. 2002:71(2).

Visual Field Test

14

Ji-Woong Lee

The visual field examination is a method of measuring the sensitivity of test points and the range of visual fields from the fixation point (Fig. 14.1). The line connecting the test points that can recognize the equivalent stimulus within the visual field is called an isopter, which indicates the limit of the area within which a specific target can be seen. The visual field test is performed in patients with visual disturbance, glaucoma, diplopia, hysteria, retinal detachment, central serous chorioretinopathy, retinal pigment degeneration, retinal vein occlusion, papillary edema, and optic disc disease. In addition, it is performed in patients with headache, epilepsy, brain tumor, head trauma, and fracture. Since the optic nerve fibers have constant arrangement from the retina to the cortex, lesions affecting the pathway of the nerve fibers cause a characteristic change in visual field. By examining these changes in visual field, important information can be obtained for diagnosis, lesion location in visual pathway, and disease progression.

In the early stage of disease, visual field test is a very useful method to detect and evaluate visual loss due to glaucoma because glaucoma does not cause a decrease in visual acuity until very advanced stage.

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14.1 Selection of Visual Field Test Method

Screening test is used to check the presence or absence of abnormalities, while threshold test is used to precisely examine the degree of abnormalities. Usually the visual field test is performed after a general ophthalmologic examination, so choose a proper method to detect the abnormality of a suspected disease. Screening test can be done in a short time, so it is useful for children or elderly people who have difficulty in having threshold examination. The Humphrey visual field analyzer, which is the most commonly used automated perimeter, includes Central 40, Full field 120, and Central 76 and full threshold (30-2, 24-2), Fastpac, SITA strategy (30-2, 24-2). The Swedish Interactive Testing Algorithm (SITA) strategy can be performed in a short period of time.

The confrontation method does not need a device and can be performed for patients who cannot be seated or if their visual acuity is very poor. The Goldman perimeter is useful for children or elderly people who cannot cooperate well because examiner can see the patient's reactions during the examination. It is also useful for the detection of peripheral visual field defect and location of intracranial disease, especially for evaluation of occipital lesions. On the other hand, it is difficult to precisely evaluate the central scotoma within 10 degree, and it is necessary to have an experienced examiner.

The automated perimeter is effective because it examines the sensitivity reduction near the cen-

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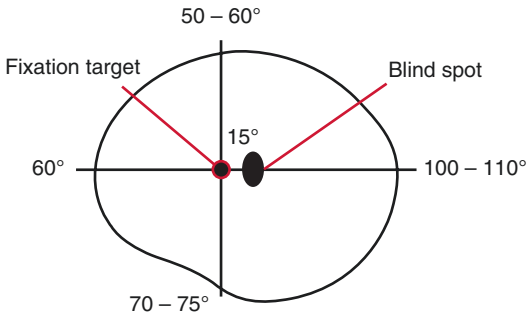

Fig. 14.1 Normal visual field. The normal range of visual field is the widest at 100–110 degrees on temporal side, 70–75 degrees on the inferior side, 60 degrees on the nasal side, and 50–60 degrees on the superior side. Normally, there is a blind spot, or physiological blind spot, at about 15 degrees from the center of the macula to the temporal side, which corresponds to an optic nerve head that does not have photoreceptor layer

ter and detects the early stage of glaucoma. It evaluates the change in visual field during the follow-up and useful in finding out the visual field defect with respect to the vertical meridian. It is not affected by the examiner's skill. However, it is necessary to consider the reliability of test results for interpretation.

Basically, it is efficient to examine the central visual field defect with the static visual field test and the peripheral visual field defect with the dynamic visual field test. Because central visual field defect occurs in the early stage of optic tract disease, static visual field is useful for the diagnosis. The lesion located ahead of the optic chiasm also often causes a central scotoma. Therefore, the examination of the central visual field is helpful for diagnosis. In a lesion of the central nervous system behind the optic chiasm, the confrontation technique may be simpler and more useful. In order to evaluate the precise boundaries of the hemianopsia, the dynamic visual field test may be useful.

14.2 Factors Affecting Visual Field Test Results

14.2.1 Patient Factors

As age increases, the visual field sensitivity decreases, and fluctuations become severe in repeated tests. The influence of age on visual field is mainly observed in the peripheral visual field and upper field. In automated perimeter, fixation loss is automatically recorded. Patient cooperation is important for visual field examination, and the patient's cooperation can be assessed through false-positive rate, false-negative rate, and fixation loss. Reliability should be considered when interpreting the results of visual field tests. The learning effect, fatigue, drug, concentration, tension, and anxiety affect the test results, so the visual field examination room should be cool, dry, dust-free, backlit, and comfortable.

14.2.2 Ocular Factors

The patients need to have visual acuity good enough to see the target used for visual field tests. Generally, Snellen visual acuity should be 0.3 or more for automated perimetry. Near vision correction according to age is necessary for patients with presbyopia. If astigmatism is less than 1.25 diopter, it should be corrected with spherical equivalent. If astigmatism is greater than 1.25 diopter, it should be corrected with cylindrical lens. The aphakic eyes are corrected with a contact lens. A pupil size of 3 mm or more is suitable. If the pupil size is smaller, the overall sensitivity decreases, so it is recommended to record the pupil size. The media opacity, such as corneal opacity, cataract, and vitreous opacity, also reduces the sensitivity.

14.2.3 Factors Related to Examination

Generally, the target has uniform brightness in white, circular shape. The bigger the target, the easier it is to be recognized. The background illumination is usually 4–31.5 apostilb (asb), and the visual field defect pattern may be different depending on the background illumination. If the target's exposure time is too short, the sensitivity may be reduced.

14.3 Manual Perimetry

14.3.1 Confrontation Test

Confrontation test can detect the approximate shape and range of visual field defect. The examiner's visual field should be normal. The patient and the examiner sit 1 m away. Cover the eyes that face each other. The right eye is examined first, but if there is a difference in visual acuity between the two eyes, the better eye is examined first. Make sure that the unexamined patient's eye is completely covered. The examiner also closes the eye opposite to the patient's covered eye. Have the patient look at the eyes or nose of the examiner. Place the target (finger or light source) at the middle in between the examiner and the patient, move the target from the periphery to the center, and examine the visual field of the patient by comparing the position at which the target is recognized by the examiner. It is convenient to use an eye-drop bottle with a colored cap (Fig. 14.2). If abnormality is found, the defect is displayed on the 360-degree visual field figure (Fig. 14.3).

14.3.2 Amsler Grid Test

Amsler grid test can detect the visual field defect from macular degeneration, central serous chorioretinopathy, and optic nerve diseases such as retrobulbar optic neuritis for central 10–20 degree macula.

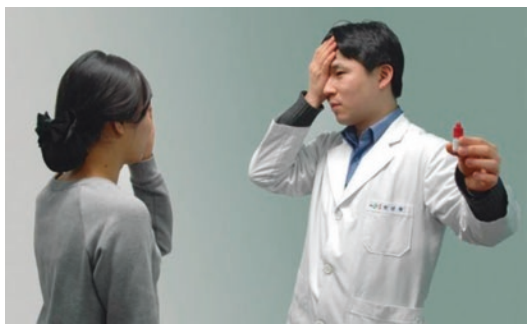

Fig. 14.2 The technique of confrontation test. The examiner has an eye-drop bottle with a red-colored cap in his left hand while he covers his right eye with the right hand

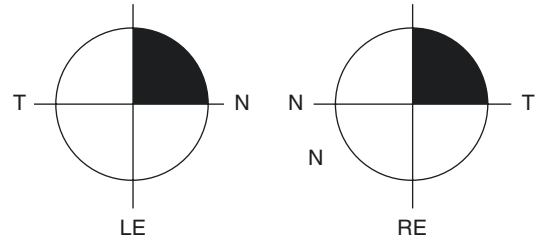

Fig. 14.3 The results of confrontation test show superotemporal quadrantanopsia

Use a white grid or a red line on a black background with a grid of 5 mm (single-pitch) spacing and 20 × 20 grid (Fig. 14.4a). Patient with near vision correction closes the untested eyes. The patient is asked to answer if the whole grid is complete with each line is parallel or it is bent while he or she is looking at the central point of the whole grid. Ask the following questions and have the patient record the results on a grid of black lines on a white background (Fig. 14.4b), the name of the patient, the eyes examined, the date, and whether the abnormality is indicated on the patient's outcome sheet:

- Do you see the point in the center?
- Looking at the center point, can you see the four corners of a large square?
- Is there a broken hole or spots in the middle of the grid? If so, where?
- Are the entire horizontal and vertical lines parallel when you are looking at the center point? Is each grid a complete square?
- Do you see anything other than faint or bent line?
- How many normal square grids can you see from the center to the faint or bent line?

14.3.3 Goldmann Perimetry

Goldmann perimetry is useful for evaluating overall visual field in patients with brain diseases, advanced glaucoma, retinitis pigmentosa, and visual disturbance of psychogenic origin particularly when it is difficult to identify the visual field defect pattern with the automated perimetry. The Goldman perimeter consists of a hemisphere

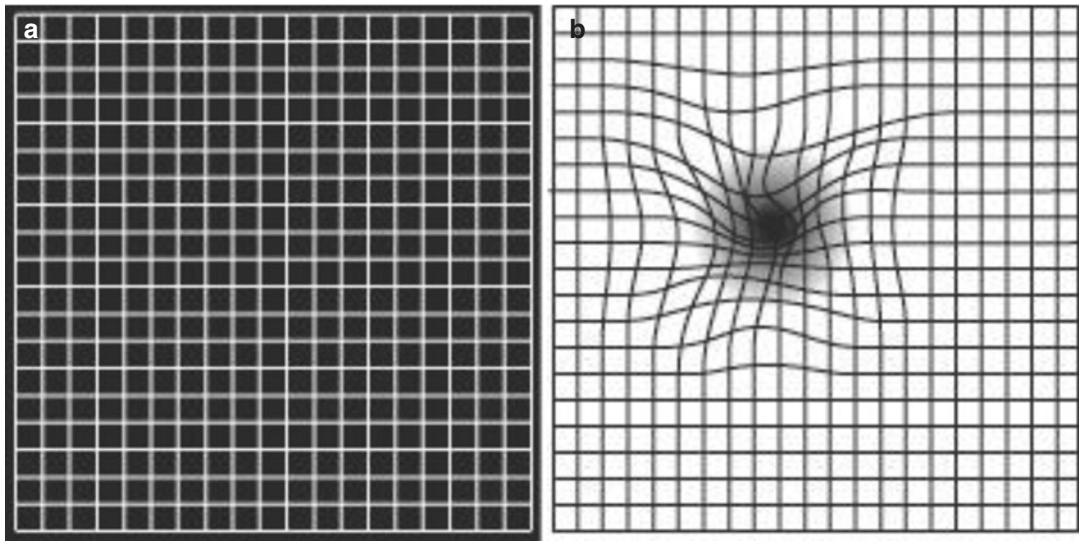

Fig. 14.4 (**a**) Amsler grid. (**b**) Amsler grid result of patient shows the lesion area where several lines are bent

Fig. 14.5 Goldman perimeter with dome and chin rest

with a white background (Fig. 14.5). It is designed to examine visual field under the constant measurement condition by standardizing the background brightness and the size and intensity of the target in several steps and test both the center and peripheral fields.

14.3.3.1 Methods

Install the perimeter so that direct light does not enter the hemisphere. Adjust the horizontal plane turning the two handles on the sides. Check whether the light source for inspection is set in proper condition. Set the target brightness. Set the target size to V and the target brightness to 4 (1000 asb), and place the recording sheet at a predetermined position. When the target moving plate is fixed to the right 70-degree position on the horizontal meridian, the target is projected on the brightness measuring instrument, and the target brightness is adjusted to be 1000 asb. Set the background brightness. If you move the plate in the brightness measuring instrument, the target is projected onto the plate with the same reflectance as the hemisphere. Set the target brightness to 1 (31.5 asb). Look through the telescope from the opposite side and adjust the target and background brightness uniform. Always adjust the target and background brightness before every measurement to make the inspection conditions constant.

The refraction of the eyes should be corrected for central 30-degree visual field test. Normal or better eyes should be performed first. Make sure that the eye is completely covered by eye patch that does not cross the nose. Raise the upper eyelid with a bandage for the eyes with ptosis. Move the chin rest to the left during the right eye test and move the chin rest to the right for the left eye

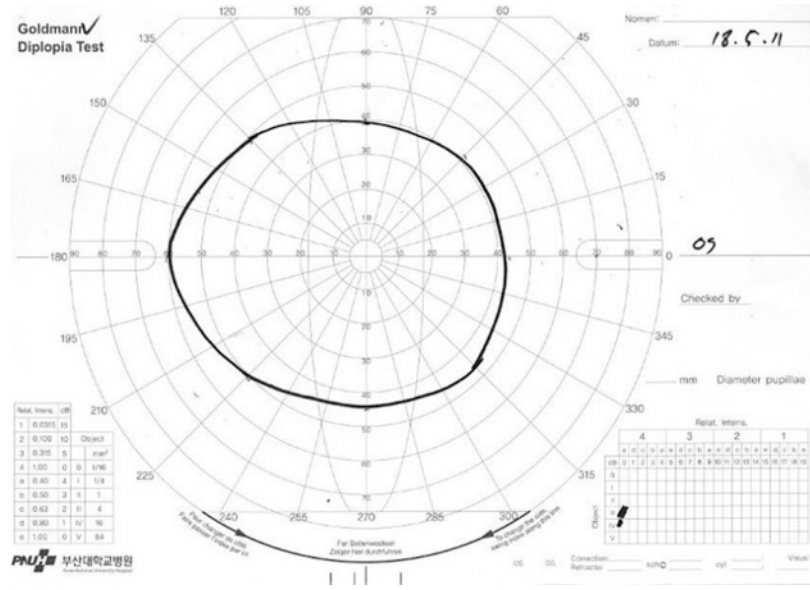

Fig. 14.6 The result of Goldman perimeter of the left eye

test. Allow the patient to be used to the perimetry for 2 minutes before starting the test. Behind the hemisphere through the telescope, adjust the patient's pupil position to the center with the adjusting screw, and observe the fixation status frequently during the examination. The target size ranges from 0 to V (0, 1/16 mm^2; I, 1/4 mm^2; II, 1 mm^2; III, 4 mm^2; IV, 16 mm^2; V, 64 mm^2). The stimulus intensity ranges from 1 to 4 (increased by 5 dB) and a to e (increased by 1 dB). The test generally starts from I-4-e, I-3-e, I-2-e, and I-1-e. If the isopter is narrow, check with larger targets (II–V).

Start examination while moving the target from the periphery of the meridian to the center at a rate of about 5 degrees/sec, and examine the central field at a rate of 2–3 degrees/sec. The meridian is measured at an interval of 30–45 degrees. When measuring the next isopter, check the meridian that has not been inspected before. The V-4 target does not need to be measured very precisely, just move the target at a 45-degree interval. When the patient looks at the target and signals, record the target with a pencil, and connect the points as smoothly as possible to draw an isopter. When moving the target from the center to the periphery, be sure to turn off the target before moving.

The blind spot is located at about 15 degrees on the temporal side and 3 degrees on the inferior side of the horizontal meridian. Move the I-4 target to the center of the blind spot after turning off the target and confirm that it is invisible by flashing the target. Move the target in four directions up and down, left and right from the center, and eight directions in between. Then draw a line connecting the points which the patient signals. Normally, each isopter is drawn at almost the same interval. If there is scotoma, the range of the scotoma is quantitatively measured by changing the brightness or size of the target. If there is no scotoma, change the brightness of the target, and measure the isopter in the middle area (Fig. 14.6).

Refractive correction for examination distance (33 cm) should be done. If patients have myopic glasses, they may use it. Use the corrective lens after performing the refractive correction if the visual field is narrower than the normal range of each isopter or if the target is not visible. Always monitor the patient's attention during the examination. Some patients do not blink because they focus too much on the test, but in this case, fatigue or dryness of the cornea may reduce the accuracy of the test.

14.3.3.2 Characteristic Visual Field Findings and Examination Method

From the shape of the visual field defect, it is possible to speculate where the brain lesion is present. Ring scotoma is characteristic visual field

defect of retinitis pigmentosa. First, measure from the periphery with the V-4 target, and then measure with the I-4 target. If a ring scotoma is suspected, the V-4 target is statically illuminated between V-4 and I-4. If there is no abnormality with the V-4 target, you may use II-4 or III-4 target. In the early stage, scattered isolated scotomas may be found in some cases.

Glaucoma is characterized by paracentral scotoma, Bjerrum scotoma, and nasal step. In more than 90% of cases, the scotoma is located within the central 30 degree.

Central scotoma is found in cases with optic neuritis and macular holes. First, measure from the periphery with the V-4 target, identify each isopter, and then move the target from the center toward the periphery to check the size of scotoma. If the decline in sensitivity at the center is not severe, the I-4 target can be used because the scotoma may not be detected with the V-4 target.

14.4 Automated Perimetry

The automated perimetry is a visual field system that automatically illuminates the target and records the response of the patient to the target illuminated. It is possible to quantitatively measure the photosensitivity of the area by changing the brightness of the target at a predetermined check point so that it is possible to detect a small scotoma more sensitively than the manual perimetry and standardize the inspection conditions equally so that the objective visual field can be judged. Because of installed age-matched sensitivity, the accuracy and reproducibility of the test results were excellent, and it became the standard of glaucoma visual field test. Typical automated perimetries include Octopus® and Humphrey® (Fig. 14.7).

The backlight is generally fixed depending on the device. Octopus uses a brightness of 4 asb, and Humphrey uses brightness of 31.5 asb, same as the Goldman perimetry. Depending on the equipment that illuminates the target, the type of perimetry can be divided into one with a projection method or a semiconductor method. Humphrey and Octopus project their targets in a projection manner. The projection method can change the color of the target, and early detection of glaucoma has been attempted using short-wavelength automated perimetry (SWAP) which project a blue target on a yellow background.

Humphrey projects stimulus for 0.2 second and Octopus projects stimulus for 0.1 second. The interval between projections of stimulus can be adjusted according to the reaction of the patient. The size of the stimulus is the same as the Goldman perimeter size III (4 mm^2), and the brightness is adjusted according to the strategy. The distance from the eye to the stimulus is about 30–51 cm depending on the perimetry. Patient fixation can be monitored directly by the examiners or monitoring of pupil position and eye blinking using a video camera and stimulation of the blind spot.

Several statistical programs have been developed to analyze the visual field change. The most commonly used ones are Humphrey's STATPAC and Octopus's Delta program. These statistical programs incorporate statistical data on the normal visual field sensitivity of the patient's age group, assessing the significance on the visual field abnormalities from the patient's visual field sensitivity and assessing progression compared with previous examinations. These statistical programs provide an accurate interpretation of visual field changes, but the judgment by experienced ophthalmologist is essential in the application in clinical practice.

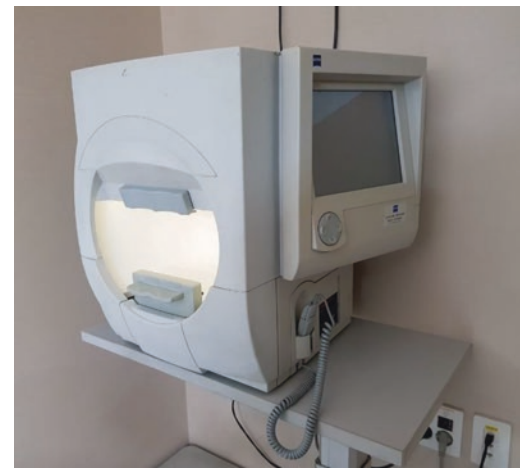

Fig. 14.7 Humphrey perimeter

14.4.1 Testing Strategies

Suprathreshold static perimetry is a measurement method that gives a stimulus slightly higher than the normal threshold to the corresponding retina to detect the presence or absence of the reaction. The test time is short and is used as a screening test, but it is not suitable for finding the depth or shape of a scotoma. To compensate for aforementioned drawbacks, a threshold-related strategy that projects 4–6 dB brighter stimulus than the threshold of the patient's previous examination to can be used to determine the progression of visual field defect. 'Three Zone' option of the multiple level test (Humphrey) distinguishes the absolute scotoma from the relative scotoma by stimulation of a field defect with maximum intensity that did not respond to suprathreshold stimulus. Octopus program 03 or 07, 'Quantify Defects' options measure the sensitivity of a field defect that does not recognize the suprathreshold stimulus.

Threshold static perimetry is the standard method to detect the threshold of each test location of patient's visual field with first projecting suprathreshold stimulus and then increasing or decreasing the stimulus intensity gradually. A commonly used program is to measure the thresholds of 70–80 test points in the central 24 degree and 30 degree with a 6-degree-apart grid test (Octopus program 32, Humphrey central 24-2 and 30-2). For patients with central visual field abnormality, the central 10-2 examination with 2-degree-apart grid is recommended (Table 14.1).

The basic algorithm is a full threshold. The first stimulus gives a brighter light than the expected threshold of the patient. If the patient recognizes the stimulus, the brightness of the stimulus decreases by 4 dB until it cannot be recognized. The brightness is then increased by 2 dB (4-2 algorithm). It is checked once more by 2 dB (4-2-2 algorithm). Repeating three times takes longer but more accurate than repeating only two times. At present, the general visual field test system uses the 4-2 algorithm. Thus, the time required to examine the central visual field 30 degrees is about 15–20 minutes, which requires considerable patient fatigue. Several algorithms have been developed to shorten the examination duration.

Fastpac measures threshold only once per test location with changing the stimulus intensity by 3 dB. The examination duration is shortened to about 70%, but it is affected by the patient's mistakes, and the fluctuation of the threshold value is large. The error between the tests was reported to be similar to that of the full threshold. The SITA strategy, reduced the test time to half of the full threshold with visual field modeling and information index, control of the examination time depending on the patient response time, and recalculation of the measured thresholds. Test results were reported to be similar to that of full threshold.

14.4.2 Methods

Turn on the power and select the type of visual field test. Enter patient information such as identification number, name, date of birth, correction lens, and other eye conditions (diagnosis, pupil size, visual acuity, intraocular pressure, cup-to-disc ratio). The pupil should be located at the center of the corrective lens, and a contact lens is more preferred for patients with ±6 diopter or more. After covering one eye not to be inspected,

Table 14.1 Typical threshold testing program for Humphrey perimeter

Program	Purpose	Location	Number of test points	Density
Central 30-2	Within 30 degree	Central grid	76	6 degree
Central 24-2	Within 24 degree	Central grid	54	6 degree
Central 10-2	Within 10 degree	Central grid	68	2 degree
Macula	Macula	Central grid	16	2 degree
Peripheral 60-4	30–60 degree	Peripheral grid	60	12 degree

have the patient to get accustomed to the brightness of the visual field machine for about 3 minutes before the examination. Have the patient look at the bright light of fixation target in the center, and press the response button when the stimulus projected to the hemisphere is flashing. The examiners monitor through the screen whether patient's gaze is directed at the fixation target. If the patient feels tired during the test and is unable to focus on the test, the test can be temporarily discontinued with the response button pressed. After the test is completed, save the test result and examine the fellow eye and print the result if necessary.

14.4.3 Interpretation of Reliability

To determine the threshold of one test location, usually five stimuli are needed. If there is a visual field defect, the number of stimuli increases. In particular, if the patient's response is inconsistent, the number of stimuli and the test time will increase. Reliability is low when more than 550 stimuli are projected or when the test takes more than 18 minutes. On the other hand, the patient's fatigue may increase and the sensitivity of the visual field may decrease. In extreme cases, the visual field may show the cloverleaf shape because of the difference in sensitivity between the test area in the late stage of the test and the test area in the early stage of the test. If the patients press the response button even when the stimulus is projected to physiological scotoma, it is considered as fixation loss (Heijl-Krakau technique). A warning sign is displayed if the fixation loss rate is over 20%.

When the patients press the response button even when stimulus is not projected or the stimulus under threshold is projected, it is considered as false-positive error. If the patients keep pressing the button, they are probably "trigger-happy" patients. If false-positives are above 33%, a warning sign is displayed. When the patients do not press the button when the greater stimulus is projected to the area where the threshold was already measured, it is considered as false-negative error. It can be scored high regardless of reliability in patients with advanced glaucoma because of fatigue. If the false-negative rate is more than 33%, a warning sign is displayed.

In Octopus, 10% of the total stimuli given are catch-trials, and the number of catch-trials with wrong answer is given as a reliability factor and expressed in %. If the reliability factor is 10%, it is assumed that 10% of the answers in the other tests are not answered correctly, and care must be taken when the reliability factor value is more than 10%. The wrong answer should not be more than 15%. The threshold values are measured twice at the predetermined 10 points to evaluate the consistency of the response. Short-term fluctuation is used to calculate corrected pattern standard deviations and increases in visual field defect. The SITA algorithm does not calculate short-term fluctuation.

Normal subject may also have visual field defects at initial examination. Most patients with glaucomatous visual field defects should be trained for visual field testing until reliable visual field results are obtained. The learning effect is minimal at the central visual field, while peripheral visual field is more likely affected by learning effect. It is unlikely that a visual field appears normal due to the learning effect. Therefore, if other reliability indices are reliable and the visual field test result is completely normal, the test result is reliable. In the case of three or more of the following factors in the visual field test, the reliability is low:

- Total questions ≥400
- Fixation loss ≥20%
- False-positive responses ≥33%
- False-negative responses ≥33%
- Short-term fluctuation ≥4.0 dB

14.4.4 Interpretation of the Results of Automated Perimetry

14.4.4.1 Numeric Results and Grayscale

There are two largest images on the printout next to the reliability indices. The image with actual threshold values at each test location has numeric results expressed in dB scale. The grayscale plot

is extrapolated from the corresponding sensitivity of numeric results. The higher threshold value or the brighter the gray scale is, the higher the sensitivity is and the vice versa.

If there is media opacity like cataracts or a small pupil, the overall sensitivity is reduced. Local sensitivity deterioration is more important than overall sensitivity deterioration. Identify the glaucomatous visual field changes, such as the paracentral scotoma, the arcuate scotoma, and nasal step.

Continuous visual field defect in multiple test points is more significant than a severe sensitivity deterioration in one point. A sensitivity reduction of 5–6 dB at three continuous points, 8–9 dB reduction at two continuous points, and reduction of sensitivity more than 10 dB at one point in two or more consecutive visual field tests are considered as local visual field sensitivity loss in patients with early glaucoma.

14.4.4.2 Global Indices

1. Mean deviation (MD, Humphrey) and mean defect (MD, Octopus)
   - MD is an averaged value of overall difference between the expected threshold value of the same age group with normal visual field and the actual threshold value of the patient. The Humphrey perimetry provides mean deviation value. The more negative mean deviation value means the lower visual field sensitivities. The Octopus perimetry provides the mean defect value. The positive mean defect value means visual field sensitivity loss.
2. Shor-term fluctuation (SF)
   - Shor-term fluctuation means intra-test variability. It is calculated with examining ten predefined test locations for two times and is less than 2 dB in 90% of group with normal visual field. SF is not used by SITA algorithm.
3. Pattern standard deviation (PSD, Humphrey), corrected pattern standard deviation (CPSD, Humphrey), loss variance (LV, Octopus), and corrected loss variance (CLV, Octopus)
   - How similar is the shape of the visual field of the patient to that of normal visual field of the same age group? The higher the hill of vision, the more uneven and irregular the patient's visual field. If there is a local field defect such as glaucoma, PSD becomes significantly higher. PSD and LV are the values adjusted with short-term fluctuation value. PSD and CPSD are not used by SITA algorithm.

14.4.4.3 Total Deviation and Comparison Table

The difference between the age-matched normal value and the actual threshold value of patient at each location is calculated, and probability symbols indicating the significance of abnormality are provided. The negative value of total deviation of Humphrey perimetry and the positive value of Octopus comparison table mean that the sensitivity of the test location is lower than that of the age-matched normal group.

14.4.4.4 Pattern Deviation

When glaucoma and cataract coexist, the visual field sensitivity can decrease diffusely (generalized depression) due to the effect of cataracts, which makes differentiating visual field loss caused by lens opacity from that caused by glaucoma challenging. In pattern deviation plot, the local field defect (localized loss) becomes more apparent by excluding the diffuse deterioration of the visual field sensitivity. Pattern deviation is also helpful for excluding sensitivity loss due to a pupil contraction. A probability symbols are also displayed.

14.4.4.5 Glaucoma Hemifield Test (GHT)

GHT is a strategy provided by the Humphrey perimetry STATPAC 2 to detect localized loss. It detects early glaucomatous changes by comparing the threshold values in corresponding mirror image areas of the superior and inferior hemifield.

14.4.4.6 Examples (Figs. 14.8 and 14.9)

1. Patient data and testing strategy

   At the top of the single field printout, the patient's name and date of birth are recorded.

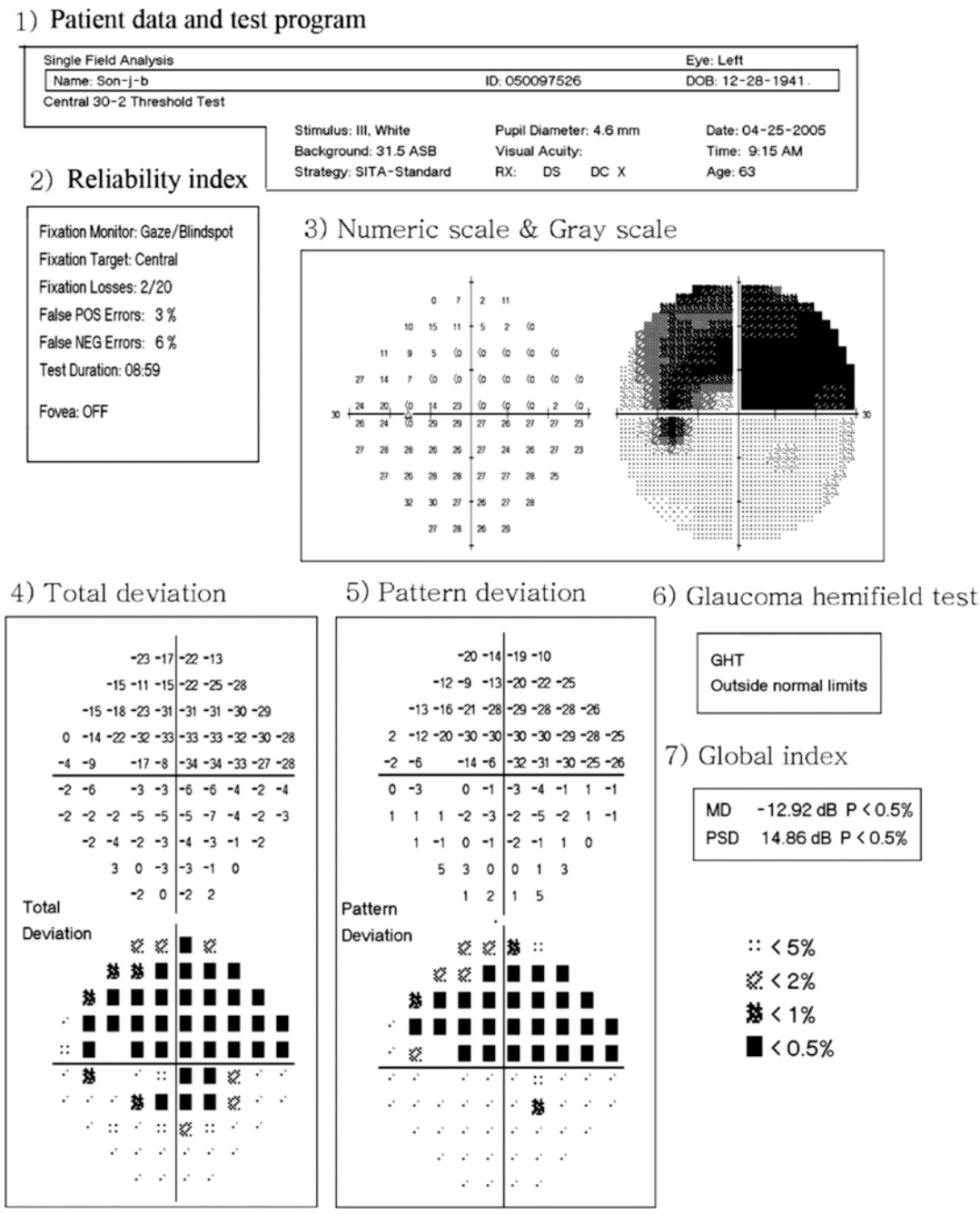

Fig. 14.8 A printout of visual field test shows patient data and test program, reliability index, numeric scale and gray scale, total deviation, pattern deviation, glaucoma hemifield test, and global indices

Beneath it, the patient's pupil size, visual acuity, test date, and test program are shown. This patient underwent a Central 30-2 and SITA-standard test program. If the size of the pupil is less than 3 mm, the overall sensitivity of the visual field may decrease. If the corrected visual acuity is less than 0.3, the reliability may decrease.

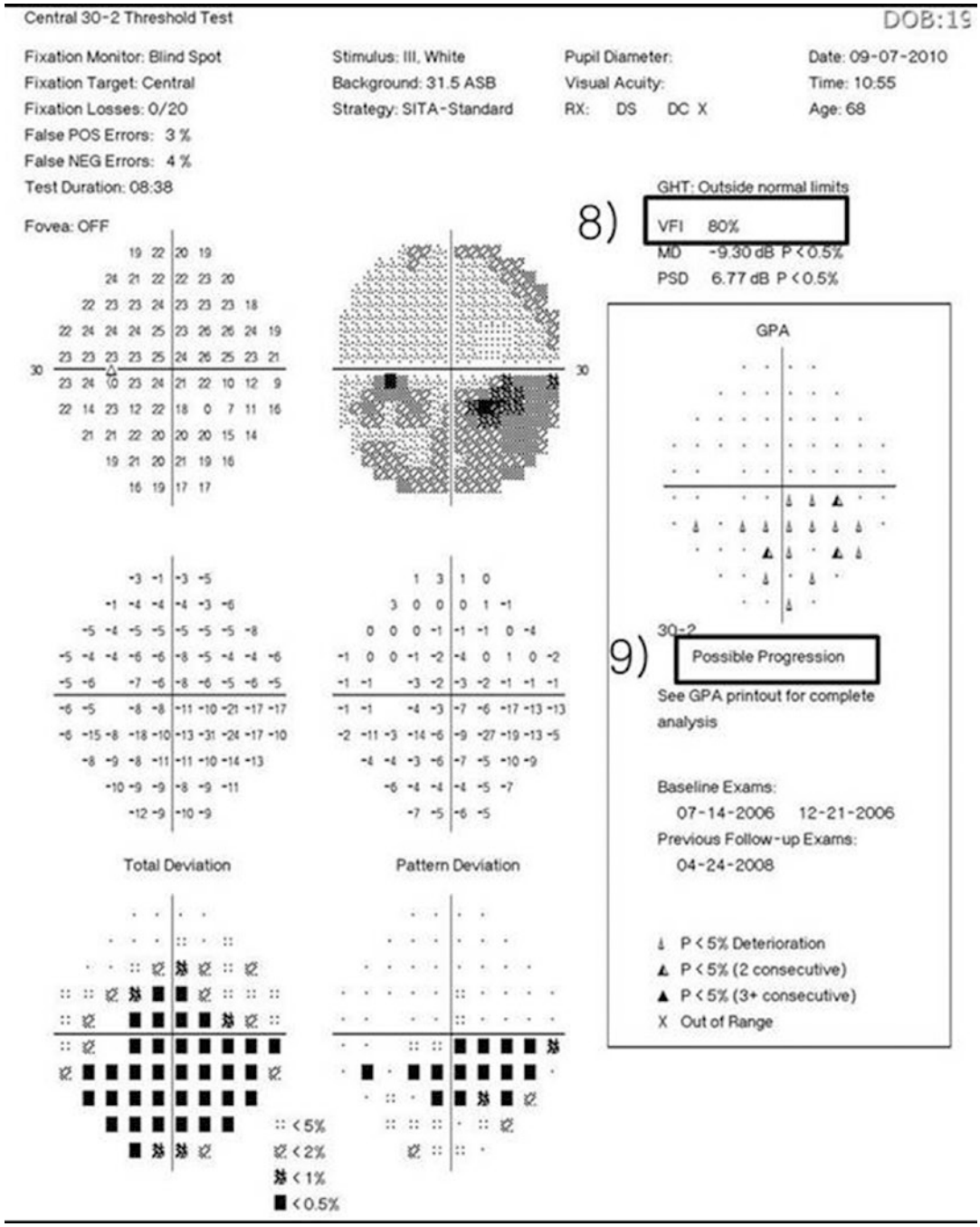

Fig. 14.9 A printout of visual field test shows visual field index (VFI) and guided progression analysis

2. Reliability
   Fixation loss, false-positive rate, false-negative rate, and test time are shown as the reliability indices of the test. The printout of this patient shows 10% (2/20) of fixation loss, 3% of false-positive rate, 6% of false-negative rate, and the test time less than 9 minutes.

3. Numeric scale and gray scale
   This patient shows a typical arcuate scotoma in the upper visual field.
4. Total deviation
   In this patient, the decrease in sensitivity is noted as negative value of dB in the arcuate scotoma and is also displayed in the probability plot below.
5. Pattern deviation
   In this patient, the upper visual field defect is shown similar to the result of total deviation.
6. GHT
   The results of GHT (the comparison of threshold value of the corresponding five mirror zones for lower and upper hemifield) are comprised of the following five findings. This patient has "outside normal limits" message because the sensitivity in the upper visual field was significantly reduced compared to the lower visual field.
   - Outside normal limits: The pair difference is greater than that found in 1% of the normal population in one or more areas.
   - Borderline: The pair difference is that found in less than 3% of the normal population, but the criteria for outside limits are not met.
   - General depression of sensitivity or abnormally high sensitivity: General depression of sensitivity means even the highest value is lower than 0.5% the normal control group value. Abnormally high sensitivity means the highest 15% of the values are greater than 99.5% normal population value.
   - Within normal limits: If the above criteria are not reached, this message is displayed.
   - Global indices in this patient: MD was −12.92 dB, showing a large difference in mean threshold value compared to the normal control of the same age group. PSD was measured as high as 14.86 dB, indicating that there is a local field defect. SF and CPSD are not shown because the SITA-standard testing strategy was performed in this patient.
7. Visual field index (VFI)
   VFI was developed by Boel Bengtsson and Anders Heijl in 2008. It is displayed in between the glaucoma hemifield test and global indices (MD, PSD) on the printout. The VFI based on pattern deviation analysis is reported to be less affected by cataract than MD. The VFI is presented in %, where 0% indicates blindness and 100% represents normal visual field. A linear regression analysis of VFI can be displayed if more than five visual field tests are performed for at least 3 years.
8. Guided progression analysis (GPA)
   GPA helps detect the visual field progression, which is available in SITA standard, SITA Fast, and full threshold modes of Humphrey perimetry.
   Triangle symbol display
   - Small open triangle: when it was significantly worse at any point ($p < 0.05$)
   - Half-filled triangle: when it was significantly worse on two consecutive tests
   - Filled triangle: when it was significantly worse on three consecutive tests

   GPA alert
   - Possible progression: significant deterioration at three or more points on two consecutive tests
   - Likely progression: significant deterioration at three or more points on three consecutive tests

14.4.5 Frequency Doubling Technology Perimetry (Fig. 14.10)

There are two types of retinal ganglion cells: P cell and M cell. P cell constitutes the majority of retinal ganglion projecting to the parvocellular layer of lateral geniculate nucleus. The conduction velocity is slow because the axon diameter of these cells is relatively small. P cells respond to stimulus with high spatial frequency and low temporal frequency. Another cell is called M cell. M cells account for about 15% of human retinal ganglion cells projecting to the magnocellular layer of lateral geniculate nucleus. The conduction velocity is fast because the axon diameter of the cells is relatively large. These cells respond to stimulus with low spatial frequency (large target) and high time frequency (moving target) and are

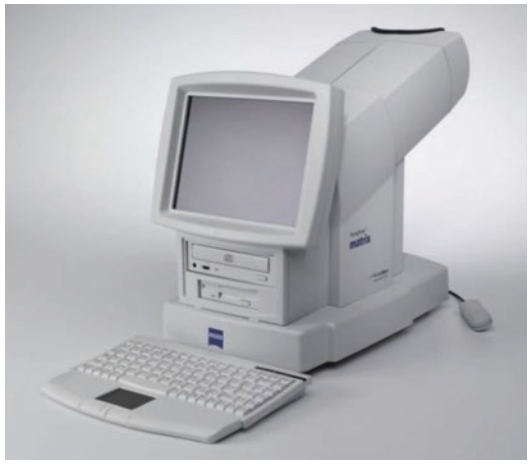

Fig. 14.10 Frequency doubling technology perimetry

mainly involved in motion processing and high-frequency flicker information.

When a flicker stimulus is applied at a high time frequency of 15 Hz or more with a low spatial frequency grating pattern of 1 cycle/degree or less, it looks like a grating pattern of double frequency rather than gray. This is an induced optical illusion of flickering called frequency doubling illusion. M cells are involved in this phenomenon. FDT is useful for early detection and screening of glaucoma. FDT, which selectively stimulate M cell, can detect glaucomatous visual field defect earlier than white-on-white perimetry because M cell may be more susceptible to glaucomatous damage.

Screening tests are performed with 0.25 cycle/degree grating pattern with 25 Hz flicker stimulus to induce frequency doubling illusion. The test time is short (about 1 minute for one eye) because it is performed with suprathreshold stimulation. The C-20 screening test examines a total of 17 test locations within central 20 degrees: the test points consist of four rectangular-shaped targets of 10 degrees in diameter for each quadrant and one target with a radius of 5 degrees in the center. The N-30 screening test has two more points with a diameter of 10 degrees at nasal side.

C-20 and N-30 threshold tests randomly select 1 test point from 17 test points and show the target and change the contrast sensitivity step by step. The two added points are measured after the examination of 17 points mentioned above. It takes 4–5 minutes to test one eye with C-20 and 5–6 minutes with N-30. The results of the threshold test are printed with basic information such as name, test time, actual value of the contrast sensitivity in dB, and the analysis result compared with the age-matched normal contrast sensitivity of the FDT perimetry data base.

The contrast sensitivity of each test point is compared with the contrast sensitivity of the age-matched normal subjects in the FDT. The total deviation and pattern deviation same as the Humphrey visual field were calculated. They are divided into four significance levels: the significance level $< 5\%$, $< 2\%$, $< 1\%$, and $< 0.5\%$. In the FDT perimetry, there are several parameters such as MD and PSD corresponding to the global indices of the Humphrey perimetry, and it is possible to comprehensively evaluate the test results using statistical techniques.

14.4.6 Interpretation of Visual Field Test in Clinical Practice

Hemianopsia is defined as a defect in half of the visual field, and quadrantanopsia is defined as a defect in one fourth of the visual field. It is called temporal, nasal, or vertical according to the location of the defect and is divided into homonymous and heteronymous according to the spatial relationship of the two eyes.

14.4.6.1 Depression

The depression indicates the decrease in threshold sensitivity compared with normal expected value. It can be divided into general depression and local depression.

14.4.6.2 Contraction

The isopter moves toward the center due to a decrease in sensitivity of the peripheral visual field. The sensitivity decreases in the periphery while the sensitivity is normal near the fixation.

14.4.6.3 Scotoma

1. Absolute scotoma is a visual field defect that persists even when the highest stimulus is used, while relative scotoma disappears when

tested with brighter stimulus. The central visual field defect is named as the central scotoma, and adjacent scotoma is named as the paracentral scotoma. The cecocentral scotoma is the visual field defect that extends from center to the blind spot (Fig. 14.11).

2. An arcuate scotoma is a visual field defect that occurs in area about 10–20 degrees

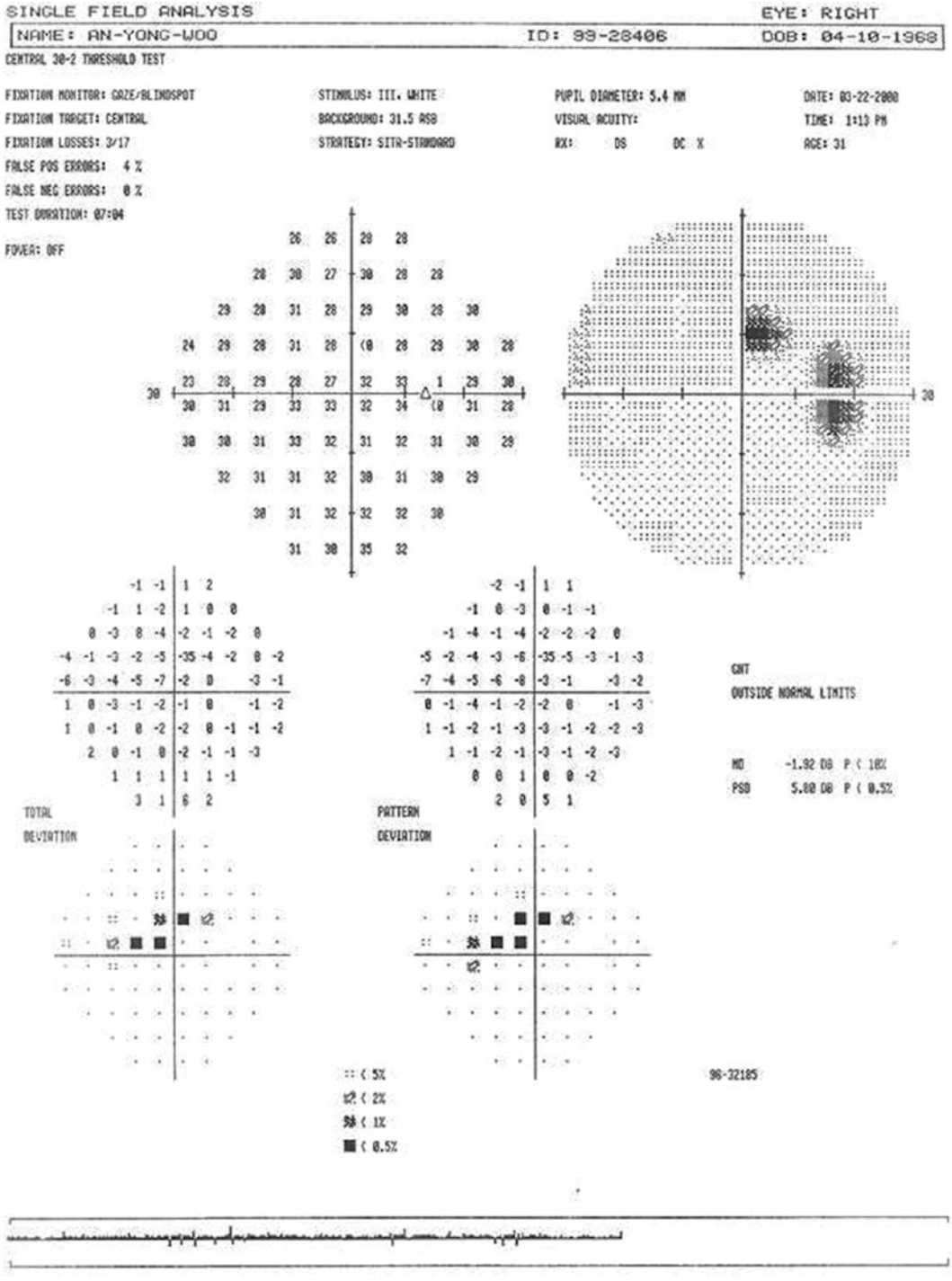

Fig. 14.11 Superior paracentral scotoma in the right eye

upward or downward from the fixation. Seidel scotoma is the arcuate scotoma that is connected to a blind spot. The ring-shaped visual field defect with superior and inferior arcuate scotoma is called a ring scotoma (Fig. 14.12). The arcuate scotoma appears in glaucomatous optic neuropathy but may also occur due to retinal disease, optic disc lesions, anterior optic nerve lesions, and lesions on the posterior part of the optic pathway.

3. When the upper and lower arcuate scotoma meet at the temporal raphe, the difference in the size of the two scotomas can lead to a stepped field defect called the nasal step (Fig. 14.13.).
4. Central scotoma or central blind spot is observed in dominant optic atrophy and optic neuritis (Fig. 14.14). Because the nerve fibers of the temporal retina intersect at the optic chiasm, the lesion before the optic chiasm does not follow the vertical meridian, and the visual field damage due to the lesions at the optic chiasm and lesions posterior to optic chiasm follow the vertical meridian (Fig. 14.15).

14.4.6.4 Examples of Incorrect Test Results

The visual field test results can be influenced by the edges of the corrective lens, fatigue, ptosis, learning effect, and trigger-happy phenomenon (Figs. 14.16, 14.17, 14.18, and 14.19).

a

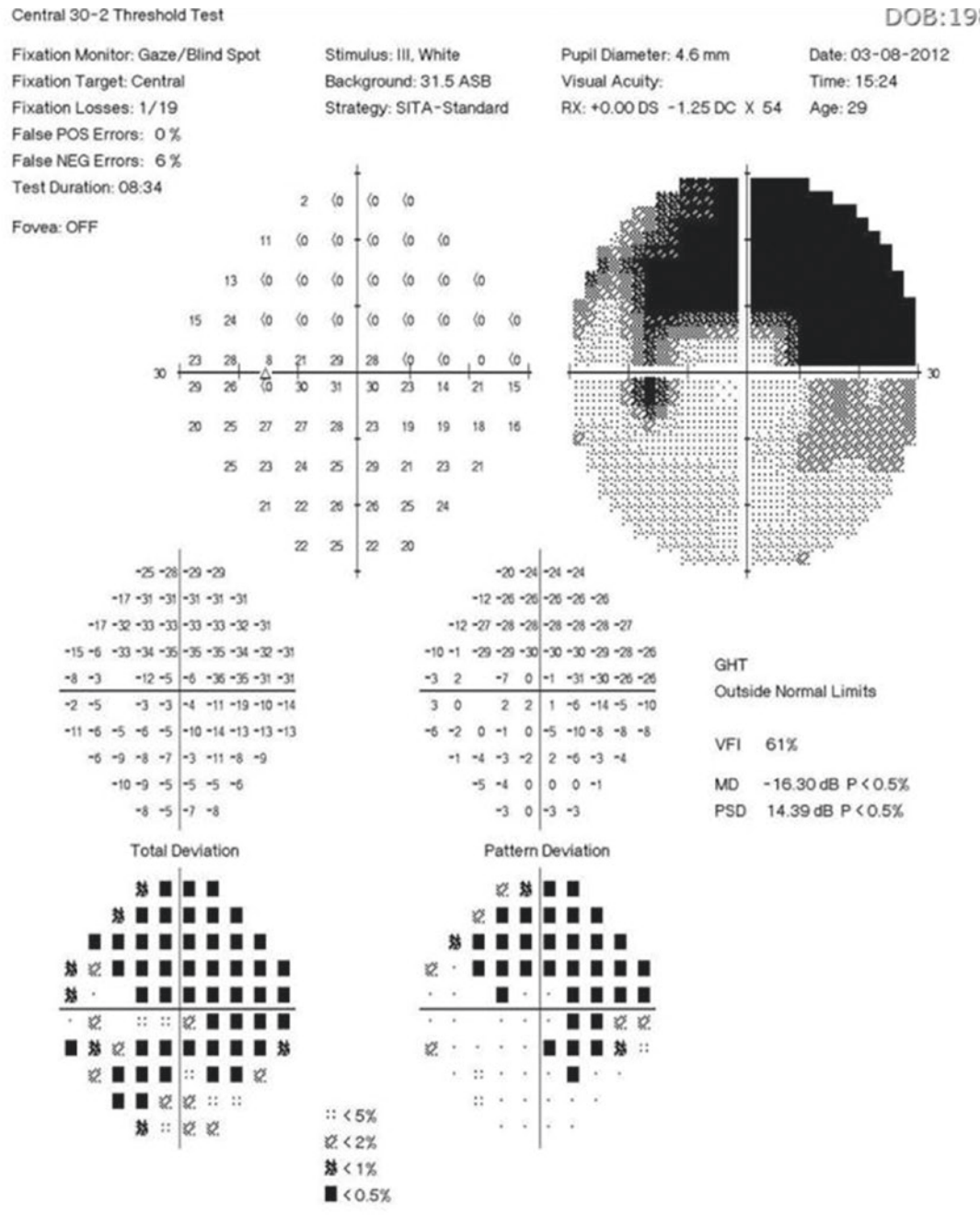

Fig. 14.12 (**a**) Superior arcuate scotoma of the left eye. (**b**) Ring scotoma of the left eye

b

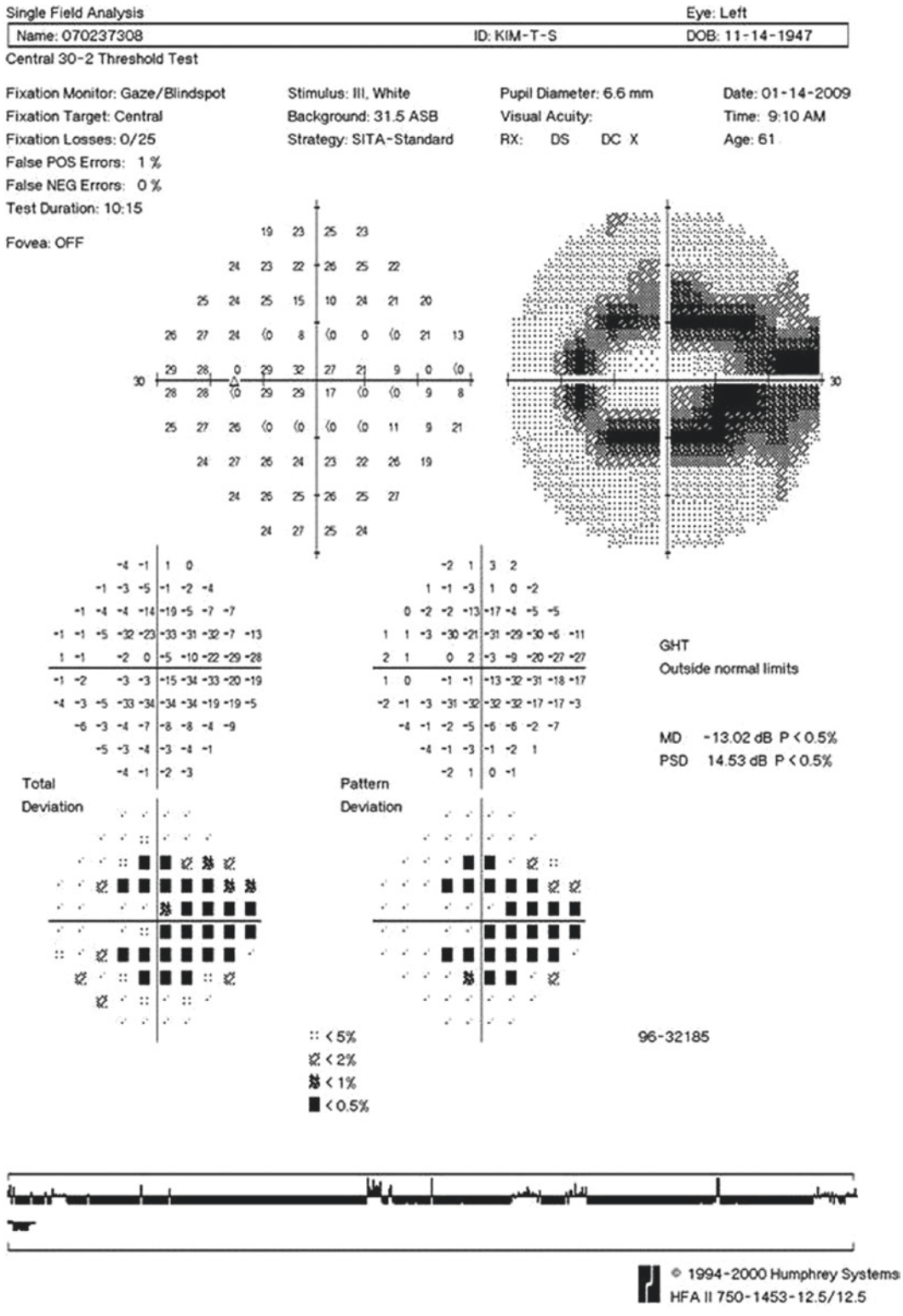

Fig. 14.12 (continued)

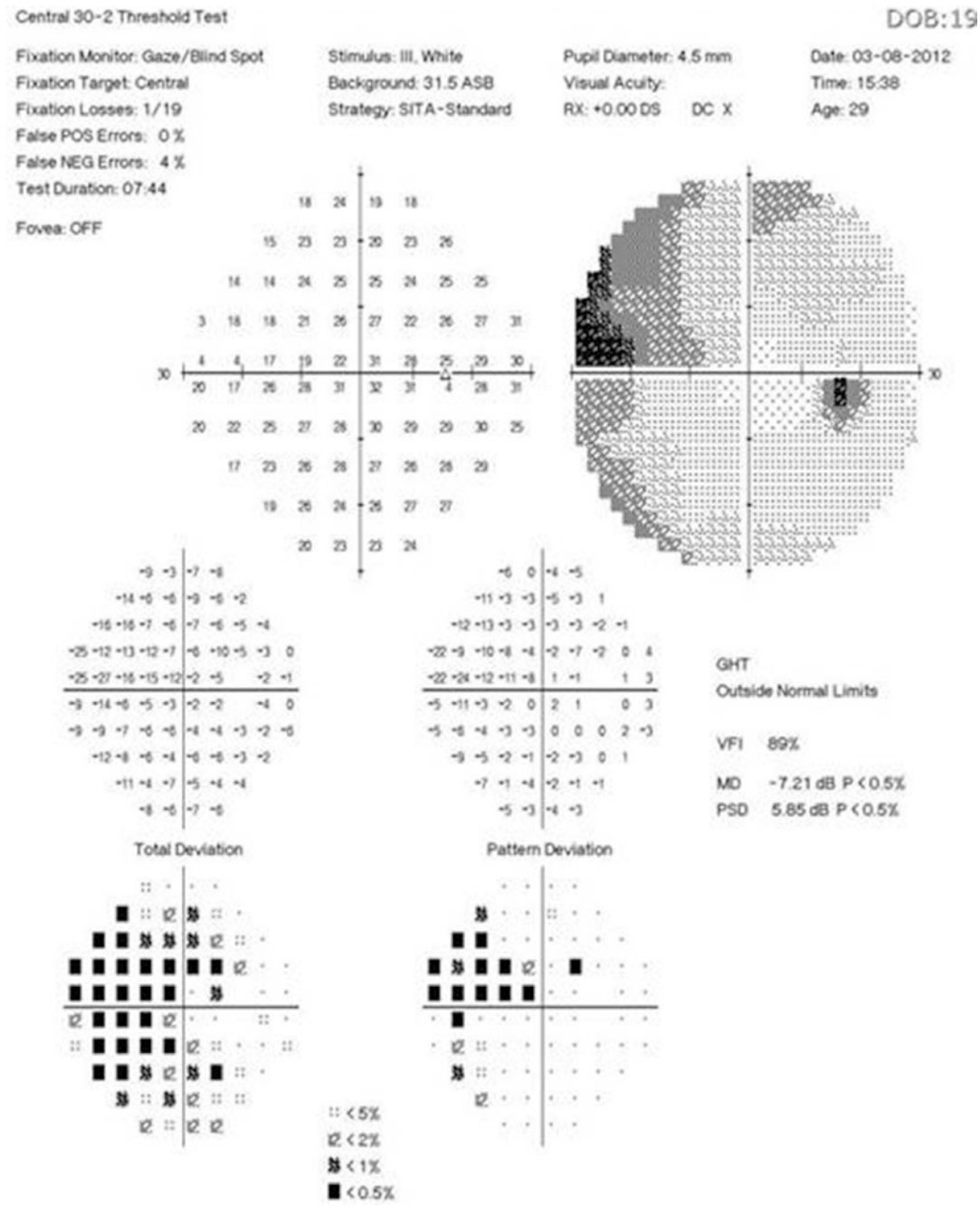

Fig. 14.13 Nasal step in the right eye

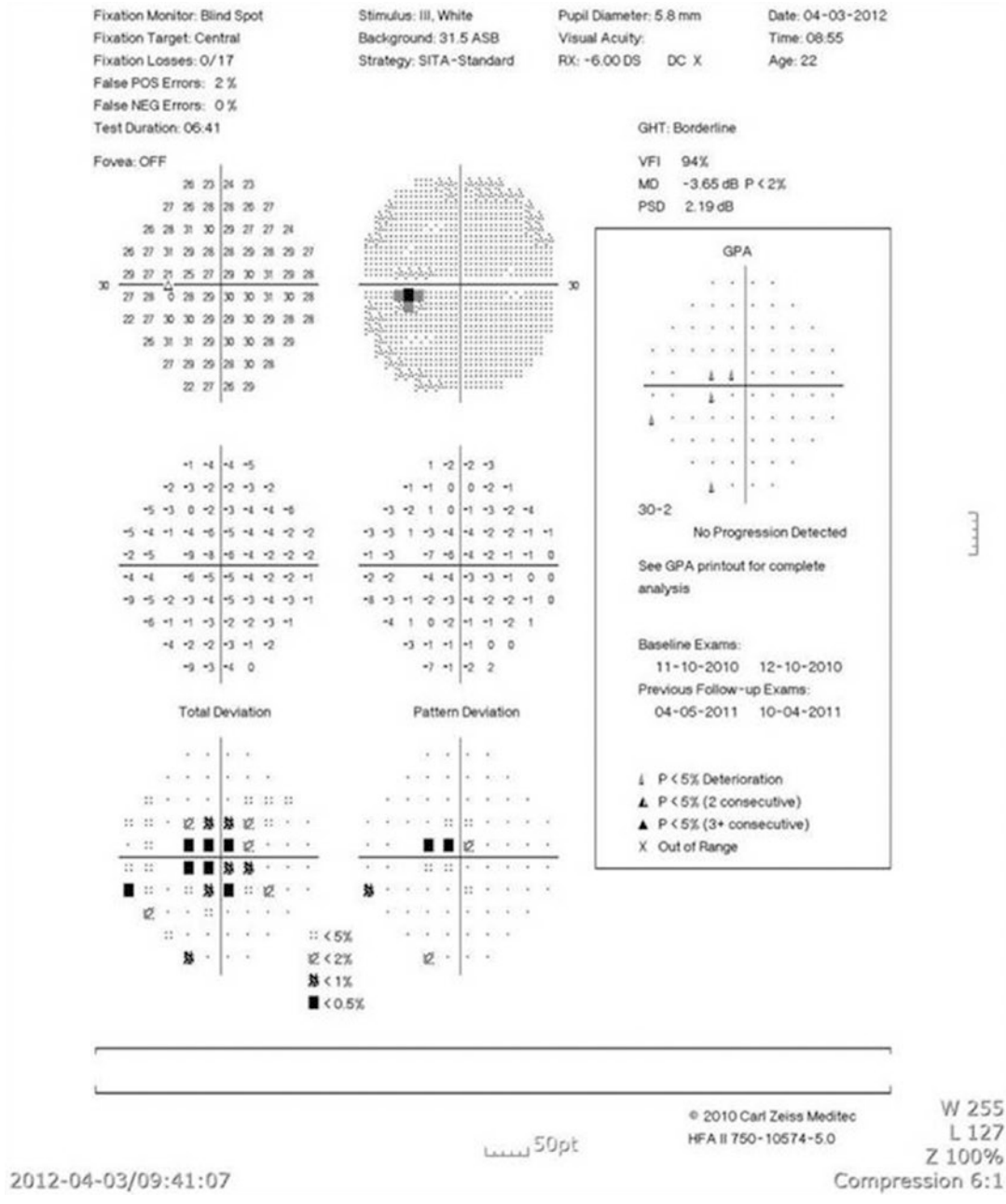

Fig. 14.14 A 21-year-old female patient with central scotoma in both eyes. She had a history of familial history and an OPA1 mutation and was diagnosed as autosomal dominant optic atrophy

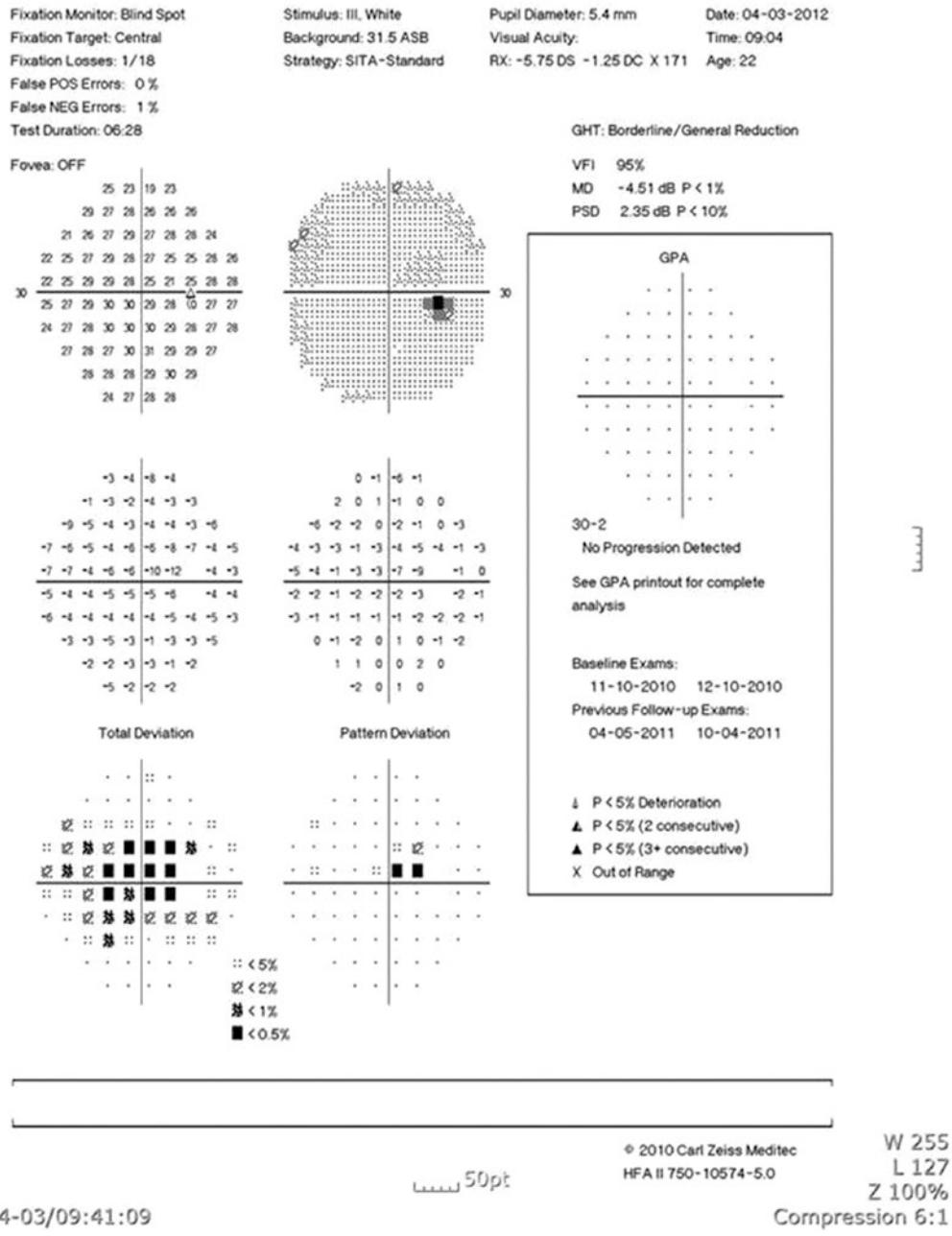

Fig. 14.14 (continued)

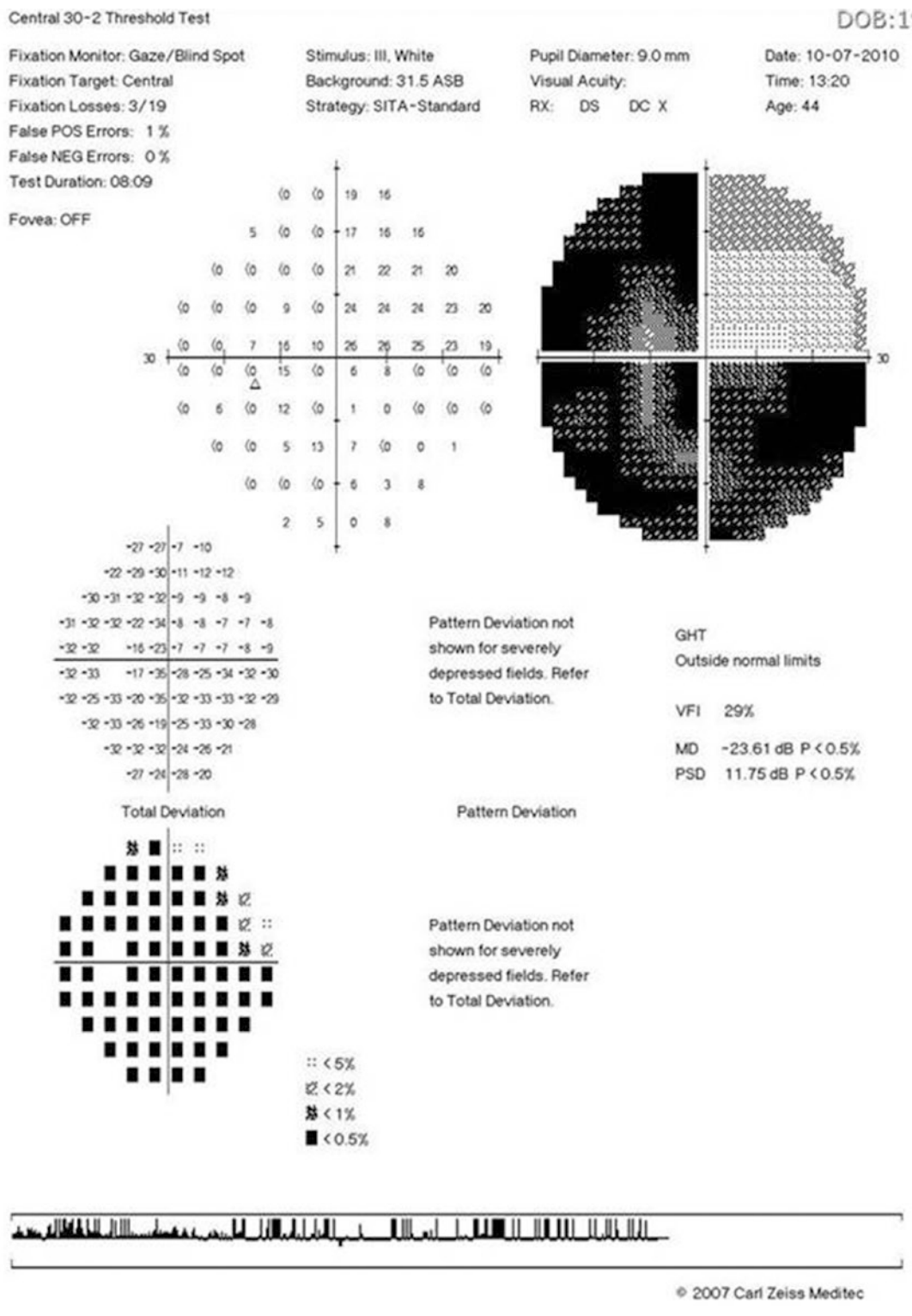

Fig. 14.15 Asymmetric bitemporal visual field defects in a 44-year-old male patient who reported a sudden drop in visual acuity in his left eye a month ago. A pituitary gland adenoma was found in the pituitary MRI scan

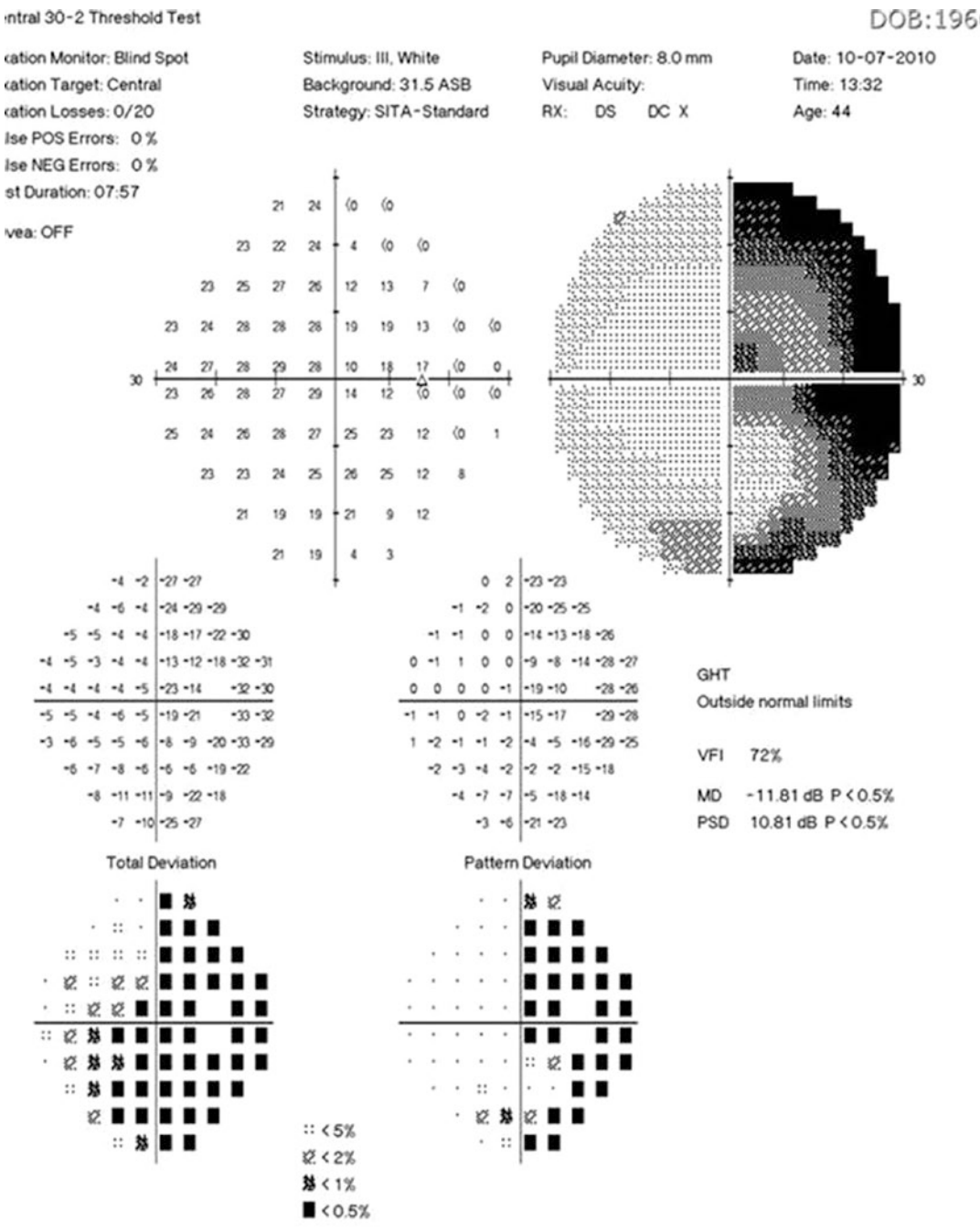

Fig. 14.15 (continued)

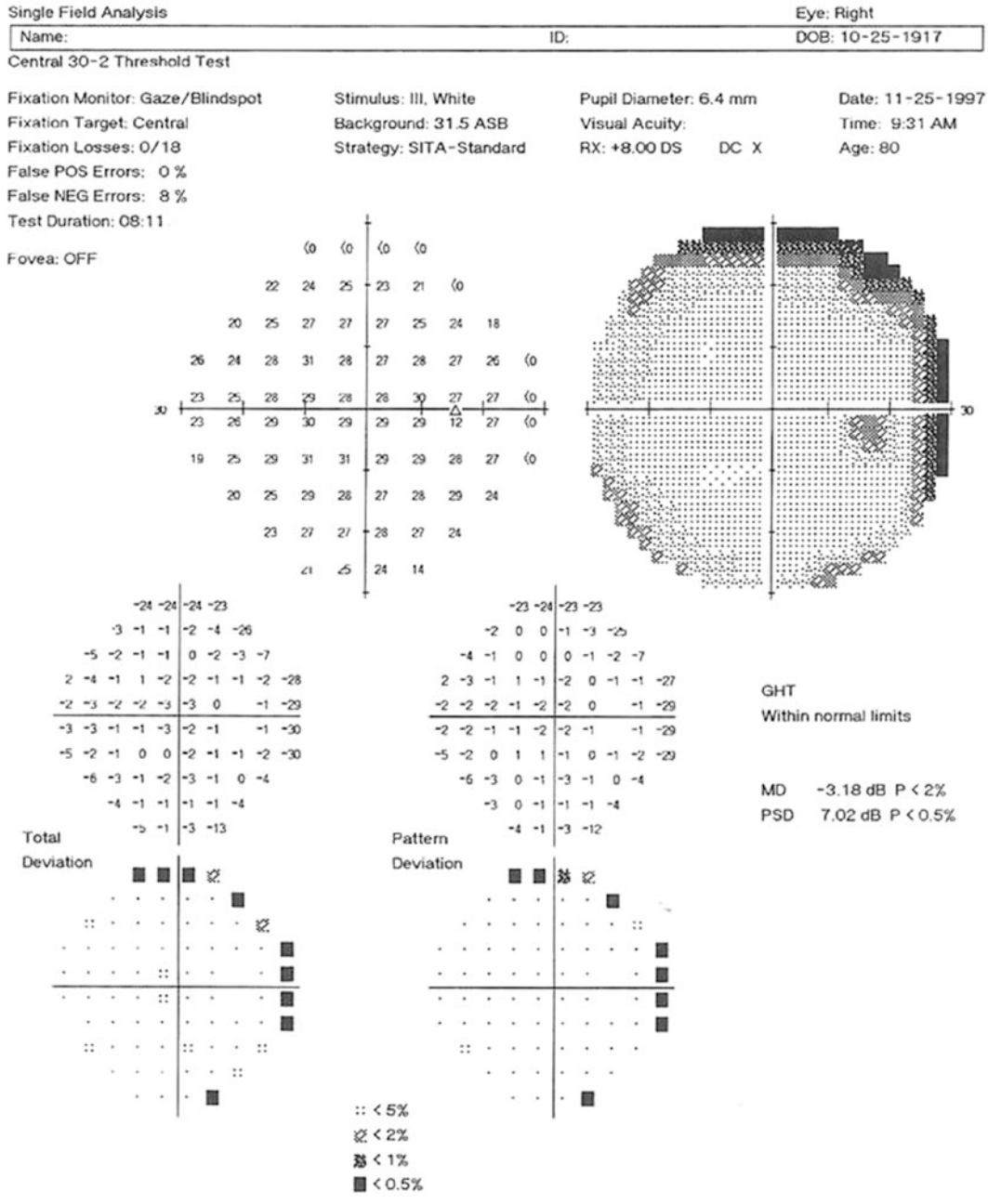

Fig. 14.16 Example of incorrect test result due to corrective lens rim

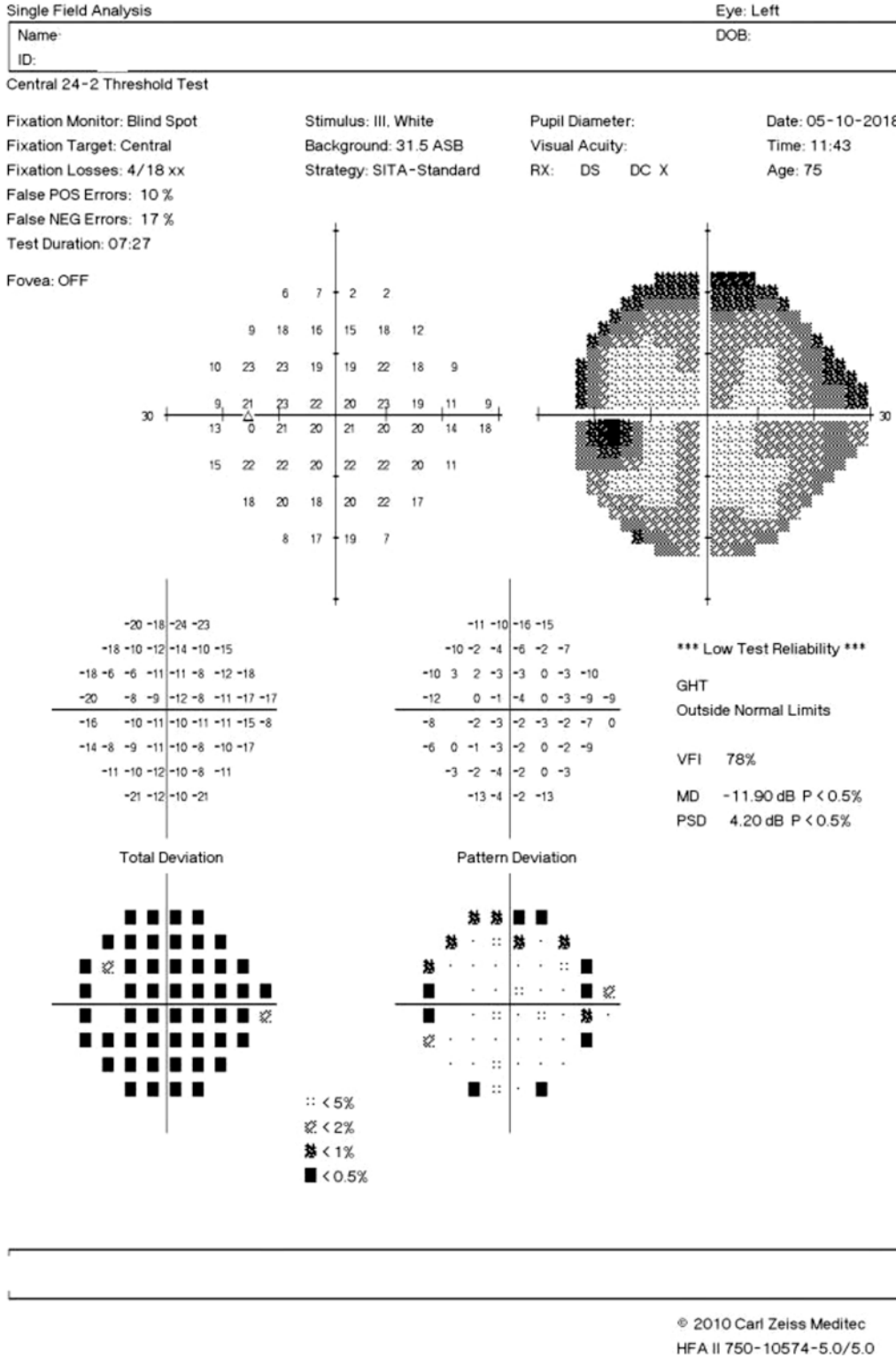

Fig. 14.17 Clover leaf appearance due to increased false-negative rate related to patient fatigue

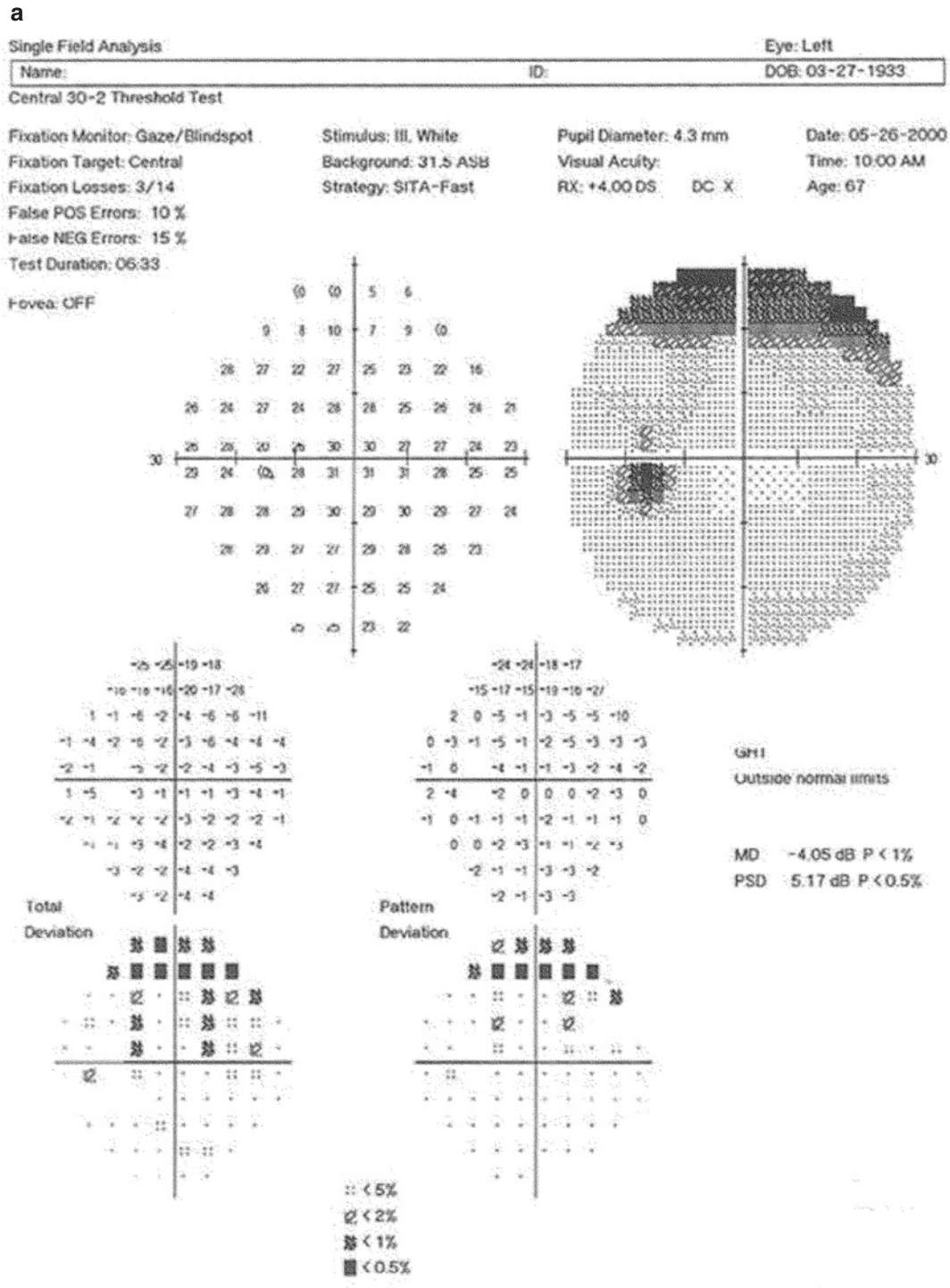

Fig. 14.18 Upper visual field defect (**a**) due to ptosis is not found in visual field examination (**b**) after ptosis correction

b

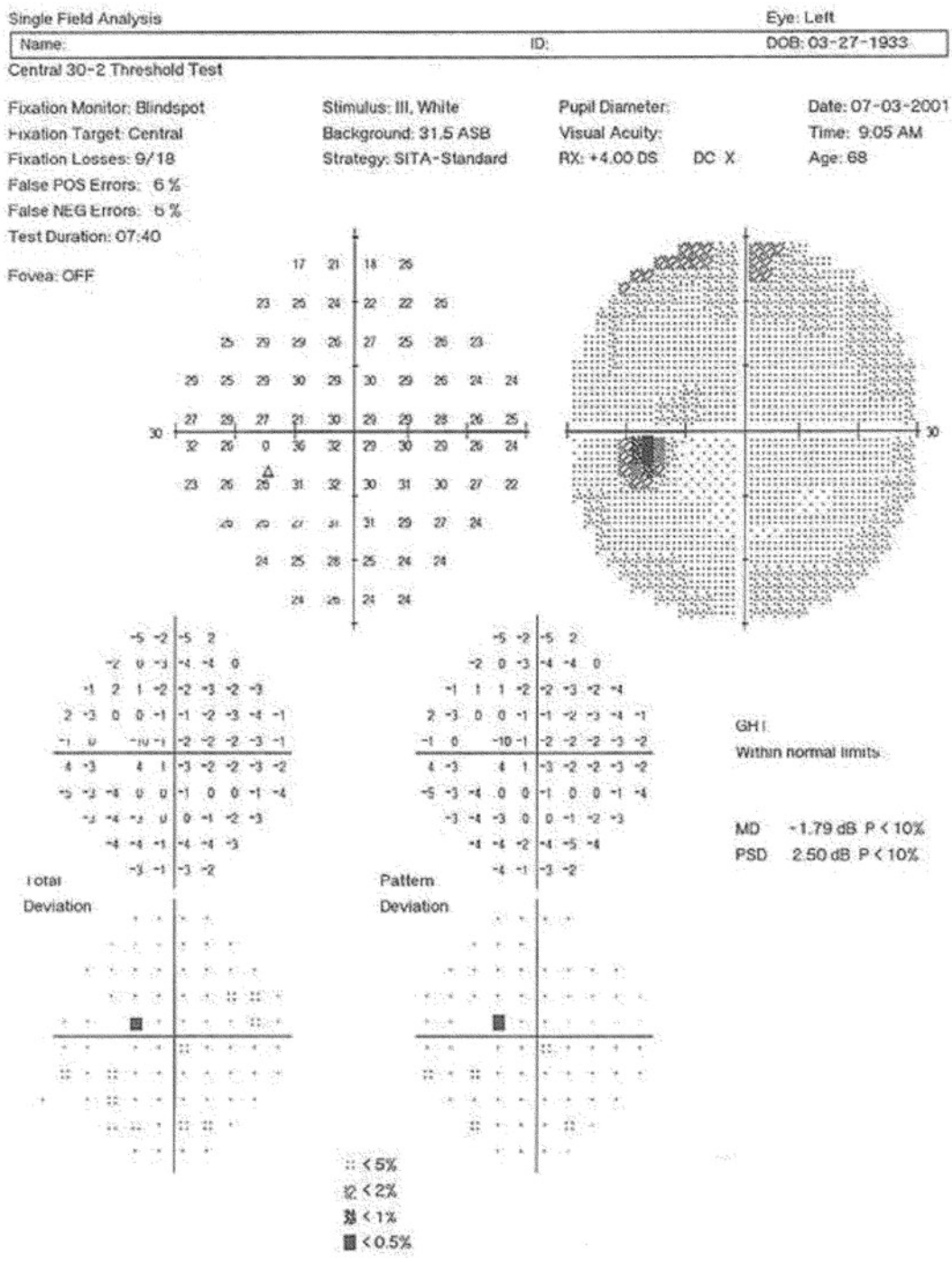

Fig. 14.18 (continued)

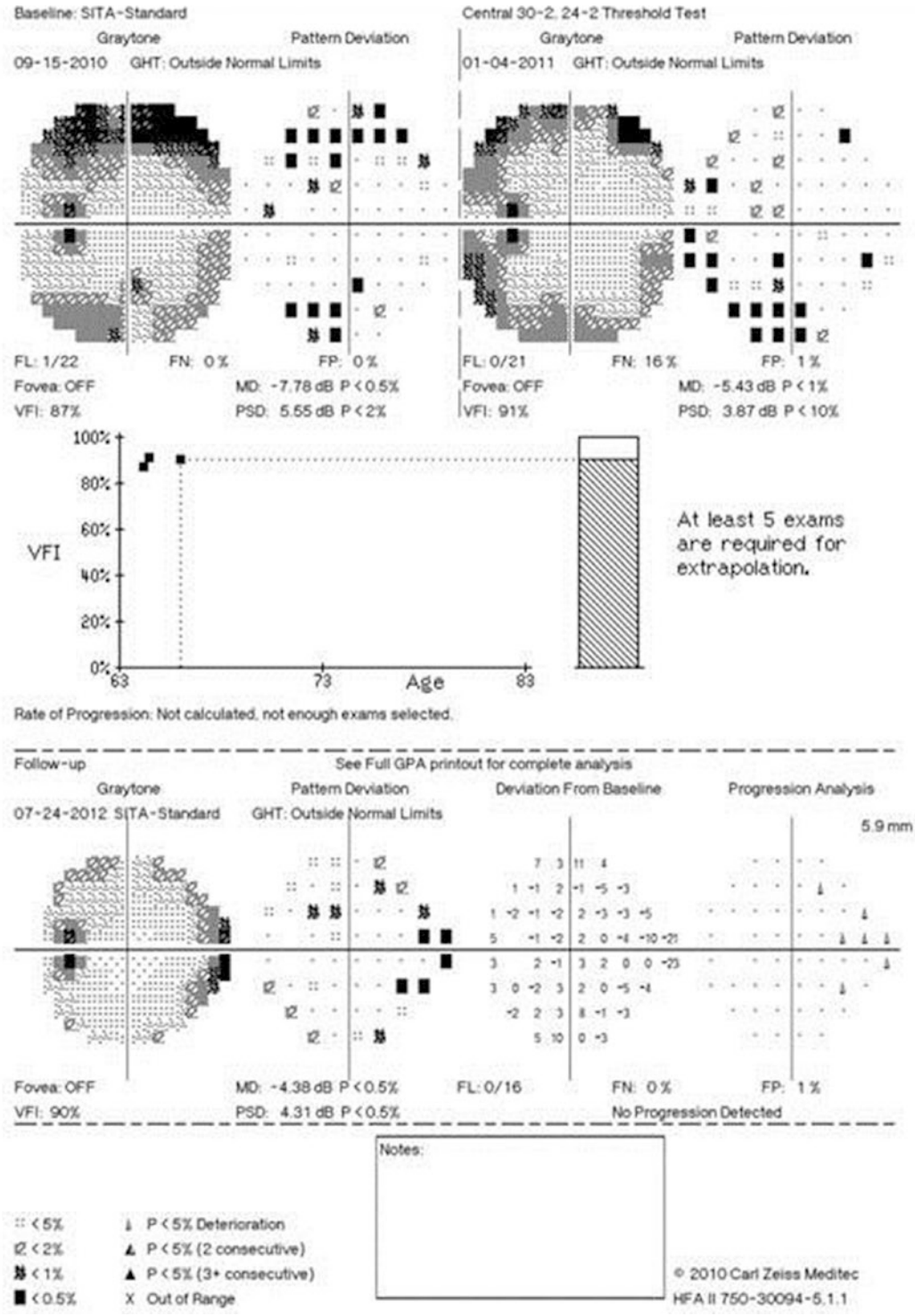

Fig. 14.19 Learning effect of visual field test. Since the automated visual field test has a learning effect, the initial visual field tests may not be reliable. Patients in this case had severe damage in the initial visual field test, but the visual field improved remarkably as the patient became accustomed to the test environment

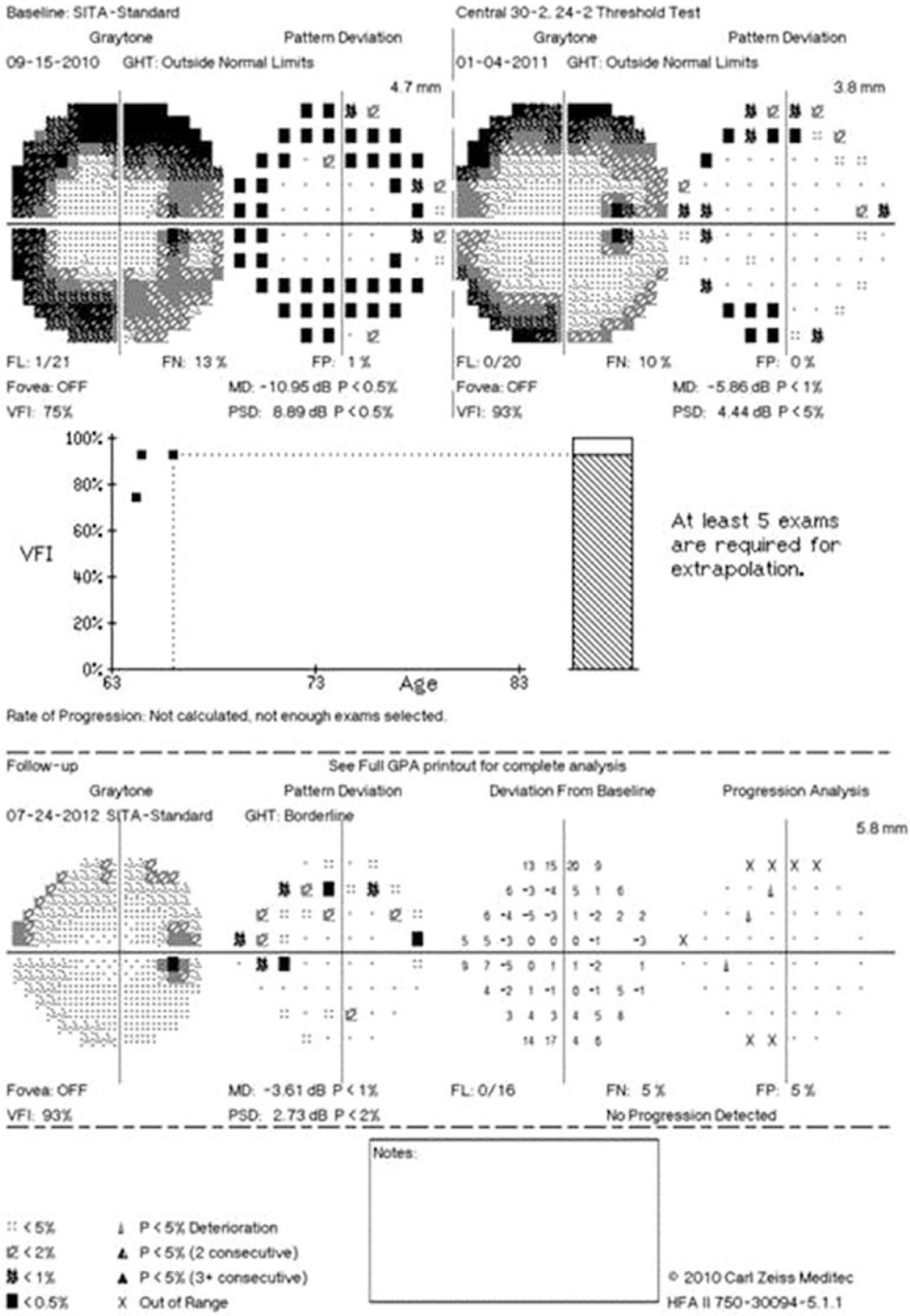

Fig. 14.19 (continued)

Suggested Reading

Alencar LM, Medeiros FA. The role of standard automated perimetry and newer functional methods for glaucoma diagnosis and follow-up. Indian J Ophthalmol. 2011;59(Suppl):S53–8.

Anderson DR, Patella VM. Automated static perimetry. St. Louis: Mosby; 1999.

Arnalich-Montiel F, Casas-Llera P, Muñoz-Negrete FJ, Rebolleda G. Performance of glaucoma progression analysis software in a glaucoma population. Graefes Arch Clin Exp Ophthalmol Albrecht Von Graefes Arch Für Klin Exp Ophthalmol. 2009;247(3):391–7.

Bengtsson B, Heijl A. A visual field index for calculation of glaucoma rate of progression. Am J Ophthalmol. 2008;145(2):343–53.

Caprioli J. Should we use short-wavelength automated perimetry to test glaucoma patients? Am J Ophthalmol. 2001;131(6):792–4.

Heijl A, Leske MC, Bengtsson B, Bengtsson B, Hussein M, Early Manifest Glaucoma Trial Group. Measuring visual field progression in the Early Manifest Glaucoma Trial. Acta Ophthalmol Scand. 2003;81(3):286–93.

Lee J-W, Morales E, Yu F, et al. Effect of cataract extraction on the visual field decay rate in patients with glaucoma. JAMA Ophthalmol. 2014;132(11):1296–302.

Leeprechanon N, Giaconi JA, Manassakorn A, Hoffman D, Caprioli J. Frequency doubling perimetry and short-wavelength automated perimetry to detect early glaucoma. Ophthalmology. 2007;114(5):931–7.

Leske MC, Heijl A, Hyman L, Bengtsson B. Early Manifest Glaucoma Trial: design and baseline data. Ophthalmology. 1999;106(11):2144–53.

Fundus Examination

15

Han-Jo Kwon and Sung-Who Park

The fundus exam views the eye's interior through the pupil, which is a small hole.

If necessary, the pupil is examined after it is dilated with 0.5–1% tropicamide or 2.5–10% phenylephrine. Because pupil dilatation may cause angle closure glaucoma, it should be performed after checking the anterior chamber depth.

The fundus examination can be performed through fundus photography or by means of direct ophthalmoscope, indirect ophthalmoscope, and slit lamp.

15.1 Direct Ophthalmoscopy

The direct ophthalmoscope is compact and doesn't weight much, making it portable and easy to operate. It has an upright image with a magnification of 15. It is suitable for observing the posterior pole including optic discs, retinal vessels, and macula. The direct ophthalmoscope, however, does not allow stereopsis, and it is difficult to observe things if the lens or the vitreous bodies are opaque. The observation range is narrow, ranging from 8° to 10° (Fig. 15.1).

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The rays of the light bulb built in the ophthalmoscope are reflected on the patient's retina through the pupil, and the reflected light returns to the eye of the examiner through the pupil (Fig. 15.2a).

15.1.1 Methods

15.1.1.1 Setting the Ophthalmoscope (Fig. 15.2b)

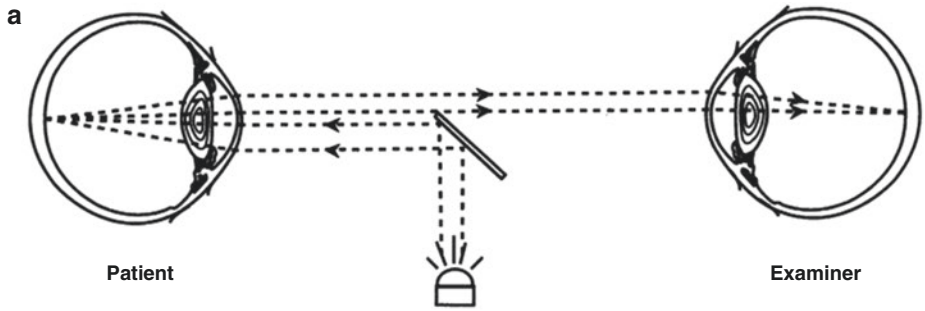
- The white color is used for the illumination light.
- Choose the narrow illumination light in the not dilated pupil.
- Choose the wide illumination light in the dilated pupil.
- Place the lens power scale at 0 diopter. Check the being in the focus with 0 diopter scale.

15.1.1.2 Process

- Dim the light.
- The examiner sits opposite the patient or stands next to the patient.
- Open both eyes of examiner and the patient.
- Place the hand that is not holding the ophthalmoscope on the patient's head, and pull the eyelid with thumb, when the eyelid fissure is too narrow to be examined.
- Have the patient look at an object 3–5 m away and slightly higher than the eye level.
- When examining the patient's right eye, hold the ophthalmoscope with your right hand, and

J.-S. Lee (ed.), *Primary Eye Examination*, https://doi.org/10.1007/978-981-10-6940-6_15

Fig. 15.1 Direct ophthalmoscope



b

Aperture	Description	How to use
	Large aperture	When viewed through a large pupil
	Small aperture	When viewed through a small pupil
	Red-free filter	Detect changes in the retinal nerve fiber layer or observe microaneurysm and vascular abnormalities
	Slit beam	Detecting the contour of the retina
	Reticle	Small retinal lesion, measuring vessel diameter (in 0.2 mm increments)

Fig. 15.2 (**a**) Principle of the direct ophthalmoscope, (**b**) Parameters of the direct ophthalmoscope

Fig. 15.3 How to hold the direct ophthalmoscope

look with your right eye. When examining the patient's left eye, hold the ophthalmoscope with your left hand, and look with your left eye (Fig. 15.3).

- As an examiner, place your index finger on the front of the lens so that you can adjust the diopter of the lens diaphragm during the examination, and hold the ophthalmoscope with the rest of your fingers. Fix the head of the ophthalmoscope to your eyebrow, and bring your eye as close as you can to the observation hole.
- Check the red fundus reflex by putting a light on the patient's pupil about 30 cm away from the patient.
- As you continue to approach the red eye reflex, you will see the reflection of the cornea surface. The reflection disappears, and fundus will appear when you are 7–8 mm away from the cornea. The closer the distance, the wider the field of view becomes.
- When the patient is looking straight, you can see the patient's optic disc if you look into the eye about 15° to the ear. If you can't find optic disc, follow thicker vessel to find it.
- Focus on the retinal vessels by turning the lens power scale.
- The green number on the lens power scale indicates the plus diopter, and the red number indicates the minus diopter.

15.2 Indirect Ophthalmoscopy

The indirect ophthalmoscope has a wide and stereoscopic view. It can provide relatively clear view even with some degree of opacity in the eye

Fig. 15.4 Indirect ophthalmoscope, scleral depressor and convex lenses

medium. It is the best way to exam the fundus with a scleral depressor, so that it is commonly used in examination of retinopathy of prematurity and in scleral buckling surgery. Using a scleral depressor, you can examine the anterior portion of the equatorial retina, the ora serrata, and even the pars plana. The indirect image can be confusing as it is reverse and upside down, and one needs practice in order to use the indirect ophthalmoscope well. It has a rather low magnification of two to five, which limits the observance of microscopic changes to the retina (Fig. 15.4).

15.2.1 Methods

15.2.1.1 Principle and Process

The rays from the ophthalmoscope converge at a point on the pupil after passing a convex lens placed in front of the patient's eye, which then ray get in the inside of the eye. The rays reflected from the fundus pass through the same convex lens, and examiner can observe reverse images at 30–50 cm apart from the observer (Fig. 15.5).

Put the ophthalmoscope on your head, and fix it by turning the vertical and horizontal fixing screws after putting the ocular lens as close to your eye as possible. It is better not to wear eyeglasses to shorten the distance between your eyes and ocular lens, because it provides wider view.

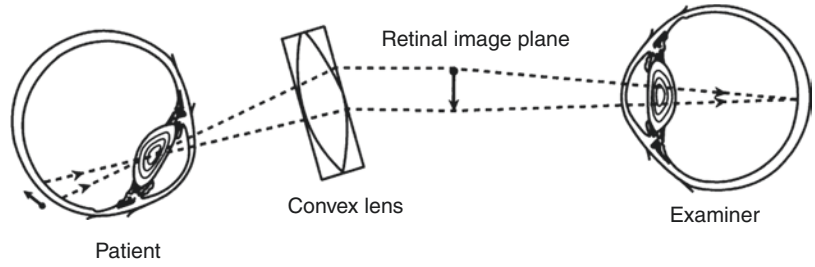


Fig. 15.5 Principles of the indirect ophthalmoscope

You can insert the lens to correct your refractive error into the ocular lens of the ophthalmoscope.

Place your thumb 40 cm apart from your eyes. Adjusting the pupil diameter, make your thumb the center of each view when you close the other eye. And then check your binocular vision.

Make direction of the illumination ray come into the upper half of your view. An excessively bright light might cause phototoxicity. Make sure you select the appropriate brightness, and avoid long examination on fovea.

Dilate the pupil.

Examination is possible when the patient is in bed or sitting. However it is better that patients lie down when the examination takes long or when scleral depressor is used (Fig. 15.6).

Check the red pupil reflex without convex lens at the distance of about 30–50 cm.

If you are right-handed, hold the convex lens using your left thumb and index finger, and put your ring and little finger on the patient's eye socket or his/her forehead. Your left middle finger could pull the upper or lower eyelid. You can pull the other eyelid or press the sclera with your right hand.

Move the lens slowly toward the patient's eye from a distance of about 15 cm in front of the patient's cornea, and find a spot where the fundus is clearly visible. You can also find the spot by moving the lens gradually away from 1.5–2 cm in front of the patient's eyes.

Observation Procedure

Stand on the right side of the patient and examine the right eye. Observe the optic disc first and then the macula. Then observe the area nearby along the blood vessel. When you observe the superior fundus, do so by moving close to the patient's foot and looking up from there or by making the patient look up. Observe the temporal, inferior, and nasal fundus in the same way. It is better for you to observe the patient from various directions and angles by moving yourself around than moving the patient's eyes, because you can make a continuous observation that way.

Observe the ora serrata and the peripheral retina using a scleral depressor.

The pupil is tilted when you observe the peripheral retina, which makes the field of vision narrow. You should adjust your head and body position in order to get a stereoscopic view. You cannot get a stereoscopic vision if one of your visual axes is located within the pupil.

15.2.1.2 Choosing and Using the Lens

Make sure that the convex side of both lenses faces toward the examiner.

You can use a lens of +14–+40 diopters. The most commonly used one is a +20 diopter lens.

The higher the power of lenses, the closer the distance between the examiner and the patient and the distance between the lens and the patient's eye. The distance between the lens and the patient's eye is 100 cm divided by the lens power. In other words, a +20 diopter lens should be placed about 5 cm in front of the patient's eyes, 14 diopters 7 cm, and 30 diopters 3.3 cm.

The magnification is inversely proportional to the power of convex lenses. It is obtained by dividing the refractive index (about 60 diopters) of the patient's eye by the power of the convex lens. In other words, the magnification using a 20-diopter lens is 60/20 = 3 times, 4 times for a 14-diopter lens and 2 times for a 30-diopter lens.

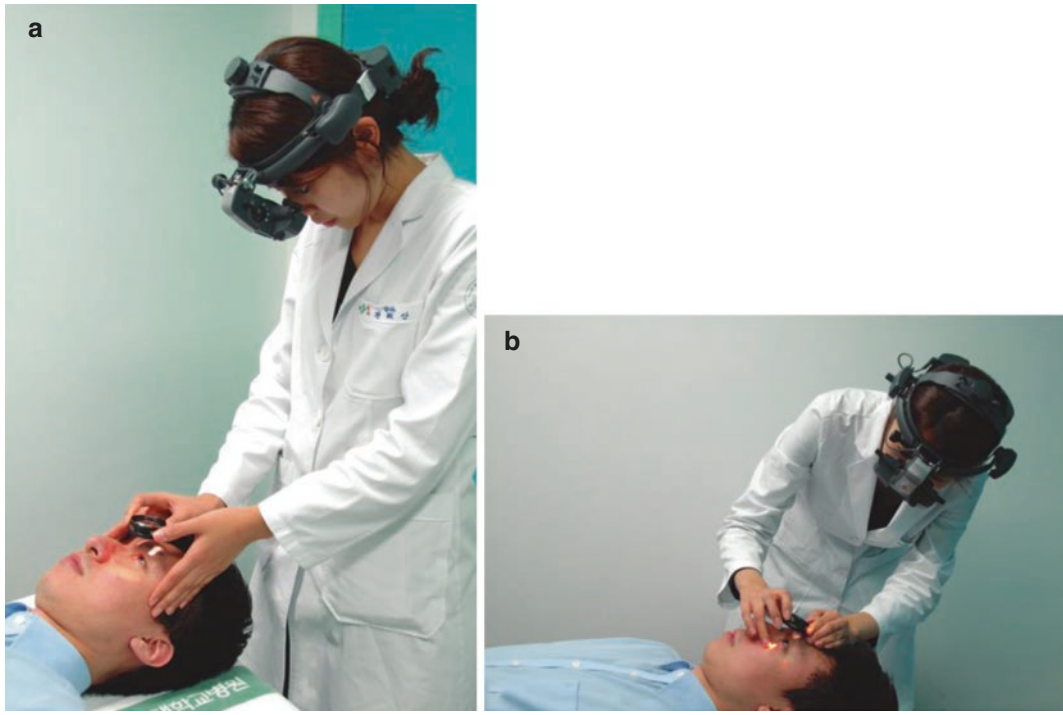


Fig. 15.6 Indirect ophthalmoscopy. (**a**) Indirect ophthalmoscope. (**b**) The doctor is standing and checking around the patient's head. The patient is laid down, and the chair is raised, and the examiner is bent and examined in a low-gaze position. Record the fundus findings on a chart placed upside down on the patient

Lenses with low magnification such as the +30 diopter lens have a wide field of vision, but the fundus appears dark and small. Lenses with high magnification such as the +14 diopter lens have a bright fundus and a high magnification but a narrow field of vision.

A lens with a low magnification such as a +30 diopter lens is recommended in cases with small pupil or opacity on its medium.

Using yellow filter lens, which reduces short-wavelength light that is easily scattered, is helpful in case of opacity on its medium.

15.2.1.3 Highlights in Using a Scleral Compressor (Fig. 15.7)

Scleral depression is performed to examine areas between the equatorial portion of the fundus (14 mm from limbus) and the ora serrata (8 mm from limbus). When the scleral is depressed, the retina can be observed from various angles, allowing the retinal ridge, tear, and traction to be observed more clearly.

Let the patient lie down straight after dilating the pupil to the maximum. Put the eye under anesthesia in appropriate methods such as topical anesthesia.

There are various types of sclera depressors: some put pressure on the eyelid, while others put pressure on the conjunctiva.

The end of the depressor, the pupil of the patient, the convex lens, and the axis of illumination light must be aligned for the optimal observation.

Because the superior, inferior, and temporal sides are easy to press, but the nasal side has no eyelid, the examiner finally anesthetizes the eye and compresses on the conjunctiva.

15.3 Slit Lamp Ophthalmoscopy

The slit lamp ophthalmoscopy allows us to examine the vitreous body and the retina in stereoscopic vision. It had been mainly used for an

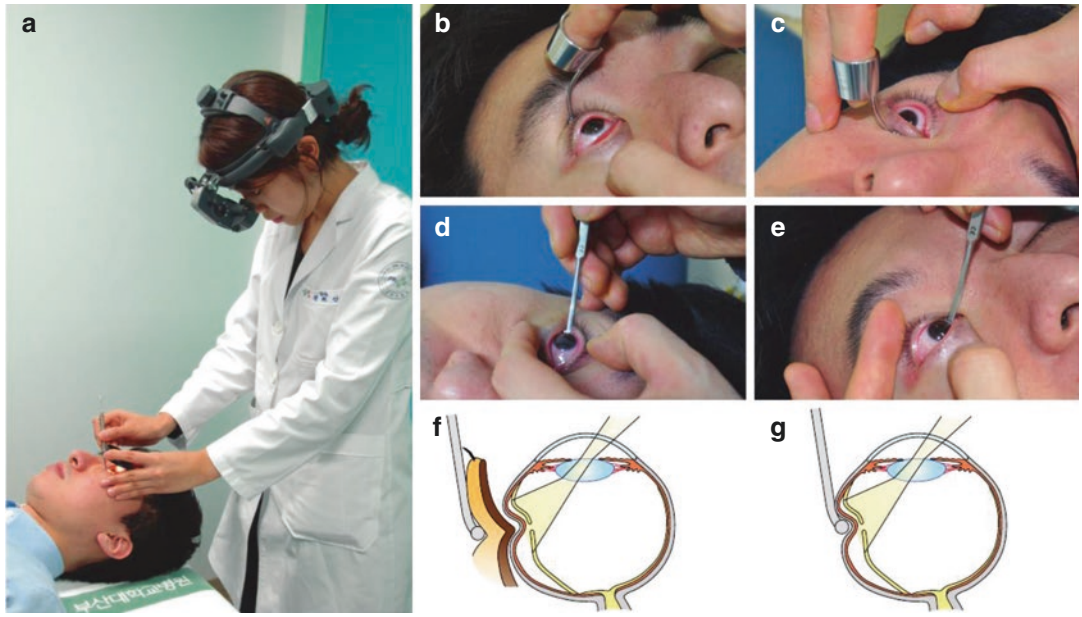


Fig. 15.7 Indirect ophthalmoscopy using a scleral depressor. (**a**) Examination posture. (**b**) Superior side. (**c**) Inferior side. (**d**) Temporal side. (**e**) Nasal side. (**f**) Above the eyelid. (**g**) Pressure on conjunctiva

in-depth examination of a lesion found through indirect or direct ophthalmoscopy, but it has recently become a common examination method for the retina and vitreous.

15.3.1 Methods

The slit lamp alone can only let you observe one third of the anterior of the vitreous body, so an auxiliary lens is needed for you to observe the fundus. The concave lens neutralizes the refractive power of approximately +60 diopter of eyes to allow for the direct observation of the fundus. The concave lens is contact lens.

The convex lens also can be used to exam the fundus. Some are contact lens, and the others are noncontact. You can observe the fundus indirectly by placing a convex lens (contact or noncontact lens).

15.3.1.1 Noncontact Lens

Make the examination room as dark as possible and dilate the pupil sufficiently.

Place the patient on a slit lamp.

Adjust the magnification of the slit lamp to 10–16 times. Note, however, that increasing the magnification does not mean an increased resolution.

Set the illumination device to almost match with the visual axis of the microscope while putting the focus on the center of the corneal surface with a slit width of 4 mm.

Choose the brightness of the light within the range that the patient can easily tolerate.

Hold a convex lens of +60–+90 diopters with your thumb and forefinger, and place it 4–12 mm in front of the patient's cornea. The distance between the lens and the patient's cornea is shorter if the lens' power is higher. Put your hand on the head immobilizer or on the patient's cheek to support and your elbow on the stand, and open the patient's eyelids with your middle and ring fingers. Check that the patient's pupil is at the center of the lens.

Keep the slit light at the center of the convex lens and cornea. Hold the handle of the slit lamp with the other hand, and pull it toward you and away from the patient's eyes to identify red reflexes and retina.

If the light reflection is severe, tilt the convex lens a little to reduce the light reflection.

It is advisable to have a routine of fundus examination. In general, you should check the optic disc first, and then check the peripheral area and the macula. Observe the patients' fundus while making him/her look away or look at your finger.

When observing the vitreous body, change the direction of the illumination light such that the angle between the illumination light and the microscope is approximately 10–15°, and focus on the vitreous body by pulling the noncontact lens slightly toward the examiner. Making the patient move the eyeballs around may help as it creates movement of the vitreous body (Fig. 15.8).

15.3.1.2 Contact Lens

Perform topical anesthesia. Make the patient sit comfortably in front of the slit lamp and fix his/her head and jaw. Place one or two drops of the 1–2% methyl cellulose solution on the concave side of the contact lens without letting the air in. Let the patient open the eyes wide and look upward. Open the eyelids with the thumb and the index finger of your other hand. Place the lower part of the lens in the lower fornix conjunctiva under the cornea and the lower part of the cornea, and put the lens close to the cornea. When you let the patient slowly look straight, then the lens will be attached to the front of the cornea (Fig. 15.10). When examining the right eye of a patient, hold the lens with the left hand; when examining the left eye of the patient, hold the lens with the right hand. This will allow you to fix your elbow with the elbow support, and you can take a stable posture. When air bubbles enter into the lens, you can make them disappear by letting the patient move the eyes a little or by tilting or rotating the lens if the bubbles are small. If the air bubbles are large, refit the lens.

Hold the lens with your thumb and your index finger, and fix it with a light pressure so that it does not fall out during the observation. Support the lower part of the lens with your middle or ring finger, and fix your little finger on the patient's eye socket. If there are light reflections, tilt the lens slightly. The axis of the illumination system and observation system of the slit lamp should be 5–10°. Set the slit lamp light to the brightest and narrow the width. Adjust the height of the slit lamp light so that the rays can enter the pupil, and lower the magnification to 10–16 times. Move the adjustment knob up and down and back and forth to focus on posterior pole of the fundus.

Start the observation while changing the magnification and the direction of the slit lamp light. If necessary, you can give it the vertical tilt by rotating the direction of the slit lamp light axis by 90° so that the light beam can be projected up from below. Wrinkling eyelid or pressing the

Fig. 15.8 Contact lens insertion method. (**a**) After the patient has seen the upper side, the lens is inserted into the inferior conjunctival fornix. (**b**) Contacting a lens to half the lower surface of the eyeball. (**c**) The patient looks at the front, and then the lens is in full contact with the eyeball

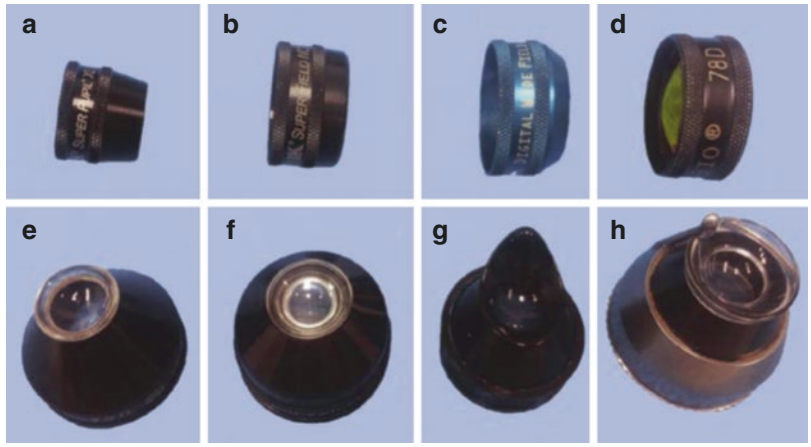


Fig. 15.9 Types of auxiliary lenses Volk noncontact lens: (**a**) Super Pupil XL lens. (**b**) Super Field NC lens. (**c**) Digital Wide Field lens. (**d**) 78 diopter Volk contact lens. (**e**) Area Centralis lens for observation of posterior pole. (**f**) SupraQuad 160 lens for observing the periphery retina. Fundus peripheral examination lens with scleral depressor: (**g**) Kyoto Contact lens (suitable for Asians with narrow palpebral fissures). (**h**) Haag-Streit lens

sclera near the lens edge disconnects the contact between the lens and the cornea.

15.3.2 Characteristics and Tips of Lens

15.3.2.1 Noncontact Lens

If the patient's palpebral fissure is narrow, lift the upper eyelid up with the middle finger holding the lens, and fix the lens at the same time (Figs. 15.9 and 15.10).

A +54 to +130 diopter lens, high-refraction convex, has aspheric on both sides, so there is no front side difference. A focal length of +90 diopter lenses is about 6 mm from the cornea and that of +60 diopter lenses is about +12 mm. The +90 diopter is widely used, because it shows wide vision and is easy to use even when the pupil is small or when media opacity was existed. A + 60-diopter lens provides higher resolution and narrower vision than +90 diopter, making it advantageous for macular observation.

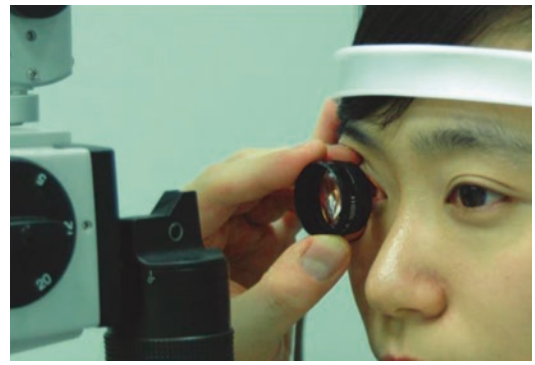


Fig. 15.10 Widening of the palpebral fissure

15.3.2.2 Contact Lens

Goldman Three-Mirror Lens

A Goldman three-mirror lens is a concave lens, providing direct and narrow view. It is difficult to observe eyes with small pupil diameters or opacity on the medium. It consists of a central lens (−58 to −60 diopters) and three reflectors around the lens, 59° (goniscopic), 67° (peripheral), and 73° (equatorial).

About 30° of the posterior pole of the retina is observed through the central lens, and the peripheral and anterior chamber angles are observed through the reflector. Observe the peripheral retina and anterior chamber angle as you rotate the lens 360°. The central lens provides a direct image with the field of vision of 30°, and it is used to observe the macula of the papilla. When you observe the peripheral retina with three reflectors, set the long axis of slit light to be per-

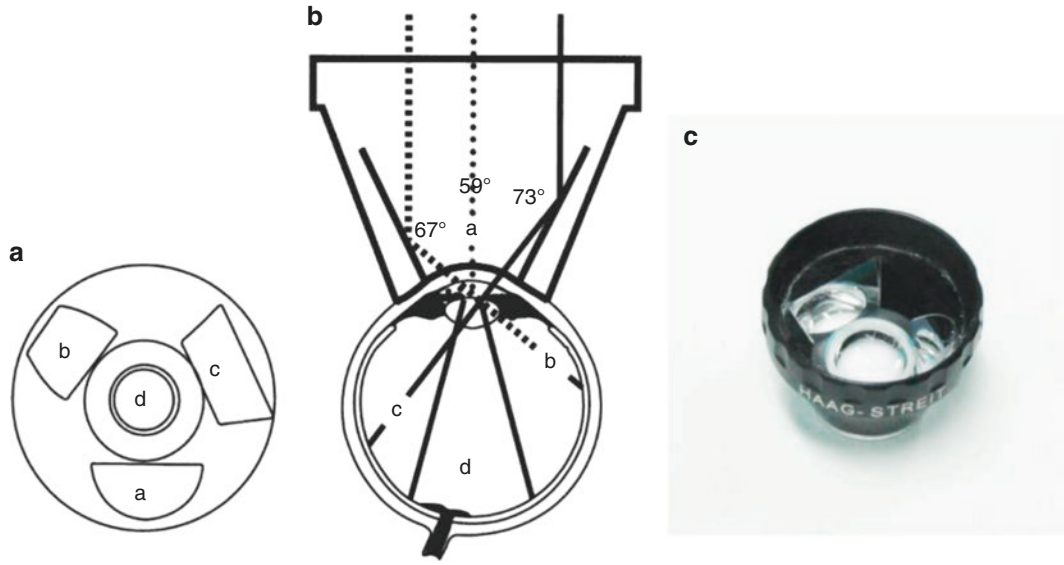


Fig. 15.11 Range of observation of slit lamp fundus examination using Goldmann three-mirror lens. (**a**) Structure of Goldmann three-mirror lens. (a) From peripheral retina to pars plana and anterior chamber angle. (b) From the equator to the ora serrata and pars plana. (c) 30° to the equator. (d) Observation of 30° range including macula. (**b**) Range of fundus visible by each lens. (**c**) Goldmann three-mirror lens

pendicular to the reflector for easier observation (Fig. 15.11).

Use a vertical slit light when observing at 12 or 6 h periphery retina, and it does not matter whether the illumination light is shed from the left or the right side (Fig. 15.12a). When the reflector is located at 6 o'clock, periphery retina at 12 h was observed with the image upside down. When you are observing the inferior retina with the reflector sitting obliquely on the upper part of the horizon, let the light come in from the same side as the reflector and from the meridian direction with the light providing an elevation as it shines up from below (Fig.15.12b, c). When you are observing the inferior retina with the reflector sitting obliquely on the upper part of the horizon, let the light come in from the opposite side to the reflector and from the meridian direction with the light providing an elevation angle (Fig. 15.12d, e). Increase the angle of elevation as the reflector is closer to the horizontal. At 3 and 9 o'clock (i.e., in the horizontal direction), the maximum angle of elevation is given horizontally with the vertical slit light providing illumination, and the angle between the slit light and the microscope is 0 or coaxial (Fig. 15.12f).

Tilting the lens or changing the patient's line of sight makes the range of vision wider. To see more of the peripheral side with the reflector, provide as much mydriasis as possible, and let the patient face the opposite side of the reflector.

A lens with a scleral depressor should be used to observe the ora serrata and the pars plana.

High-Refraction Convex Lens

The fundus is observed as indirect image with upside down. Peripheral fundus can be observed even in pseudophakia, media opaque, or small pupil. There are various lenses ranging from 60° for posterior pole to 165° for ultra-wide-field view. The higher the power of refraction provides, the wider the field of vision. However, its image is darker and lower magnificated.

It is easy to observe using a slit light without an angle. And you can move the slit light slightly to the left and right in order to obtain a stereoscopic effect. It is possible to observe the periphery if you tilt the lens toward the opposite side from your vision. The magnification of the image is the power of the eye (about 60 diopters) divided by the power of the convex lens. That is, a 60-diopter lens has a magnification of 1×, but a

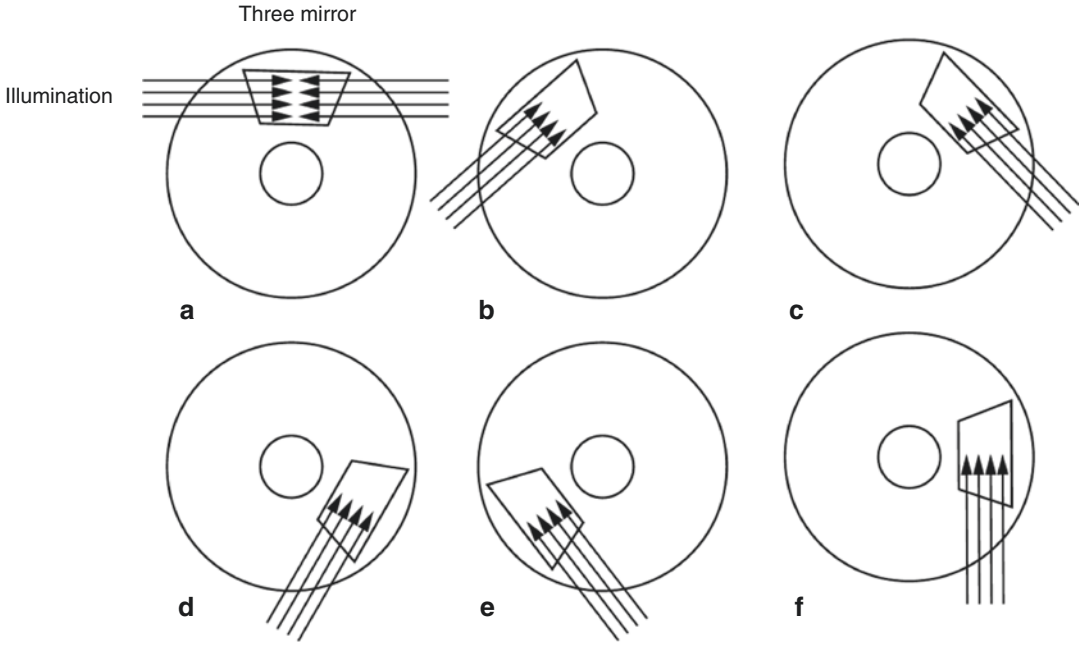


Fig. 15.12 Direction of illumination of the slit lamp fundus examination with Goldmann three-mirror lens. (**a**) Reflector at 12 o'clock, 6 o'clock position: Both sides can be illuminated. (**b**, **c**) The reflector is located on the superotemporal and superonasal sides: reflects the light from the same side of the reflector. (**d**, **e**) The reflector is located on the inferotemporal and inferonasal sides: reflects the light from the opposite side of the reflector. (**f**) Reflector at 3 o'clock, 9 o'clock position: illuminates coaxially and give maximum angle of elevation

90-diopter lens has a magnification of 60/90 = 2/3×. [The resolution of the image obtained by a lens with high refractive power does not increase even if you increase the magnification of the slit lamp microscope.] Volk's SuperQuad 160 lens and Ocular's Mainster PRP 165 lens are some of the ultra-wide angle lenses, and they are useful when you perform panretinal photocoagulation or when you are looking for a retinal break. The low-magnification lens has higher resolution and narrower visual field and is appropriate for focal laser treatment on the posterior pole. However its visual field is wider than that of Goldman three-mirror lens (concave lens).

15.3.3 Choosing the Lens

The noncontact convex lens is the most convenient because it does not require the process of fitting the lens to the eye. It is difficult to examine patients with poor cooperation under bright light.

Using a contact lens (convex lens, concave lens) is advantageous in that although the process of fitting the lens to the eye itself is cumbersome, the eye movement and the blinking of the eye can be restricted after the fitting.

Using a contact concave lens (a Goldman three-mirror lens), it is difficult to observe the periphery in case of insufficient mydriasis or opacity on the medium. You can be confused with the direction during observing the periphery because the image is turned upside down. An advantage is using a contact concave lens that the anterior chamber angle can be checked simultaneously.

The contact convex lens has various magnification types, and you can select the appropriate one as needed. It is commonly used in photocoagulation. The contact concave lenses has narrow visual field, so it is restricted using in panretinal photocoagulation.

15.3.4 How to Examine the Vitreous Body

15.3.4.1 Observing the Anterior One-Third of the Vitreous Body

The anterior part of the vitreous body is well observed without any ancillary equipment. Pupil dilatation is needed to observe fine change. Changing the illumination angle by 15–20° or moving the focus of the slit lamp might be helpful to observe the anterior part of the vitreous body. The wrinkle-rich membrane looks like a curtain. It moves together when the eyeball moves.

15.3.4.2 Observing the Posterior Two-Thirds of the Vitreous Body

Put the focus on the retinal surface first and then move the focus to vitreous.

Changing the illumination angle might be helpful to observe the vitreous body.

Observe vitreous movement while eyeball is moving.

15.3.4.3 Interpretation of Vitreous Change

Young people appear to have a homogeneous gel-like structure of the vitreous, but it becomes liquefied as they age. The liquefied parts appear optically void. In case of high myopia or vitreoretinal degenerative diseases, thickened gelatinous vitreous membranes are often seen. If posterior vitreous detachment occurs, the anterior vitreous gel is enriched and often shows ring-shaped Weiss ring in front of the optic disc. Vitreous opacity can be caused by various factors such as degeneration, inflammation, or hemorrhage, and it requires accurate diagnosis. If vascular or fibrous tissue proliferation is observed in the vitreous body, note the area and the degree of adhesion to the retina.

15.4 Fundus Photography

Fundus photography involves capturing a photograph of fundus. Fundus photography can be classified to camera type and scanning laser ophthalmoscopy according to the light source.

15.4.1 Camera Type

Fundus cameras consist of an intricate microscope and a flash-enabled camera.

The optical design of fundus cameras is based on the principle of monocular indirect ophthalmoscopy. A fundus camera provides an upright, magnified view of the fundus. A typical camera views 30–50° of retinal area, with a magnification of 2.5×. The optics of a fundus camera is similar to those of an indirect ophthalmoscope in that the observation and illumination systems follow dissimilar paths. When the button is pressed to take a picture, the retina is illuminated by flash, and reflected light are captured onto film, a digital charge-coupled device (CCD), or complementary metal-oxide semiconductor (CMOS).

15.4.2 Scanning Laser Ophthalmoscopy Type

Scanning laser ophthalmoscopy (SLO) is a method of examination of the eye using the technique of confocal laser scanning microscopy.

A small point laser beam is scanned in the fundus, and images are formed by the reflected light, which is observed with CCD. Because it uses very low light intensity, it can obtain clear images with little glare. High degree of spatial sensitivity can be obtained. Since the single-wavelength light is used, a real color image can't be obtained by SLO. Ultra-wide-field retinal imaging devices of Optos used two wavelengths (red laser 635 nm and green laser 532 nm) and can produce digital pseudo-color images.

15.4.2.1 Optos

You can shoot without enlarging the pupil, but if you enlarge the pupil, you can shoot a wider range 200° more clearly. Because it utilizes laser light, relatively clear images can be obtained even in cases of cataract or media opacity, but it is affected by the patient's movement or lid laxity. Because the color image is digitally recombined from two wavelengths, it differs from the color seen in actual fundus examination. Although it shows a wide range view of 200°, the resolution

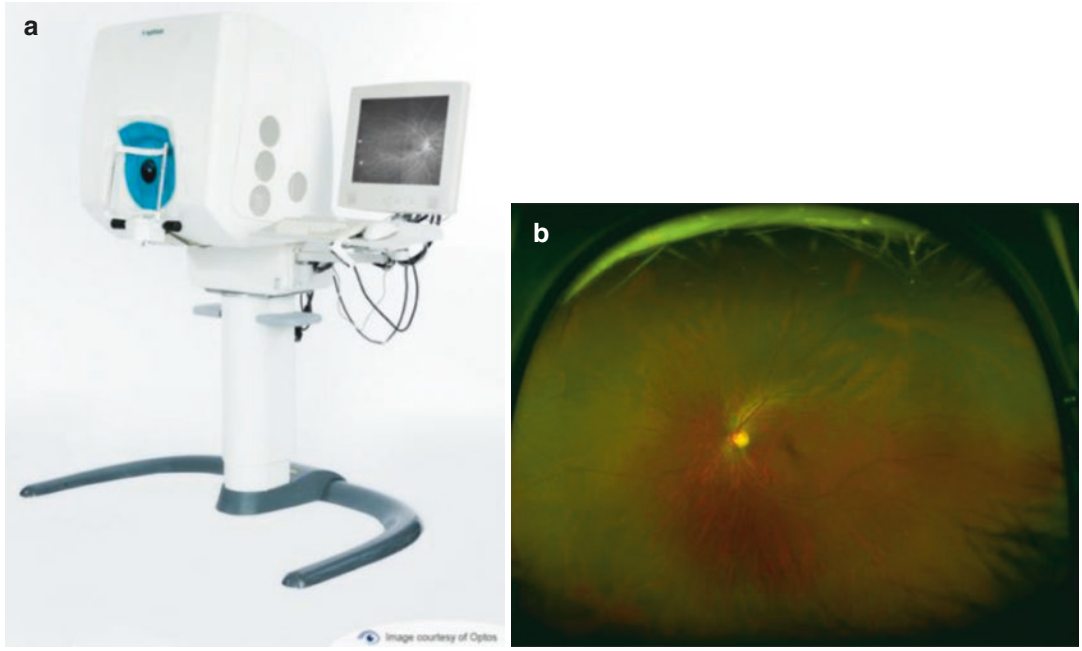


Fig. 15.13 Optos ultra-wide-angle scanning laser ophthalmoscope. (**a**) Machine appearance. (**b**) Fundus photography of normal eye

is less than that of a digital camera with a range of 30–50°. Image distortion occurs in periphery because the spherical eyeball is shown as a plane (Figs. 15.13 and 15.14; Table 15.1).

15.5 Red-Free Photography

The longer the wavelength of the light, the less scattering occurs, and it can reach to deep areas of tissue (Fig. 15.15). On the other hand, short-wavelength light is reflected on the superficial area. Camera type (fundus photography) uses white light as light source which consists of various wavelengths. Red-free photography takes a fundus photo with short-wavelength light only. Its photos mostly have the information of the superficial area of the retina. It is useful for observing retinal vessels, hemorrhage, reticular drusen, exudate, pigmentation of retinal pigment epithelium, retinal edema, macular frontal membrane, and nerve fiber layer defect on retinal surface layer (Fig. 15.16a). Green filter on white light source makes short wavelengths of around 500 nm.

15.6 Fundus Autofluorescence

A fluorophore is a material that can re-emit light upon light excitation. Fundus autofluorescence is an imaging technique that maps the distribution of fluorophore in the fundus. Lipofuscin granules accumulating in the retinal pigment epithelium are the main fluorescent material. Collagen and elastin component in the choroidal blood vessels act as minor fluorophores.

The scanning laser ophthalmoscope (SLO) uses a light source of 488 nm in wavelength and detects autofluorescence by using an emission filter of 500–700 nm. It takes several images and amplifies the autofluorescence to produce an image. The camera, on the other hand, uses a light source of 580 nm filter as excite light and an emission filter of 695 nm.

Fundus autofluorescence can be obtained by using near-infrared rays. The light of 805-nm wavelength was used as the stimulating light. The autofluorescence excited by near-infrared is known to be mainly related with melanin pigment of the choroid.

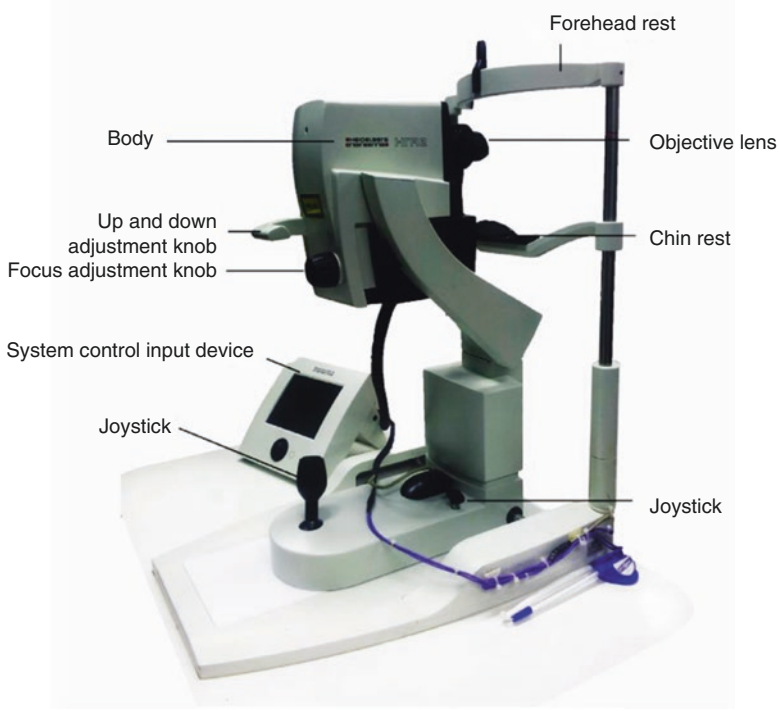


Fig. 15.14 Laser scanning ophthalmoscope (HRA)

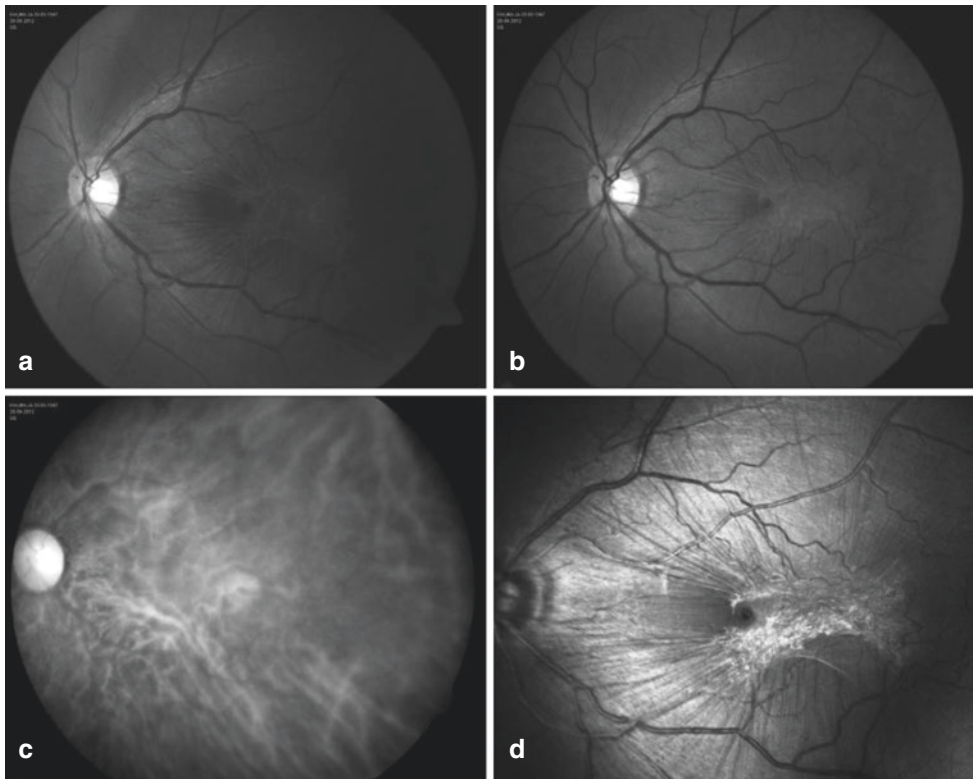


Fig. 15.15 Pictures taken with the same epiretinal membrane. (**a**–**c**) Camera-type fundus photography. (**a**) Blue light fundus photography. (**b**) Green light fundus photography. (**c**) Red light fundus photography. (**d**) Red-free fundus photography. (HRA2 shot with laser scanning ophthalmoscope)

Table 15.1 Comparing fundus photography

	Digital camera	Ultra-wide-field SLO (Optos)
Light source	White light	Laser (532um and 633um)
View	30–50°	200°
Image	High resolution Color	Low resolution Pseudo color
Challenging condition	Media opacity(cornea, lens, or vitreous) Photophobia	Eyeball movement Lid laxity

15.6.1 Reading

15.6.1.1 Normal Autofluorescence

Taken images depend on excite source, emission filters, and used devices (camera or SLO).

SLO (488 nm-Light Source with 500–700 nm Emission Filter)

The macular pigment of xanthophyll causes the macula to appear dark, and the large retinal vessels and optic nerve head also have low fluorescence.

Near-Infrared SLO

Because the density of choroidal pigment is high in macula and long wavelength less affected by Xanthophyll was used, macula appears bright. The retinal vasculature and optic disc appear as a low fluorescence just as it did in the short-wavelength fundus autofluorescence.

15.6.1.2 Hyperfluorescence

Hyperfluorescence is observed when lipofuscin accumulates excessively. It is often seen in genetic illnesses such as Stargardt's disease and Best disease. It can also be observed in central serous retinopathy as the illness progresses. Drusen make also hyperfluorescence (Fig. 15.16).

15.6.1.3 Low Fluorescence

Low fluorescence can be seen in fluorescence blocking lesions such as hard protein or subretinal hemorrhage present on the retinal pigment epithelium or retinal pigment epithelium atrophy and defect.

15.7 Normal Findings in Fundus

The fundus is divided into four quadrants by the horizontal and vertical meridians with the fovea as the center of the eye, and they are called superotemporal, superonasal, inferotemporal, and inferonasal quadrants. The anterior end of the retina is the ora serrata, and the circumference connecting the neck of the vortex vein is called the equator. The area surrounded by the superior and inferior vascular arcade, including the macula and the optic nerve, is called the posterior pole. The area from the vascular arcade to the umbilical vein along the umbilical artery is called the mid-periphery. The area from the vortex vein to the ora serrata is called the periphery. Peripheral fundus can be divided into equatorial parts and ora serrata parts (Fig. 15.17).

15.7.1 Posterior Pole

Optic disc is an oval shape with a diameter of 1.8 ± 0.3 mm horizontally and 1.9 ± 0.3 mm vertically. Optic disc diameter (about 1.5 mm) can be used to measure the size and position of fundal lesions. Disc margins are usually sharp, but the nasal side can be a little unclear. A choroidal pigment or a vascular network can be sometimes observed in the form of a blur light gray half-moon near the corner of the temporal disc, and this is called conus. It is common for myopic eyes. A white ring around the optic disc and a black ring around it can be seen, which is called the scleral ring and the choroidal ring, respectively.

The color of the optic disc is pink. It is called "physiologic disc cupping" because the center of the optic disc is depressed with a somewhat lighter hue than the circumference. When this cupping is deep, the lamina cribrosa passing through the optic nerve appears as gray spots. The cup/disc ratio, which is the ratio of the horizontal diameter of the disc cupping to the horizontal diameter of the disc, is 0.4 for normal people. In the case of glaucoma, however, the diameter of the cupping increases, and the cup/disc ratio increases. The vein on the optic disc

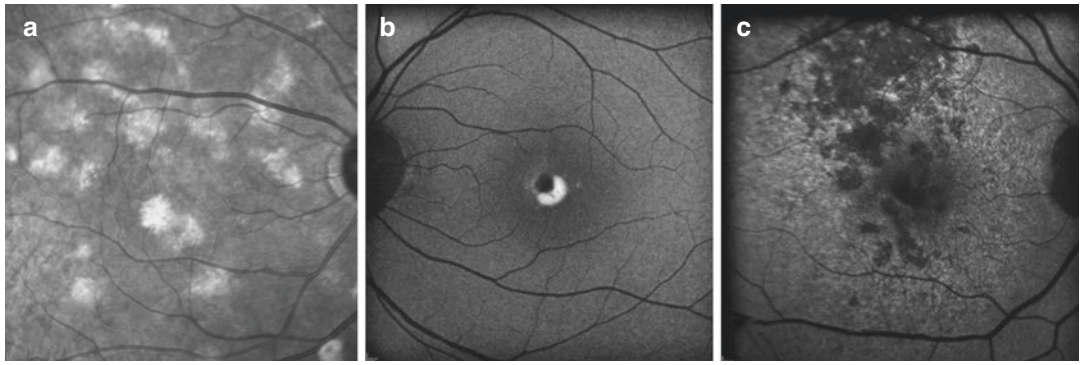


Fig. 15.16 Autofluorescence. (**a**) Drusen. (**b**) Best disease (hyperfluorescence). (**c**) Dry age-related macular degeneration (hypofluorescence)

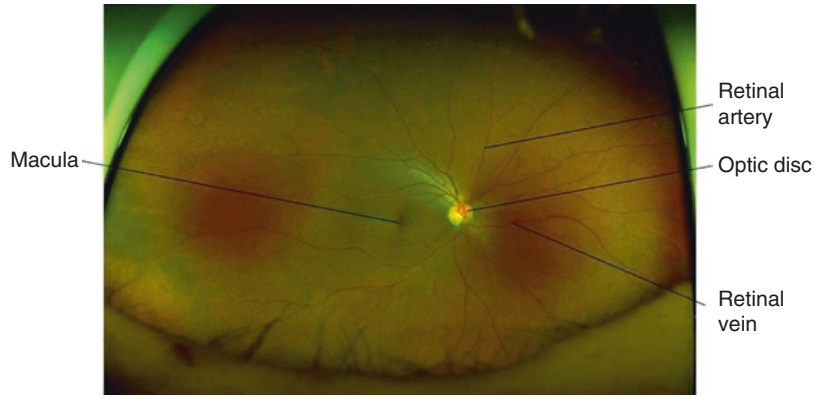


Fig. 15.17 Anatomical location of normal fundus

can pulsate occasionally, but pulsation on the artery is abnormal (Fig. 15.18).

The central artery and the central vein of the retina come from the optic disc head and are divided into four stalks which are called superotemporal, superonasal, inferotemporal, and inferonasal arteries and veins. In healthy eyes, the vessel walls are transparent, and what is seen using the ophthalmoscope is the blood flow in the blood vessels. Arteries are slightly thinner than veins, and the ratio of arterial diameter to vein diameter is 2:3 or 3:4. The arteries are bright red, and veins are dark red. They all have light reflexes (light streaks) at their centers, but the arteries have clearer and thicker reflexes. In case of atherosclerosis, this reflex is increased. The nasal artery runs relatively straight, but temporal arteries are distributed in the arcuate shape above and below the macula. Arteries and veins run in similar ways, but veins often exhibit tortuosity, and the run and the thickness change easily when there is an abnormality in blood circulation. Arteries and veins often cross, and arteries usually pass through the upper part of the veins. The junctions of arteries and veins should be carefully monitored in case of hypertension and atherosclerosis. The cilioretinal artery sometimes moves out from the choroidal vessels and is located near the macula at the edge of the temporal disc regardless of the retinal artery.

The macula is located two disc diameters away from the temporal edge of the optic disc head, and it is the center of posterior pole. Macular reflection can be observed with about 2 mm diameter in center of posterior pole, the inside of which is called a macula. Macula has rich xanthophyll so it looks dark brown. The center of macula is avascular area of 500 μm diameter. Macula has a central depression with diameter 350 um which is called fovea. Fovea consists of

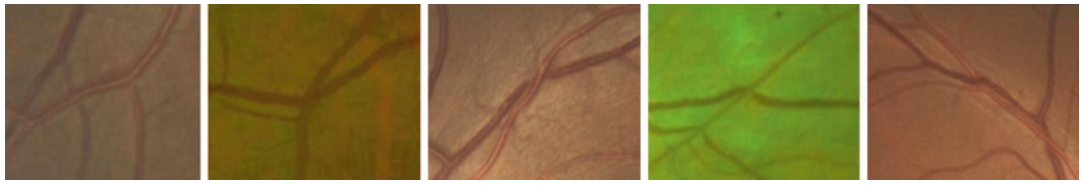


Fig. 15.18 Crossing phenomenon of retinal vessels

only cone cell. Macular and foveal reflexes are more distinctive in young age and become less distinctive as aging.

15.7.2 Peripheral Retina

The equator is the longest circumference of the eyeball and is located midway between the corneal apex and the fovea. Since the equator is not an anatomical structure, its position is recorded with respect to other structures. The equator is 13 mm away from the corneal limbus and is twice distant from where the rectus muscle is attached. Ophthalmologically, the equator is located four disc diameters away from ora serrata and just in front of ampulla of vortex vein. The peripheral retina has one-third of the total area of the retina.

Long ciliary nerve is a flat, light yellow straight line whose diameter is 1/3 of the disc diameter, and it passes through the ora serrata horizontally from the equatorial region. Long ciliary arteries appear red with medium size of retinal vessel and have no branches.

Short ciliary nerves are light yellow and are seen above and below the vortex veins. They are slightly curved, irregular in diameter, and sometimes branched.

It is called a vortex vein when the choroidal veins gather to form a vortex and pass into the sclera. The line connecting this vortex vein becomes the equator.

Lattice degeneration, cystoid degeneration, retinal tear and dialysis, pars plana cyst, and retinal detachment are common in peripheral retina.

15.8 Fundus Drawings

Sketching fundus findings is helpful not only for record but also for determining the overall fundus status, understanding the disease course, and deciding the treatment policy.

In general, the retinal fundus recorder has three concentric circles. The center corresponds to the fovea, the inner circle is the equator, the middle circle is ora serrata, and the outer circle is the posterior edge of the ciliary process. Twelve meridians are marked radially with time hours like a clock (Fig. 15.19).

The recording process of fundus is as follows.

First, draw optic disc.

Draw vessel from disc to the periphery in four quadrants. The blood vessels are one of the major indices indicating the position of the retinal lesion, so make sure you draw them accurately.

Draw the vortex veins. Those are also indicators of the equator.

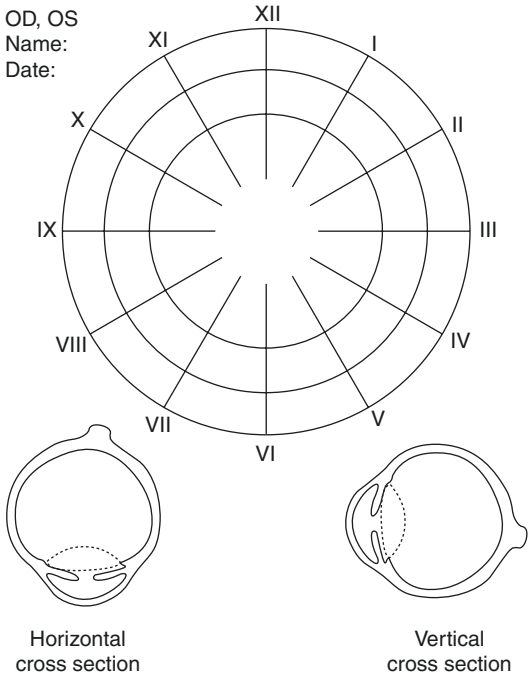


Fig. 15.19 Fundus chart

Record the observed fundus findings with colored pencils accurately and in detail using the standard symbols and standard color codes on the fundus chart (Fig. 15.20, Table 15.2).

The commonly used color codes are modified slightly in each hospital. The basic principle is that the red color is used to note optic discs, retinal artery, retinal hemorrhage, the blue color to note retinal detachment and retinal vein, the green color to note media opacity such as corneal opacity or vitreous opacity, the yellow color to note acute or active changed lesions, the brown color to note choroid findings, and the black color to note cicatrix and old changes. Attached retina in the eyes with retinal detachment can be colored with red, but it is commonly left uncolored. These color codes would be recommended, but some modification of color code would not matter if they do not differ within same hospital (Table 15.3).

Fig. 15.20 Color code

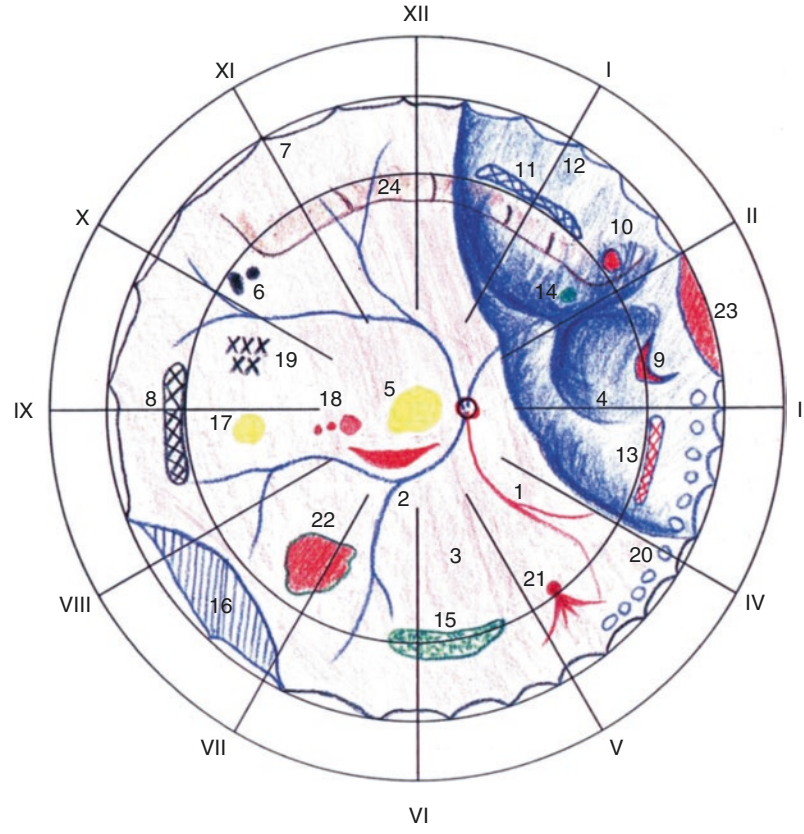


Table 15.2 Characteristics of various fundus examinations

	Direct ophthalmoscope	Indirect ophthalmoscope	Slit lamp microscope	Slit lamp microscope
Contact/ noncontact	Noncontact	Noncontact	Contact lens	Noncontact lens
Range of observation	Posterior of the equator	Up to peripheral retina	Up to ora serrata using scleral depressor	Posterior of the equator
Convenience	Good	Less comfortable	Uncomfortable	Less comfortable
Resolution	Low	Low	High	High
Field of view	Narrow 10°	Wide 45°	Wide	Wide
Medium opacity effect	Strong	Weak	Little weak	Middle
Stereopsis	No	Yes	Yes	Yes
The skill of the examiner	Not needed	Somewhat needed	Needed	Needed
Observational image	Direct	Indirect	Indirect (Goldmann three-mirror lens: direct and mirror image)	Indirect (Hruby: direct)
Purpose of use	Observation of macular vascular changes and optic disc	Observation of the wide range of retina Stereoscopic observation of peripheral retina by compression	Used for photocoagulation Poor dilatation of pupil can be used	Standard inspection with stereoscopic, wide field of view and magnification conversion

Table 15.3 Color code (with description of Fig. 15.20)

Color	Fundus findings
Blue	Retinal vein (2), detached retina (4), retinoschisis (16), ora serrata with detached surroundings (12), cystoid degeneration, retinal fold, white-without-pressure, retinal tuft (20) Blue lattice in blue circumference: lattice degeneration on detached retina (11)
Red	Not detached retina (3), preretinal and intraretinal hemorrhage (18), microaneurysm, retinal artery (1), vortex vein (21), hole of retinoschisis. chorioretinal atrophy, hemangioma, anastomosis vessel, not detached fovea (Represented by +), optic disc Red in blue circumference: retinal tear (9), retinal hole (10), thin retina in the detached retina (13), ora dialysis (23)
Green	Medium opacity (e.g., lens opacity (14), corneal and vitreous opacity (15), vitreous hemorrhage (fresh bleeding is marked in red and surrounded by green lines, 22), posterior hyaloid membrane, epiretinal membrane, foreign body in the vitreous
Black	Retinal and choroidal pigmentation (6), fibrous proliferation tissue, cotton wool spot, laser photocoagulation and cryopexy (19), ora serrata with not detached surroundings (7), exudate (represented by x), conus, occlusive retinal artery and vein, borderline of chorioretinal atrophy, cotton wool spot (represented by C) Black lattice in black circumference: lattice degeneration on not detached retina (8)
Brown	Choroidal pigment under the detached retina, choroidal detachment, subretinal detachment (it can be expressed in red), suprachoroidal hemorrhage, boundary of scleral buckling (24, under the detached retina), choroidal tumors,
Yellow	Chorioretinal hard exudate (17), macular edema (5), active chorioretinitis, recently treated laser photocoagulation and cryopexy lesion, drusen, retinal vascular sheath, long ciliary nerve
Orange	Elevated neovascularization
Purple	Flat neovascularization

Suggested Reading

Eifrig DE. A system for examining the ocular fundus. North Carolina Med J. 1983;44:631–3.

Feeney-Burns L, Berman ER, Rothmann H. Lipofuscin of human retinal pigment epithelium. Am J Ophthalmol. 1980;90:783–911.

Nover A. The ocular fundus: methods of examination and typical findings. Blodi FC, Trans. 4th ed. Philadelphia: Lea and Febiger; 1981.

Paton D, Hyman BN, Justice J Jr. Introduction to ophthalmoscopy. Kalamazoo: Upjohn Co.; 1976.

Phillips CI. Dilate the pupil and see the fundus. Br Med J. 1984;288:1779–80.

Schmitz-Valckenberg S, Holz FG, Bird AC, Spaide RF. Fundus autofluorescence imaging: review and perspectives. Retina. 2008;28(3):385–409.

16 Fluorescein and Indocyanine Green Angiography

Ik-Soo Byon

16.1 Fluorescein Angiography, FA

The purpose of FA is to evaluate the abnormalities of the following retinal structures:

- Retinal vessels: morphologic abnormalities (dilation, tortuosity, stenosis, anastomosis, aneurysm, etc.), perfusion, circulation, retinal neovascularization, and hyperpermeability of the retinal vessel due to functional abnormalities
- Retinal pigment epithelium: morphological changes such as pigmentation, atrophy and tear, and hyperpermeability due to blood retinal barrier impairment
- Choroidal vessels: loss of choriocapillaris, choroidal circulation abnormalities, and choroidal neovascularization

FA is essential for the detection of vascular filling defect, non-perfusion area, and choroidal neovascularization. These FA findings can help the physician to diagnose and treat the intraocular disease.

Fluorescein used as a contrast agent absorbs blue light energy with a wavelength of 465–490 nm in the dissolved state and emits green-yellow fluorescence with a wavelength of 485–600 nm. When fluorescein is injected into the blood vessels and blue flash is illuminated using a blue excitation filter in front of the flash, fluorescein molecules that reach the blood vessels and tissues in the eye generate green-yellow fluorescence. The reflected blue light is shielded by the green filter and only the green-yellow fluorescence is passed through (Fig. 16.1).

Eight percent of fluorescein dye is bound to albumin in the blood, and the remaining 20% diffuses freely in the bloodstream, emitting fluorescence and leaking into extravascular tissues. The leakage of fluorescein is not observed in the normal retinal tissue because of the blood retinal barriers of the retinal vascular endothelial cells. And the fluorescence from the choroid is blocked by the retinal pigment epithelium. The retinal vessels can be clearly observed in the healthy eye.

16.1.1 Method

Dilate the patient's pupil in the dark room, then sit in a comfortable position in front of the device (Fig. 16.2), and focus on the fundus.

Take a fundus photograph and red-free fundus photograph by inserting a green filter.

Insert a barrier filter under blue light and take one or two images.

Run the timer while quickly injecting 5 ml of 10% fluorescein into the anterior vein of the antecubital vein.

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J.-S. Lee (ed.), *Primary Eye Examination*, https://doi.org/10.1007/978-981-10-6940-6_16

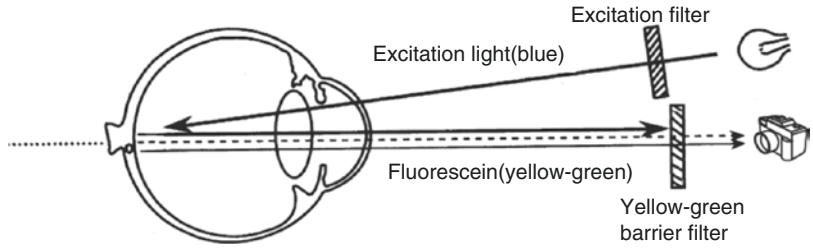

Fig. 16.1 Principle of fluorescein angiography

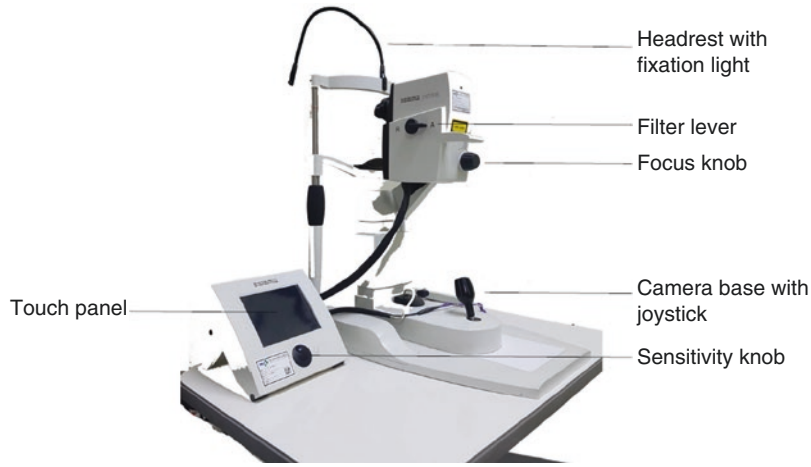

Fig. 16.2 Angiography device

The choroidal fluorescence appears at approximately 7–8 s after the injection, and photos of the retinal arteriovenous phase are continuously taken for 20 s at intervals of 1 s.

After retinal venous phase, you can take images at 3, 5, 10, and 30 min or as many hours as you need, depending on the purpose. The photos of the peripheral retina are taken by moving the eyeball or by moving the fundus camera. It is good to take the photos of another eye.

To evaluate the retinal circulation, continuous photographing should be performed. In order to examine the state of blood vessels, photographs should be taken when the contrast reaches the maximum. The photographs should be taken more than several minutes after the intravenous injection.

Stereophotography may be taken to differentiate the location of lesions within the retinal tissue. Patients with macular disease are especially advised to take the stereophotography. For the stereophotography, move the optical axis slightly to the right from the center of the pupil with a general fundus camera and then move the adjustment knob slightly to the left to take another one. At this time, the moving width is preferably about 1 mm. To emphasize the stereoscopic effect, increase the movement width. Do not change the height of the camera. Take two photos in succession. There is a camera that can take stereophotography simultaneously.

In children or patients who cannot be photographed with a fundus camera, a direct ophthalmoscope, an ophthalmoscope, or a slit lamp microscope is considered using a blue filter.

16.1.2 Normal Fluorescein Angiogram

16.1.2.1 Choroidal Phase

It appears in 8–10 s after injection of fluorescein into the anterior cubital vein. The choroidal artery and choroidal capillaries begin to appear just before the central retinal artery showed fluorescence. Irregular fluorescence from the posterior pole appeared as a map and spread widely to the periphery, gradually distributing diffuse, granular background fluorescence. Because of abundant

xanthophylls, melanin and lipofuscin pigments, the tall retinal pigment epithelium blocking the choroidal fluorescence, and physiological avascular zone of macula, the central area of macula can be dark at this phase.

16.1.2.2 Retinal Arterial Phase

Imaging of the central retinal artery begins at 9–12 s after injection of fluorescein and 1–2 s after choroidal fluorescence. The time from the initiation of intravenous injection to the appearance of fluorescence in the central retinal vein is referred to as arm-to-retina circulation time, usually 10–15 s (Fig. 16.3a).

16.1.2.3 Retinal Capillary Phase, Arteriovenous Phase

At 12–14 s after the injection, capillaries are visualized in succession on the arteries, and the capillary network of the macula is well visible.

16.1.2.4 Retinal Venous Phase

It appears 20–30 s after the injection. Fluorescence enters the large vein from the retinal capillary, and the fluorescence intensity of the vein becomes stronger than that of the artery. Fluorescein enters the retinal veins from the postcapillary venules along their walls. The blood flow is faster in the center of vessel than on the sides of it, showing laminar flow, which is called the early venous phase (Fig. 16.3b). The entire vein is then filled with fluorescein, which is called the late venous phase (Fig. 16.3c). The perifoveal capillary network is best visualized in the peak venous phase of the angiogram. Arteriovenous transit time is the period of fluorescein filling between the retinal artery and the retinal vein in the same area of vascular arcade. It is within 11 s in the healthy eyes.

16.1.2.5 Recirculation Phase

The fluorescein flush begins to gradually decrease from the retinal and choroidal circulation. However, the recirculation of fluorescence in low concentration starts at 25–30 s after injection. In 3–5 min, its flush diminishes with time. In 10 min, fluorescein almost disappears from the vessels.

16.1.2.6 Late Phase

At 30–60 min after injection, the retinal and choroidal vasculature begins to empty of fluorescein. The background fluorescein remained faint due to stain in the choroid, Bruch's membrane, sclera, and optic disk. If the blood retinal barrier is damaged, the fluorescein leak results in the staining of abnormal vessels or the pooling in the tissue space.

16.1.3 Abnormal Fluorescein Angiogram

Depending on the degree of fluorescence, it is classified to hyperfluorescence and hypofluorescence.

16.1.3.1 Hyperfluorescence

There are four causes of bright fluorescence in excess of what would be expected on a normal angiogram (Fig. 16.4). If hyperfluorescence is detected, physicians should judge where the origin of fluorescence is.

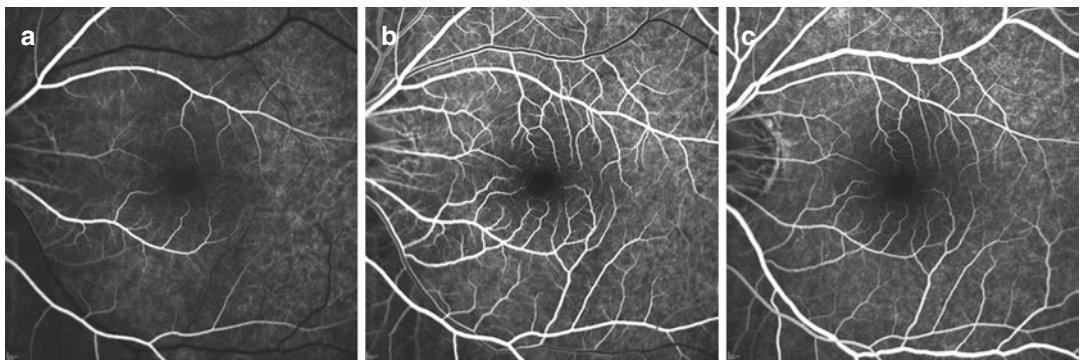

Fig. 16.3 Fluorescein angiography. (**a**) Arterial phase. (**b**) Early venous phase. (**c**) Late venous phase

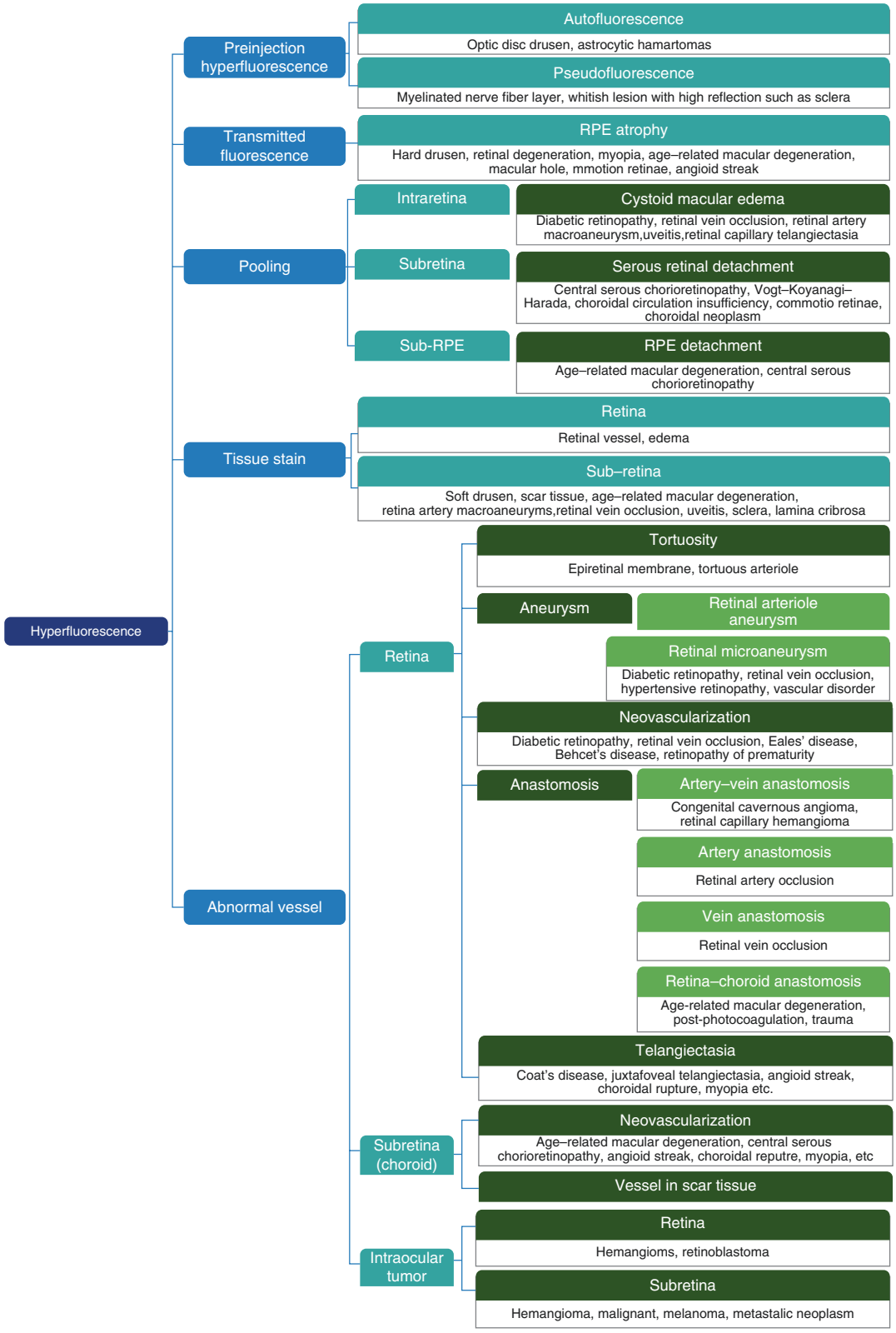

Fig. 16.4 Classification of hyperfluorescence in fluorescein angiography

1. Preinjection Fluorescence

Autofluorescence is the fluorescence of the tissue itself, which shows weak fluorescence before injection and is typically seen in the optic disk drusen. What is caused by poor combination of excitation filter and barrier filter is called pseudofluorescence.

2. Transmitted Fluorescence (Pigment Epithelial Window Defect)

The transmitted fluorescence of the retinal pigment epithelium appears at the early phase. The main causes are the atrophy of retinal pigment epithelium and decrease of pigment granules. The fluorescence of the choriocapillaries appears to be visible. The transmitted fluorescence appears simultaneously at the early choroidal phase and increases in intensity as the increase of choroidal fluorescence. The shape and size are not changed even at the late phase of angiogram. It fades and disappears as the choroidal empty of dye at the end of angiogram.

3. Abnormal Vessels

When the abnormal vessels of the retina, choroid, and optic disk such as neovascularization, telangiectasis, and hemangiomas are filled with fluorescein, they show hyperfluorescence at the early phase of angiogram.

4. Leakage

The fluorescence leaks out of the blood vessels due to breakdown of the blood retinal barrier or leaks from the choroid to the retina due to abnormalities of the retinal pigment epithelium.

If the fluorescein welled into an anatomical space such as tissue or cellular gap, it is called "pooling." It is observed in central serosal chorioretinopathy, retinal pigment epithelial detachment, Vogt-Koyanagi-Harada syndrome, etc. Cystoid macular edema that accumulates in the retina of diabetic retinopathy and retinal vein occlusion is caused by leakage from the abnormal retinal capillaries at late phase of angiogram.

"Staining" refers to leakage of fluorescein into tissue. It is physiologically seen in glial tissues of the sclera and choroid, Bruch's membrane, optic disk, and retinal vessels, whereas it is pathologically seen in diseases including retinal vasculitis in Behcet disease and sarcoidosis, drusen, glial tissue of scar, and the pigment epithelium.

16.1.3.2 Hypofluorescence

Hypofluorescence is an abnormal reduction of fluorescence and appears dark on angiogram. There are two causes (Fig. 16.5).

1. Blocked Fluorescence

Hemorrhage, exudates, pigment, edema, etc. located in front of the retinal or choroidal vessels blocked fluorescence and show hypofluorescence on angiogram.

2. Vascular Filling Defect

Fluorescein is not present in blood vessels due to retinal or choroidal vascular occlusion, and hypofluorescence is observed from the early phase of angiogram. Strictly speaking, hypofluorescence due to a circulatory delay seen at the early phase of angiogram is called as the filling delay, whereas the complete absence of fluorescence from the early to the late phase of angiogram is called the vascular filling defect. Because the conditions are different between filling delay and filling defect, it is better to differentiate them.

Compared with ophthalmologic examination or fundus photography, the vascular filling defect can be differentiated from the blocked fluorescence. If materials are observed in fundus and correspond to hypofluorescence area, hypofluorescence is caused by blocked fluorescence.

16.1.4 Side Effects and Contraindications

Nausea, vomiting, and dizziness may appear within a few minutes after the injection due to a side effect of fluorescence, and skin rash may occur due to hypersensitivity reaction. Emergency equipment should be available at all times, since

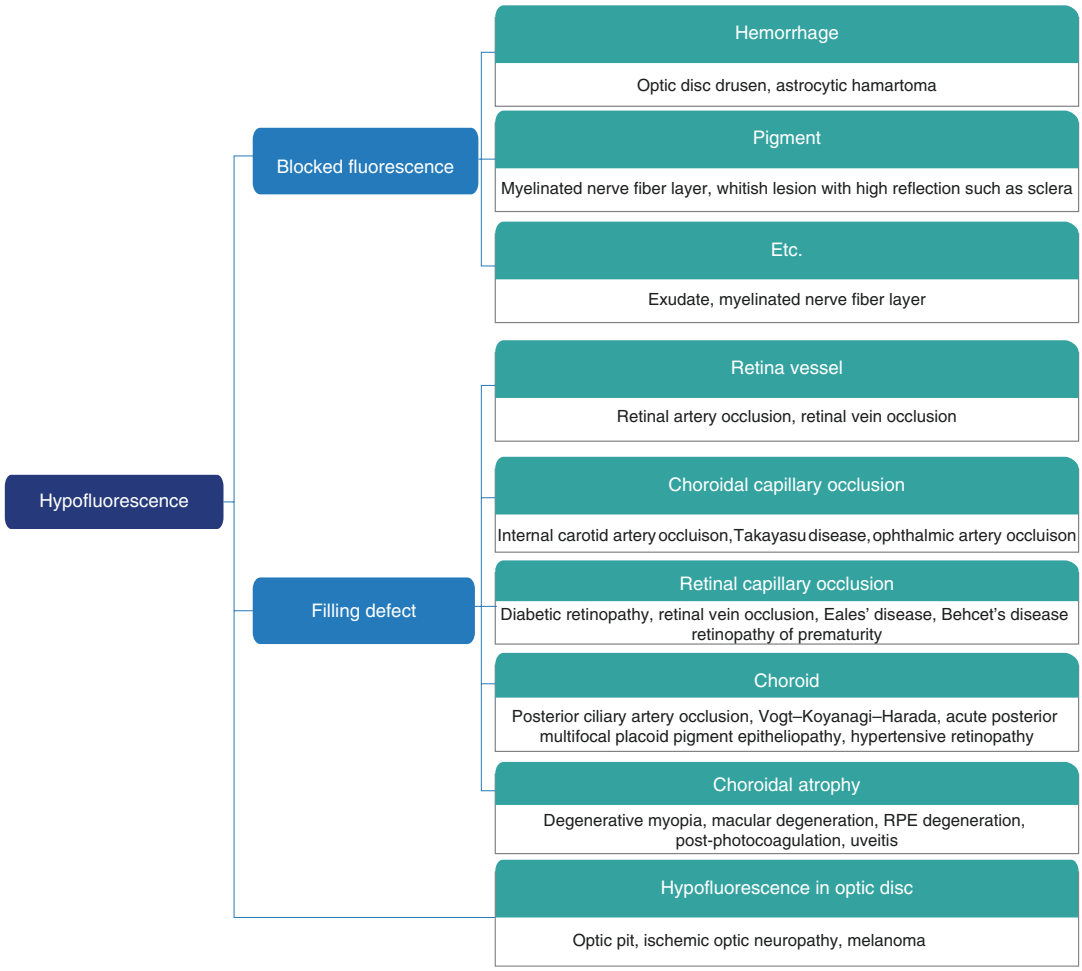

Fig. 16.5 Classification of hypofluorescence in fluorescein angiography

shocks can occur rarely. Contraindications include pregnancy, previous hypersensitivity reactions to fluorescein, side effects experienced by other drugs, etc. In such cases, you should consult your doctor about the benefit and risk of angiogram.

16.2 Indocyanine Green Angiography (ICGA)

Fluorescein-based angiography is very useful for evaluation of the retina. However, rapid leak through the choriocapillary and low penetration through the retinal pigment epithelium are the limitation in studying the vascular structure and lesions of the choroid. However, indocyanine green angiography (ICGA) can demonstrate the choroidal lesions in detail. ICG absorbs near-infrared rays (maximum absorption at 790 nm) and emits at approximately 835 nm. These characteristics of ICG can allow penetration of the retinal pigment epithelium. Therefore, it is adapted to the discovery of choroidal lesions that are difficult to detect in FA.

- To find the lesions under preretinal/subretinal hemorrhage
- To find the subretinal pigment epithelium lesions
- To find the choroidal circulation disorder

Especially, ICGA is useful in detecting and monitoring the location, activity, and response to anti-vascular endothelial growth factor or photo-

dynamic therapy in diseases that cause choroidal neovascularization such as wet age-related macular degeneration. Polypoidal choroidal vasculopathy can be typically diagnosed in ICGA.

The basic principle is similar to fluorescein angiography, but ICG exhibits different properties in two ways. First, ICG absorbs 790 nm wavelength in the near-infrared region and emits 835 nm wavelength fluorescence, which can pass through the retinal pigment epithelium. Second, minimal leakage of ICG through choriocapillaries can allow us to observe the detailed choroidal lesions because 98% ICG is bound to proteins in the vessels. However, ICG has a low fluorescence intensity of about 4% of fluorescein, and its wavelength is in the infrared region. It is difficult to obtain a good image using a general recording system. A video/digital fundus camera or scanning laser ophthalmoscopes are used to obtain ICGA. The fundus camera type has good temporal and spatial resolution, which can show the vascular leakage well. Whereas the scanning laser ophthalmoscope type can obtain images with high contrast and sharpness and minimal scatter light, this can help demonstrate the vascular structure well.

16.2.1 Method

The basic method is the same as FA.

Before dye injection, perform color fundus photography and red-free fundus photography. When the blue, green, and red filters of the fundus are photographed separately, the lengths of the wavelengths reaching each wavelength are different, so that the form of each layer of the fundus can be separated and photographed. The blue light (400–500 nm) shows the internal limiting membrane, the nerve fiber layer, and the retinal folding well. The green light (500–600 nm) shows the retinal vessels and hemorrhages, drusen, and exudates. Choroidal vessels are well observed in red light (600–700 nm). Put both the excitation filter and the barrier filter in place, and take a picture to check for autofluorescence and pseudofluorescence.

Dissolve 25–50 mg ICG in 1–2 mL of distilled water, inject intravenously, and then immediately inject 5 mL of saline.

Start photographing before fluorescent light appears after injection to obtain the earliest vessel filling image. Since the pigment enters quickly, take 8–10 s from the start of fluorescence and shoot continuously at 1 s intervals for 30 s while adjusting the appropriate amount of light at high speed. After that, it is necessary to shoot for 30 min every 5 min, such as 1 min, 3 min, 5 min, 10 min, and 15 min. In the late phase, the flash intensity increases, and the gain and focus of the video camera are adjusted to obtain as high-quality images as possible.

Re-injection of ICG: Since fluorescence becomes very weak after 30 min, the initial phase can be rephotographed by ICG reinjection. If initial imaging fails or an initial phase of the opposite eye is needed, a clear initial phase can be obtained by reinjecting half of the normal amount of ICG to identify the vascular vessels.

16.2.2 Normal Indocyanine Green Angiography

Most of the posterior ciliary arteries enter the eyeballs near the macula and are distributed in the choroid and radiate to the equator. The choroidal artery begins filling 0.5–1.0 s earlier than the central retinal artery.

Although it is difficult to summarize the normal ICGA findings because the vascular structure of the normal choroid has a three-dimensional structure with many variations, comparable to human fingerprint, three phases can be described as follows.

16.2.2.1 Early Phase

Up to 5 min after injection can be classified as early phase. The fluorescein filling of choroidal artery originating from short posterior ciliary arteries (Fig. 16.6a) starts to appear in parafoveal lesion before the filling of the retinal artery lesion about 10 s after ICG injection. The choroidal artery is flexed and meandering, running radially from the fovea to the periphery, and the choriocapillaries are filled with fluorescein simultaneously. It is difficult to identify the individual choriocapillaries because faint fluorescence appears between the arterioles. At this time, several types

of watershed zones can be seen as hypofluorescence lesions between the regions of the choroidal artery, which are physiological filling delay. The vertical watershed zone can be seen around optic disk, which is the filling delay area of the dye. After the choroidal artery begins to be visualized, the choriocapillary layer is rapidly visualized. And then the drainage vein starts to be seen. Many veins appear for 2–4 s and drain into the vortex veins in the equator of each four quadrants. Vortex veins are sometimes in the posterior pole. Because the choroid is thick and overlapped with the upper and lower vessels, the strongest intensity of fluorescence is observed in the choroidal arteriovenous phase (Fig. 16.6b). It is impossible to observe the choriocapillary layer with a capillary network. Approximately 10 s after the first appearance of fluorescence, the fluorescence of the choroidal artery almost disappears, and only the choroidal veins (Fig. 16.6c) are observed.

16.2.2.2 Mid-phase

From 5 to 15 min after injection, it can be classified as mid-phase. During this period, the fluorescence of the vessels gradually decreased over time. It is difficult to confirm the outline of choroidal vessels. Ground-glass-like fluorescence resulted from staining of the choroidal tissue, Bruch's membrane, and retinal pigment epithelium due to normal leakage from the choriocapillaries. If there is abnormal vessel, fluorescence gradually becomes stronger at mid-phase (Fig. 16.6d).

16.2.2.3 Late Phase

Fifteen minutes after the injection is in late phase. The diffuse choroidal fluorescence appears as fairly uniform background fluorescence. In the background fluorescence, the retinal and choroidal vessels look like hypofluorescence shadows as well as the optic disk. It is easy to detect abnormal hyper- or hypofluorescence at late phase (Fig. 16.6e).

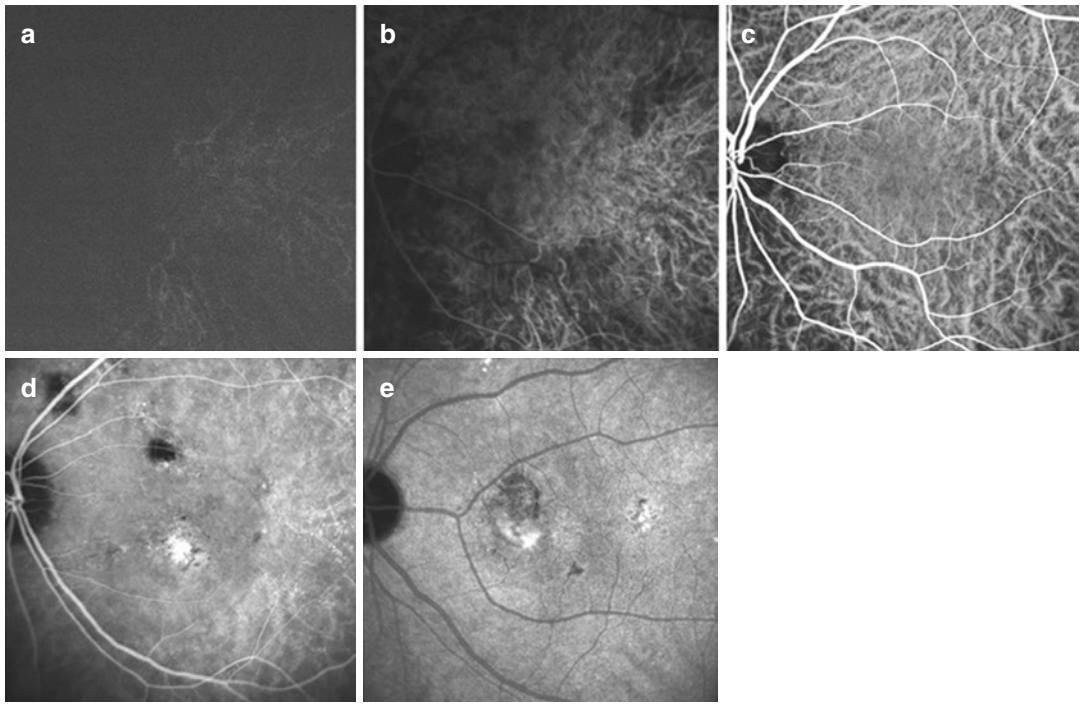

Fig. 16.6 Indocyanine green angiography. (**a**) Choroidal artery phase. (b) Choroidal arteriovenous phase. (**c**) Choroidal venous phase. (**d**) Leakage at mid-phase in central serous choroidopathy. (**e**) Late leakage in choroidal neovascularization

16.2.3 Abnormal Indocyanine Green Angiography

ICGA shows insufficient resolution of complex choroidal vasculature with a three-dimensional structure. There is also an instrumental difference in ICGA finding. Abovementioned features are the limitations for interpretation of the ICGA results. In general, the same approach as the FA is applied to distinguish between hyperfluorescence and hypofluorescence, compared to the surrounding region. Hyperfluorescence is classified to pseudofluorescence, transmitted fluorescence, abnormal vessel, and leakage (Fig. 16.7). Hypofluorescence blocked fluorescence and vascular filling defect (Fig. 16.8). Even with the same lesion, there can be many exceptions, since hypofluorescence can be initially hyperfluorescence and vice versa depending on the time.

16.2.3.1 Hyperfluorescence

In ICGA, pseudofluorescence is seen in the boundary of retinal pigment epithelial detachment and dehemoglobinized hemorrhage. ICG with high permeability is blocked by about 10% of fluorescence. Fluorescence transmission of about 10% is increased in the area of retinal pigment epithelial atrophy. Transmitted fluorescence is observed in degenerative myopia with the posterior staphyloma and thinning of the retinal pigment epithelium, choroid, and sclera.

At the early phase, abnormalities of the retinal and choroidal vessels can be detected. ICGA has an important value in case that a latent choroidal neovascularization in FA appears as a distinct choroidal neovascularization in ICGA. Although hyperfluorescence in late phase is an important diagnostic clue, the early phase of laser scanning ophthalmoscopy demonstrates the choroidal neovascularization, abnormal branching vascular networks and polyps of polypoidal choroidal vasculopathy, retinal vascular anastomosis, and neovascularization of the retinal angiomatous proliferation and feeder vessels.

Enlarged choroidal vessels are seen in central serous chorioretinopathy. In high myopia, vortex veins at the posterior pole and the circle of Zinn-Haller can be seen. Harada disease shows fewer choroidal vessels and indistinct vascular outline in ICGA. Choroidal hemangioma is characterized by a thick speculative hemangioma in the choroidal arterial phase and a severe fluorescein leakage in the late phase. Abnormal vessels inside tumor may be seen in malignant choroidal melanoma. ICGA is an effective method to detect ruptured retinal artery macroaneurysm under the thick hemorrhage. Leakage from retinal abnormal vessels and retinal neovascularization is uncommon.

Pooling is in retinal pigment epithelial detachment and retinal detachment. Retinal pigment epithelial detachment varies widely from hyperfluorescence to hypofluorescence.

Tissue staining is physiologically and pathologically staining of tissues including the blood vessel wall, pigment epithelium, Bruch's membrane, and choroid. Tissue staining of the vascular wall is observed in uveitis, hypertensive choroidopathy, and preeclampsia. Central serous chorioretinopathy shows tissue staining due to choroidal extravasation at mid phase.

16.2.3.2 Hypofluorescence

Although near-infrared rays are used, faint choroidal fluorescence at late phase can be blocked by the retinal pigment epithelium. There are various findings in a blocked fluorescence due to hemorrhage. Thick vitreous hemorrhage and subretinal hemorrhage block background fluorescence. Scanty hemorrhage shows hypofluorescence only in the late phase. In retinal hemorrhage, blocked fluorescence does not appear. Serous retinal detachment, retinal pigment epithelial detachment, hard exudate, and soft drusen may also cause blocked fluorescence in late phase. Thick choroidal tumors have a great effect of blocked fluorescence, which is helpful in determining tumor size and location.

Mild choroidal vascular occlusion is characterized by localized hypofluorescence at the early phase and then slowly filled with fluorescein with time. However, hypofluorescence (filling defect) continues until late phase in severe vascular occlusion, accompanied with tissue

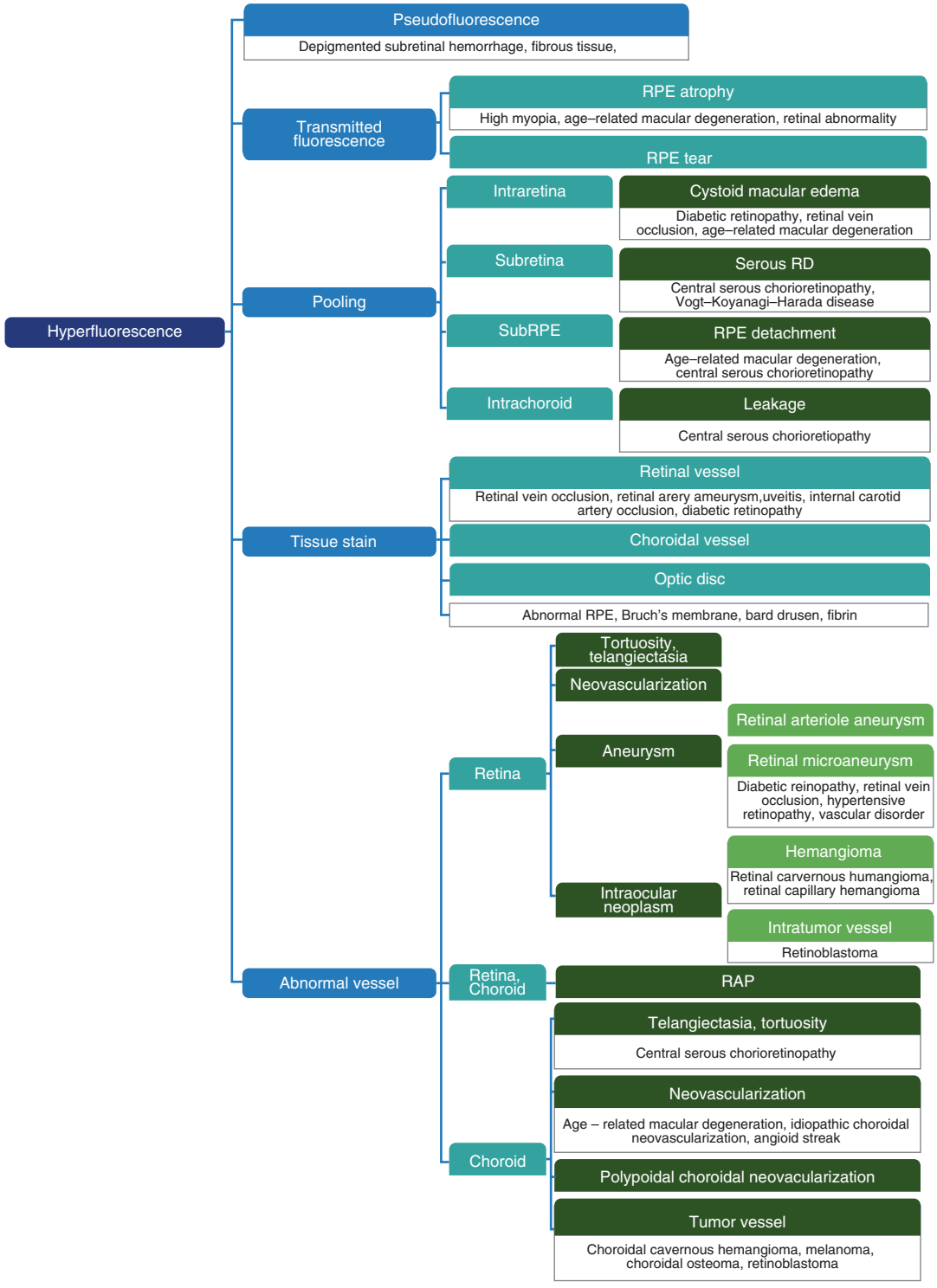

Fig. 16.7 Classification of hyperfluorescence in indocyanine green angiography

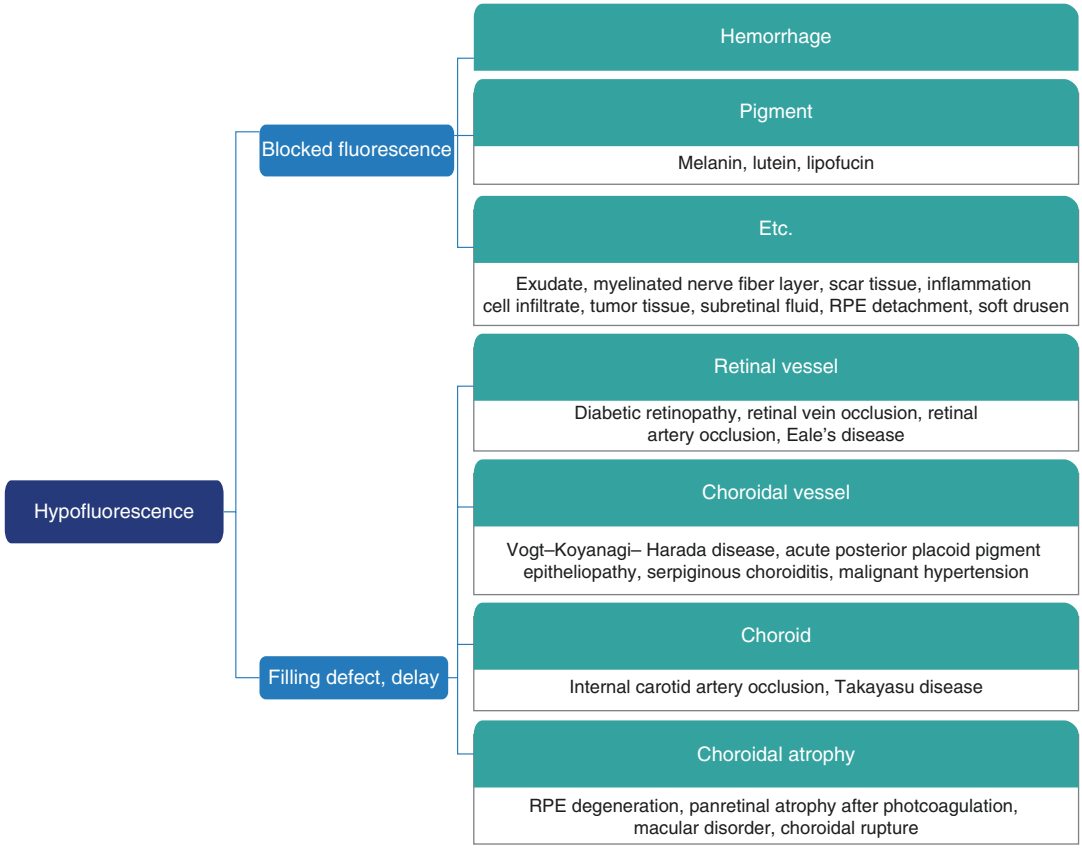

Fig. 16.8 Classification of hypofluorescence in indocyanine green angiography

staining of choroidal vessels or leakage to the subretinal space. Harada disease, hypertensive choroidopathy, and preeclampsia show a filling delay due to choroidal circulation disorder. Harada disease is characterized by diffuse filling defect due to inflammatory cell infiltration at the early stage and hypofluorescent dots consistent with the location of the capillary lobule in the late phase. The serpiginous choroiditis and acute posterior multifocal placoid pigment epitheliopathy show hypofluorescence in affected lesions and the filling defect in choriocapillaris and arterioles.

If choriocapillaries are atrophied in macular degeneration and retinal pigment degeneration, hypofluorescence remains from early to late phase. Laser photocoagulation-induced chorioretinal atrophy also shows a hypofluorescence.

16.2.4 Side Effects and Contraindications

After intravenous injection, most ICG binds rapidly to plasma proteins and is removed from the liver and excreted into the bile. There are fewer side effects and more safety than fluorescein. However, emergency equipment should be available at all times because a few severe hypersensitivity reactions have been reported. Patients with a history of severe hypersensitivity reactions or liver disease should be avoided.

16.3 Fluorescein Angiography with Laser Scanning Ophthalmoscope

Real-time photographic equipment using existing funduscopic cameras requires very bright illumination in order to obtain a good image. Therefore, it is difficult for the retina to withstand the amount of continuous illumination to obtain a continuous image, and it is difficult to obtain a good image if the pupil dilation is insufficient. FA and ICGA were developed using scanning laser ophthalmoscope (SLO) to overcome these disadvantages. The advantage of SLO is that the intensity of illumination is low, so you can observe video with continuous shooting.

A model using a fundus camera can obtain 1 to 2 images per second, but an SLO can obtain 20–30 images per second. In addition, the patient's glare is small, the burden is small, the amount of the fluorescein can be reduced to about 1/2, simultaneous imaging is possible while simultaneously injecting fluorescein and ICG, and the initial image is good. The disadvantages are that the equipment is expensive and the field of view is narrower than 40° compared with conventional real-time eye-gaze cameras, which are visible up to 60°. However, even with SLO cameras, it is possible to shoot up to 60° with a wide-angle lens. Currently available SLOs are Heidelberg's Heidelberg Retina Angiograph 2 (HRA2) and Nidek's F-10.

Fluorescein angiography in the SLO model stimulates fluorescein by 488 nm blue argon laser. The barrier filter passes fluorescence of a green-yellow wavelength around 500 nm generated by stimulation and simply shields the reflected blue wavelength. ICG fluorescein angiograms stimulate ICG by scanning the fundus with 790 nm diode laser light and isolate the stimulus light and fluorescence with a 810 nm cutoff filter. In the fundus camera model, the flash of the light is shed through the filter to the fundus through the infrared ray, and diffuse light is also casted. In addition to fluorescence parallel to the axis, scattered fluorescence is also taken. However, since the SLO model uses direct infrared laser light, it can stimulate the ICG efficiently and minimize the diffuse light. Using the same focal point, record only fluorescence in the focal plane, parallel to the time axis.

16.3.1 Method

Infrared photograms and fluorescein angiography show autofluorescence on an angiographic screen, followed by ICG fluorescein angiography and intravenous injection of ICG. The choroidal vessels should be photographed because the contrast changes rapidly from the onset of the choroidal vessels to 1 min after onset. When the choroidal vessels begin to be visualized, recording of the choroidal artery should be clearly recorded because continuously taking photograph is impossible up to 1 min after intravenous dye injection. Then, record at 3 min, 5 min, 10 min, and 15 min and record the stationary image every 5 min for up to 30 min.

Upon completion of the initial imaging of ICG angiography, fluorescein is intravenously injected, and fluorescein angiography is performed. The imaging device is photographed at the contrast medium introducer and then taken at 1 min, 3 min, 5 min, 8 min, and 10 min. Fluorescein angiography and ICG angiography are simultaneously taken at the same time. When the fluorescence is injected, a contrast image appears on the monitor. To make this image clearer, adjust the contrast and intensity of the operation touch panel. Two fluorescence angiograms can be taken at the same time after intravenous injection of both fluorescein and ICG from the beginning.

In the fundus camera type, the contrast is weak due to the reflected light and the scattered light. However, since the SLO type is mainly used for direct light, a very sharp and high-resolution image with better contrast can be obtained than the image captured by the fundus camera. In ICG angiography using SLO, choroidal neovascularization is clearly depicted. The feeding vessel to

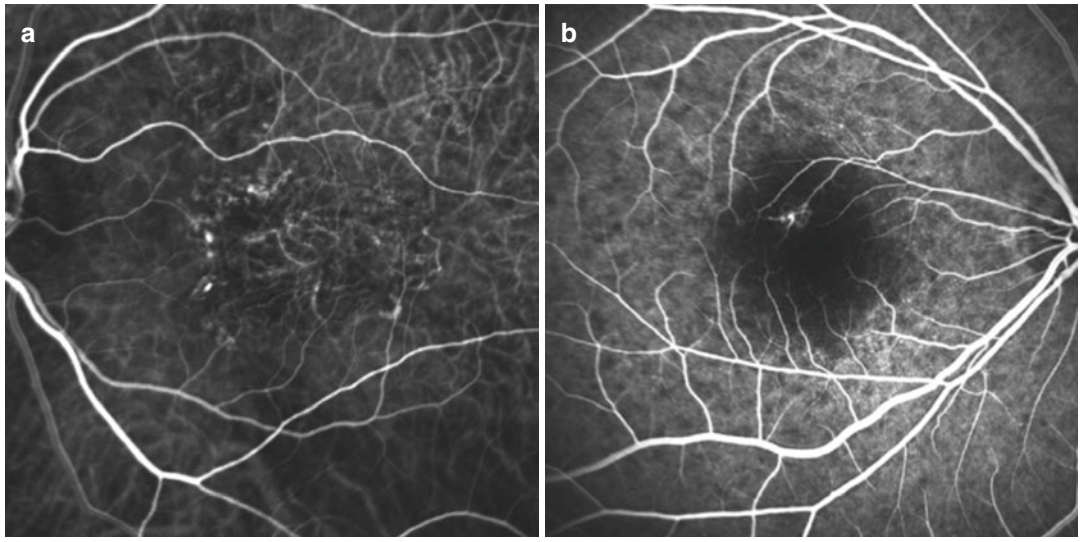

Fig. 16.9 Fluorescein angiography using scanning laser ophthalmoscope. (**a**) Indocyanine green angiography of polypoidal choroidal vasculopathy. (**b**) Fluorescein angiography of retinal angiomatous proliferation

choroidal neovascularization, the nodule of polypoidal choroidal vasculopathy, abnormal vascular plexus, and anastomosis in retinal angiomatous proliferation are clearly depicted in the early phase (Fig. 16.9). However, it is difficult to determine the fluorescence leakage of fluorescein. In addition, late phase is unclear because of the weak fluorescence of ICG in the choroid and the size of the image file is large.

On the other hand, it is difficult to identify the choroidal neovascularization or abnormal vascular network with the device using the fundus camera because the spatial resolution is low at the initial phase. In the late phase, the accumulated state of all fluorescence can be seen, and the overall fluorescence change can be seen by comparing with the initial phase. The changes in the entire layer of the choroid in wide area are observed in inflammatory choroidal disease in late phase of ICG examination. We should be cautious in interpretation because there is a difference in image findings obtained from ICG angiograms with SLO between ICG fluorescence images obtained with a charge-coupled device (CCD) and a fundus camera (Table 16.1).

Table 16.1 Instrumental difference between digital fundus camera and scanning laser ophthalmoscope

	Fundus camera	Scanning laser ophthalmoscope
Light source (wavelength)	White light	Laser monochromic light (785–790 nm)
Filter	Excitation filter (640–780 nm) Barrier filter (820–900 nm)	No excitation filter Barrier filter (805 nm)
Image acquisition	Frame	Point by point
Confocal aperture	No (light acquisition from multiple layers)	Yes (selective acquisition of particular layer)
Advantage	High temporal and spatial resolution: multilayer image Excellent expression of leaking (dying and staining)	High contrast and resolution: less scatter and chromic aberration Digital video recording: useful for very early filling analysis (feeder vessel, RAP, etc.) Selective focus (or high-degree special sensitivity) Wide-field image, recently

Suggested Reading

Haug S, Fu AD, Johnson RN, et al. Fluorescein angiography: basic principles and interpretation. In: Ryan SJ, editor. Retina. 6th ed. St. Louis: Elsevier; 2017. p. 1–45.

Lumbroso B, Rispoli M. Practical handbook of fluorescein angiography. 1st ed. New Delhi: Jaypee Brothers Medical Publishers; 2014.

Staurenghi G, Bottoni F, Giani A. Clinical applications of diagnostic indocyanine green angiography. In: Ryan SJ, editor. Retina. 6th ed. St. Louis: Elsevier; 2017. p. 46–76.

Ultrasound Exam

17

Young-Min Park and Seung-Min Lee

When the normally transparent medium of the eye becomes turbid, conventional optical fundus examination is impossible. In this case, ultrasound examination is a very useful method to obtain information about the intraocular state. Ultrasound examination also provides important information in diagnosis and classification of intraocular tumor regardless of media opacity. In addition to evaluating intraocular condition, it is also used in the process of determining the power of the intraocular lens for cataract surgery. Although A-scan and B-scan are generally used, ultrabiomicroscopy (UBM) is also useful in clinical practice because it shows details of ocular anterior segment structure using high-frequency ultrasound.

17.1 Standardized Echography

Standardized echography performs examination using both A-scan and B-scan. A-scan displays the lesion as the height of the waveform one-dimensionally and B-scan displays the shape of the lesion two-dimensionally. These two ultrasound methods are appropriately combined and used for diagnosis.

17.1.1 Object and Purpose

Ultrasound exam is useful when it is hard to observe fundus due to ocular media opacity such as cornea opacity, cataract, miosis, pupillary membrane, anterior chamber inflammation, vitreous opacity, vitreous hemorrhage, and other causes. It is also useful for the diagnosis and differential diagnosis of ocular tumors and measurement of tumor sizes. It is helpful to diagnose and identify the extent of detachment in rhegmatogenous retinal detachment and exudative retinal detachment. It provides indirect information for the diagnosis of eyeball abnormalities such as posterior staphyloma, nanophthalmos, ocular trauma, and intraocular foreign body. It is necessary to measure axial length, anterior chamber depth, and lens thickness and determine the intraocular lens. It is also used when there are orbital diseases such as exophthalmos, orbital tumor, orbital foreign body, and optic disc congestion.

Ultrasonic waves (usually 1–20 MHz) are differently absorbed or reflected depending on the density and the composition of the medium passing through. Ultrasonography generates ultrasound waves, captures reflected waves from tissues and records them.

Ocular ultrasonography uses a relatively high-frequency ultrasonic wave of 8–10 MHz

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High-resolution images can be obtained although the transmittance of ultrasound waves is low. In addition to real-time display, it is also possible to perform dynamic ultrasound examination that monitors the aftermovement of the eye structures after an eye moves. The ultrasonography is superior to X-ray radiographs and computed tomography scan in soft tissue description, and it is easier and faster to use ultrasonography than magnetic resonance imaging scan. It is also a safer method than other radiological examinations.

17.1.2 Instrument

17.1.2.1 Decibel (dB) and Gain

The reflected ultrasound from the eye tissue is very weak and has to be amplified to display on the screen. In this process, the sensitivity of ultrasonic waves can be adjusted by using the gain, which is expressed in decibel (dB). At this time, adjusting gain doesn't mean adjusting the intensity of the inspecting ultrasonic wave but means changing only that of the reflected wave displayed on the screen. If the gain is increased, the sensitivity increases, which is advantageous for examination of vitreous opacity or posterior vitreous detachment having weak echoes. Conversely, if the gain is decreased, it becomes easier to examine the retina, sclera, and other tissues having strong echoes. On the other hand, at the low gain, the central echoes are mainly recorded rather than the relatively weak peripheral echoes in the reflected ultrasonic waves, and this has the effect of narrowing width of the ultrasonic waves making the resolution of the image increased. In general, the higher gain is checked first, and then the lower gain is tested.

17.1.2.2 A-Scan

It is a one-dimensional graph in which the degree of reflection of the ultrasonic waves at each part in the path is changed to the wave height. The reflectivity of the ultrasonic waves is presented by the *y*-axis, and the distance between the points is represented by the *x*-axis (Fig. 17.1a). A-scan does not describe the shape of the lesion, but it is useful for examining the internal feature and the size (depth) of the lesion. The distance between the spikes and the amplitude corresponds to positions and characteristics of the actual ocular tissue but may vary depending on the incidence angle or intensity of the ultrasonic wave. Therefore, standardized equipment, an 8 MHz transducer that generates parallel ultrasound, should be used. Before starting the test, use a standard tissue model to set the standard sound wave sensitivity, i.e., tissue sensitivity. To set the tissue sensitivity, contact the A-scan probe with the standard tissue model, and record A-scan (Fig. 17.2a). High reflection appears in the bottom of the tissue model. This high spike in the bottom and continuous spikes generated within other parts of tissue model are recorded in the graph, and if the gain is adjusted so that the upper (a) and lower (b) areas of the wave are equal (a = b), then the gain at that time is defined as tissue sensitivity (Fig. 17.2b).

17.1.2.3 B-Scan

It is a two-dimensional inspection method that displays the degree of reflection of ultrasonic waves reflected at each point of the eyeball section on the screen with the intensity of the brightness of the point (Fig. 17.1b). The 10 MHz transducer that generates the ultrasonic waves that has focal line reconstructs the obtained signal as image by sending the sound waves as if cutting the tissue with the knife while rotating. There is a fast-moving transducer inside the B-scan probe, and the transducer moves in the direction of the marker indicated at the end of the probe. In order to obtain real-time images, the transducer has to rotate several times per second. This can be expressed as frames per second, which are typically 10–60 frames per second.

17.1.3 Normal Findings

The normal ultrasound tomographic image of the eye varies greatly according to the directing position of the probe and the angle between the probe and the globe. When examined over the eyelid, the cornea and eyelid are not distin-

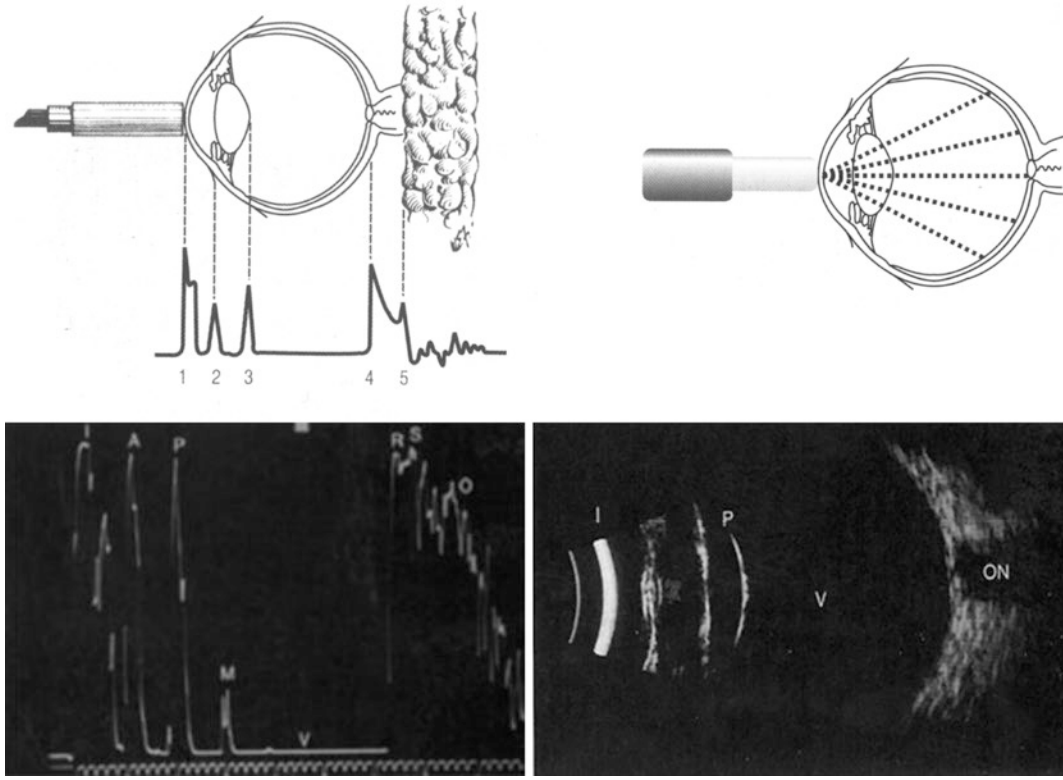

Fig. 17.1 A- and B-scan. (**a**) A-scan, I: cornea, A: anterior capsule of lens, P: posterior capsule of lens, M: polymorphic signal, V: vitreous cavity, R: retina, S: sclera, O: orbital soft tissue. (**b**) B-scan, I: cornea, P: posterior capsule of the lens, V: vitreous cavity, ON: optic nerve. (Inferior left: Green and Btme 2013)

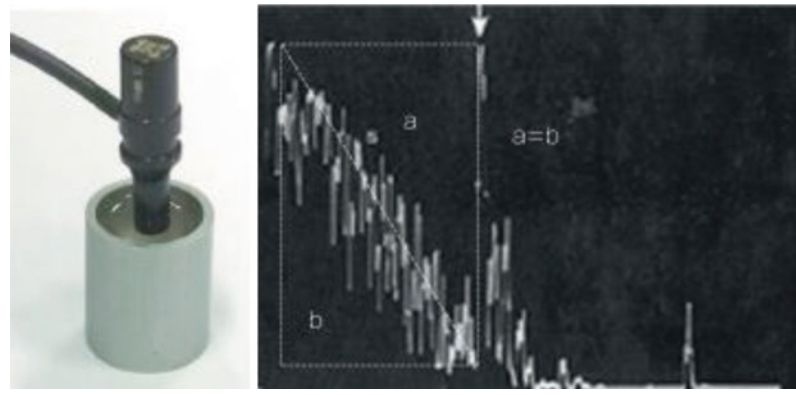

Fig. 17.2 Adjustment of the tissue sensitivity on the device. (**a**) Sensitivity adjustment of standardized A-scan probe using tissue model. (**b**) The arrow indicates the bottom of the tissue model. Adjust the decibel dial so that the upper and lower areas of the echogram are the same. (Right: Green and Btme 2013)

guished. The anterior chamber does not reflect the ultrasonic wave, and the iris is difficult to distinguish from the anterior capsule of the lens. The normal lens does not show reflection except at the anterior and the posterior capsule. The normal ciliary body is difficult to detect, and the vitreous cavity cannot show reflection normally. The retina, choroid, and sclera, three layers of the eyeball wall, cannot be detected separately. The orbital fat tissue reflects the ultrasonic waves well, but the extraocular muscle, optic nerve, and some tissue cannot observe the reflection

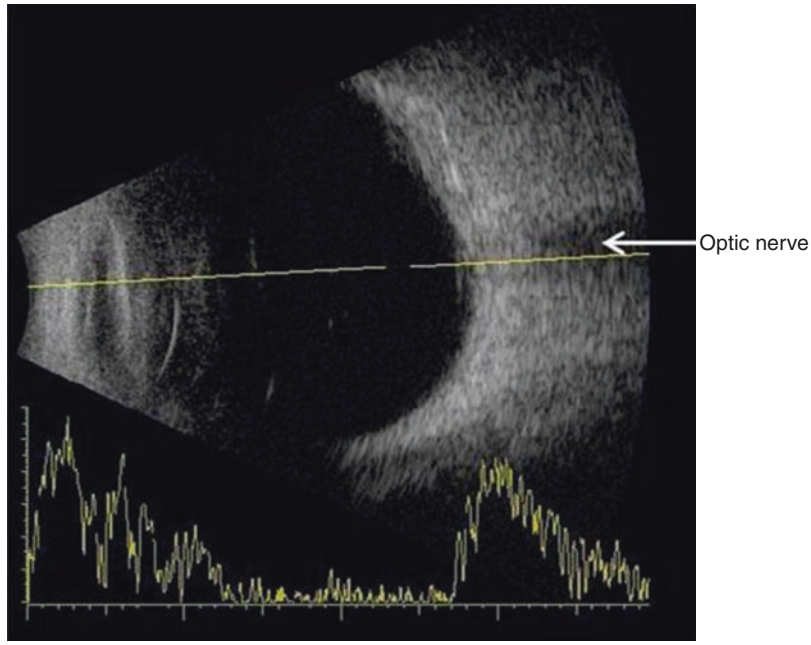

Fig. 17.3 Normal finding of the ultrasonography

well because their structures are parallel to the ultrasound wave direction. The extraocular muscle appears as a relatively low-reflection part connected to the orbital wall. The optic nerve is drawn in the orbital fat tissue by bar-shaped defectus image adjacent to the orbital wall (Fig. 17.3).

17.1.4 Method

The patient should be examined at reclining or lying down position. The examiner and the equipment should be located in the side of the patient's head and the monitor screen can be viewed at the same time. After anesthetizing with eye drops, probe is coated by methylcellulose and contacts directly to the eyeball to perform the examination. When examining the posterior part of the eyeball, contacting the probe on the eyelid causes weaking of reflection of the sound wave due to the eyelid tissue. In addition, the position of the eyeball cannot be confirmed with the eye closed, and it is recommended to contact the probe to the eyeball directly. The immersion technique is used when examining the anterior part of the eye.

17.1.4.1 Basic Screening Examination

A-scan

Adjust the decibel so that the upper and lower areas of the echo are to be equal, while the probe contacts with tissue model. Then, this sensitivity is tissue sensitivity (Fig. 17.2).

Let the patient see the 12 o'clock direction, and then contact the probe at the 6 o'clock limbus. Slowly move the probe to the conjunctival fornix while the examiner keeps watching the monitor (Fig. 17.4).

The same maneuver is performed in eight clock meridians, clockwise about the right eye and counterclockwise about the left eye, until the posterior segment is thoroughly screened (Fig. 17.4).

In the case of a test at a lower gain than tissue sensitivity, the resolution is increased, and relatively flat retinal elevation lesion that can be missed at high sensitivity can be found. After lowering the gain by about 24 dB, the test is carried out in the same manner as for the tissue sensitivity.

In order to find a tiny vitreous opacity that may not be detected in tissue sensitivity, select two meridians 90° apart, increase the gain by

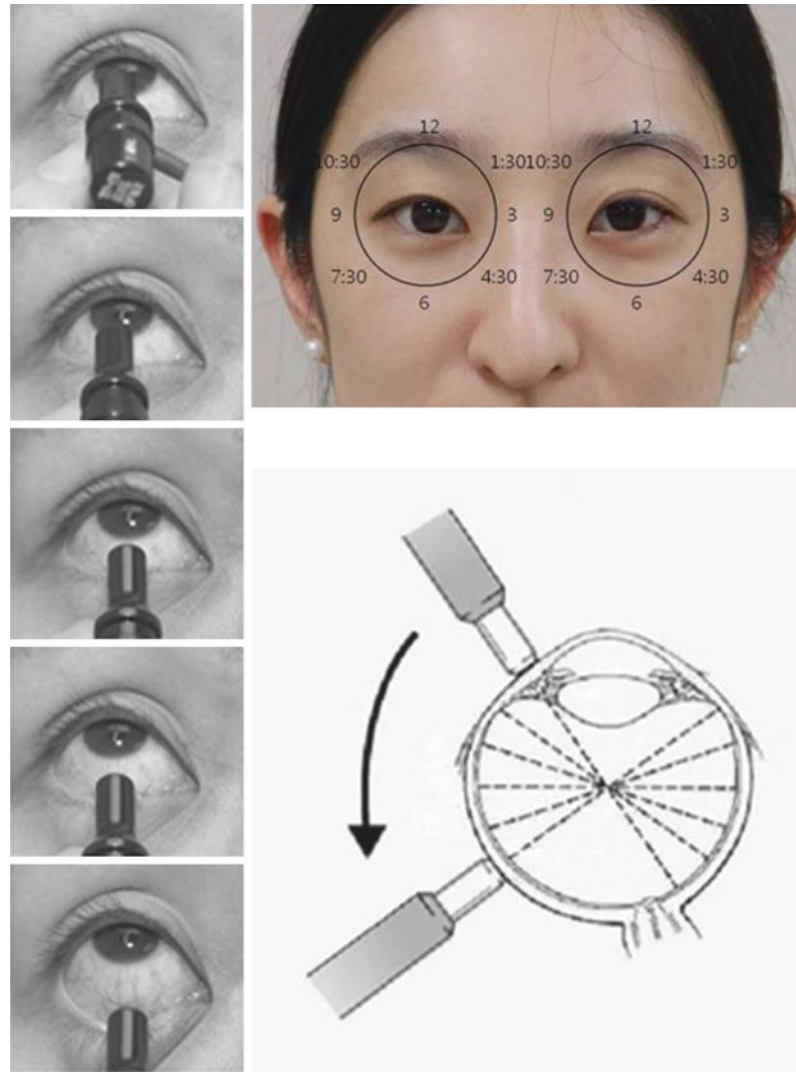

Fig. 17.4 The basic test of A-scan with eight meridians

6–9 dB above the tissue sensitivity, and then perform examination while moving from limbus to conjunctival fornix.

B-scan

The basic position of the probe about the eyeball can be divided into three categories: transverse, longitudinal, and axial (Fig. 17.5). In the transverse and longitudinal position methods, the conjunctiva is contacted without touching the cornea, and they are commonly used due to increased transparency because the sound wave doesn't pass the lens.

Transverse Scan

It is the appropriate method to check the width of the lesion by placing the long axis of the probe parallel to the limbus (Fig. 17.5a). In other words, the lesion size can be evaluated in the same way as "range from 1 o'clock to 2 o'clock." When the probe is placed at 6 o'clock and examination is performed in coronal plane, the fundus of 12 o'clock appears, and in this case, it is called transverse scan of 12 o'clock meridian. In general, when examining in transverse scan, the probe is positioned that the nasal side is displayed on the upper side of the screen or, at other

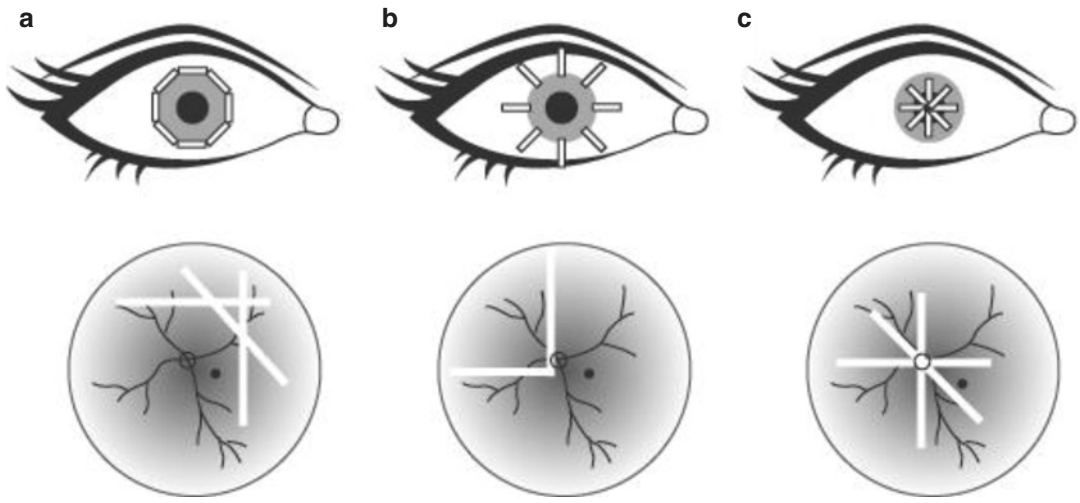

Fig. 17.5 The types of basic test of B-scan. (**a**) Transverse scan 1. Horizontal transverse 2. Vertical transverse 3. Oblique transverse. (**b**) Longitudinal scan 1. Horizontal longitudinal 2. Vertical longitudinal. (**c**) Axial scan 1. Horizontal axial 2. Vertical axial 3. Oblique axial

directions, upper part of the eyeball is to be displayed on upper side of the screen.

Longitudinal Scan

Longitudinal scan is adequate to check the anteroposterior scale of the lesion by rotating the long axis of probe 90° from the transverse direction to be right angle to the limbus (Fig. 17.5b). The size of the lesion can be assessed in the same way as "from equator to the border of macula." As in the transverse scan, in the case of positioning the probe at 6 o'clock, the fundus of the 12 o'clock appears on the screen, and it is referred to as the longitudinal scan of the 12 o'clock meridian. At the time of the examination, the marker of probe is placed toward the center of the cornea regardless of the direction of the examination, and therefore the peripheral part of the eyeball, i.e., the anterior segment, is displayed in the lower part of the image. The longitudinal scan is easy to understand in the three-dimensional structure and has better image quality than the axial scan. Especially, it is advantageous to grasp the morphology of the membrane connected to the optic disc.

Axial Scan

In this method, probe is placed at the center of the cornea with the eyeball axis keeping to the front. The lens and optic nerve appear in the center of the ultrasound image. It is the easiest way to understand the approximate location of the lesion, but it is less useful due to the reduction of the reflected sound wave amplitude and the resolution by the lens. However, it may be helpful in evaluating the lens, the macula and the membrane associated with the optic nerve. When examining the axial scan, the marker of probe is directed to the nasal side so that nasal part is located in the upper side of the image and, at other locations, the top of the eyeball is at the top of the image.

17.1.4.2 Special Examination Method

It is the examination method used to distinguish the intraocular lesion detected by the basic ultrasonographic examination. It is important for the inspector to determine when and how to perform the specific examination method for accurate diagnosis. In general, after performing the morphologic examination, the quantitative examina-

tion is performed, and lastly, a dynamic examination is done. However, if experience is accumulated, these methods can be performed in combination with other techniques in various manners.

Topographic Echography

When the lesion is found, morphological examination in multiple directions determines the anatomical location, shape, and extent of the lesion.

Topographic B-Scan

First, the transverse B-scan is performed on the medician that best repesents the lesion. If the lesion is found in the superotemporal part of the right eye, the probe is placed in the direction of 4:30, the marker is directed superonasally and is placed on the limbus side-by-side, and the transverse scan of 10:30 meridian is performed.

While moving the probe from the limbus to the conjunctival fornix, inspect the lesion from the back to the front. This allows to know the approximate shape and side size of the lesion.

And then, examination in the vertical direction is done. The probe is positioned in 4:30 meridian, and the marker is directed toward the center of the cornea. The anterior-posterior size, shape, etc. of the lesion on the 10:30 meridian between the optic nerve head and ora serrata are checked again.

To identify the location of lesion related to the normal anatomical structure, axial scan is performed. The probe is placed on the cornea, and the examination is performed while the probe is rotating from 10:30 to 4:30 meridian. If the marker is located on both meridians, the location of the lesion associated with the optic nerve is shown in the ultrasound image. The contour of the lesion can be obtained in three dimensions by appropriately combining the data obtained by these various methods.

Topographic A-Scan

After B-scan is done, A-scan is also performed. In A-scan, the morphological test of the lesion should always be carried out after being adjusted to the tissue sensitivity.

First, the probe is placed on the limbus of the contralateral side of the lesion. The probe is moved from the limbus to the conjunctival fornix, and the lesion is evaluated in the anteroposterior direction.

Scanning is carried out while the probe is moved laterally parallel to the limbus.

It is also useful to scan the lesion from various angles. The lesion is examined by ultrasound at the initial position and the position of 90° apart. These methods can be used to accurately assess the type, location, and extent of the lesion.

Macular Scan

The macula can be examined in vertical, longitudinal, and the axial scan. Alternatively, vertical macular scan can be performed. This scan is performed after the vertical axial scan is done and the macular vertical section examination is performed with the probe facing the slightly temporal side of vertical axial scan position. The quantitative examination of the macula should be carried out avoiding the lens with placing the A-scan probe at the nasal limbus.

Quantitative Echography

After obtaining the findings of the lesion by morphological examination, the reflectivity, internal structure, and sound attenuation should be determined by quantitative examination.

Quantitative Echography Type 1

Quantitative echography type 1 is used to determine the echogenicity of all types of the lesions. The echogenicity can be assessed by observing the height of the wavelength in A-scan and the brightness of the signal in B-scan. Prior to evaluation of echogenicity, it should be verified that the lesion and the direction of the ultrasound wave are vertical. The change of echogenicity according to the direction of the ultrasound wave can be an important characteristic when describing the characteristic of the lesion.

Table 17.1 Classification of echo degree

Classification	Height of wave (%)
Extremely low	0–5
Low	5–40
Medium	40–60
Medium high	60–80
High	80–100

The echogenicity can be divided into several levels according to the value of the wave height which is expressed as a percentage in A-scan adjusted to the tissue sensitivity (Table 17.1). The echogenicity in B-scan is assessed by the brightness according to subjectivity of the examiner and is less accurate than in A-scan. The B-scan is also affected by the resolution or gray scale of the monitor or the printer, so the examiners should be aware of this. In general, the relative echogenicity is evaluated by comparing the sclera with the highest degree of reflectivity and the vitreous with low reflectivity.

This method is simple but can be helpful to differentiate between the posterior vitreous detachment and the retinal detachment and to distinguish between the melanoma and other intraocular tumors. The determination of echogenicity in the mass lesion is necessary to evaluate the internal structure and sound attenuation of the tumor.

Internal Structure

The internal structure is related to the histological structure of the lesion. The internal structure can be evaluated based on the height and width of the A-scan wave and can be limitedly evaluated using the brightness of the B-scan. In the case of a regular shape wave with even height, it means that the internal structure is uniform. When the shape is irregular with a mixture of high- and low-amplitude waves in A-scan, it implies that internal structure consists of a mix of irregular various tissues.

Sound Attenuation

Scattering, reflection, and absorption of ultrasound wave within the medium result in the reduction of signal amplitude and this phenomenon is called sound attenuation. It is more severe when examining through closed eye (especially, in case of eyelid edema), high density opacity of vitreous or lens, thick membrane, and very high echogenic media (e.g. bone, calcium, foreign body). In A-scan, as the wave amplitude height decreases inside or behind the lesion, the kappa angle, which is the angle formed between the line connecting the peak and the bottom of each wave, appears large. In the same manner, the shadowing appears due to reduction of the echo intensity inside or behind the lesion in the B-scan. If echogenic medium is small, the shadow may be minute or absent. Therefore, the sound attenuation should be evaluated not only by B-scan but also by A-scan.

Quantitative Echography Type 2

If the membrane type lesion shows 100% high peak in tissue sensitivity of quantitative echography type 1 and it is difficult to do differential diagnosis using other test results, the echogenicity of the lesion should be compared with the echogenicity of the sclera (which shows the largest echogenicity in the eye and is used as the reference of intensity). The gain is adjusted using the echogenicity of sclera and the difference of the gain before and after adjustment is expressed in decibel (dB).

It is useful for differential diagnosis between the retinal detachment and dense vitreous membrane. When the difference in dB value is small, as it means that the echo reflection of the membrane-like lesion is strong, it is probably related to retinal detachment (Fig. 17.6e). On the other hand, when the difference in dB value is large, it means that the reflection is weak and it is assumed to be vitreous membrane (Fig. 17.6f). The examination method is as follows.

Determine the maximum ultrasound wavelength first (Fig. 17.6a), and draw a horizontal marker line at 50% height of this wavelength (Fig. 17.6b).

When the wavelength of the lesion reaches the horizontal marker line by lowering of the gain, the decibel is called “lesion sensitivity” (Fig. 17.6c).

Then lower the gain further so that the wavelength of the sclera reaches the horizontal

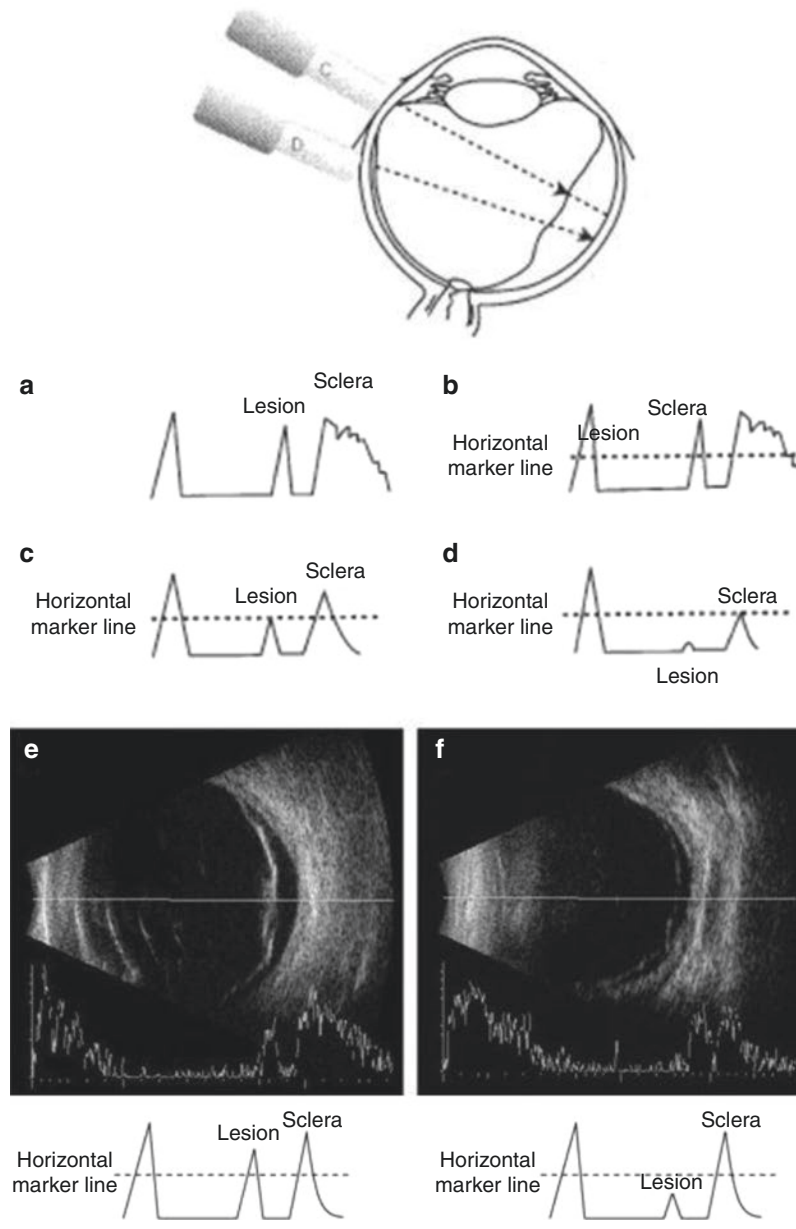

Fig. 17.6 Quantitative echography method (for differential diagnosis between the posterior vitreous detachment and retinal detachment). (**a**) Determining of maximum ultrasound wavelength. (**b**) Setting of horizontal marker line at 50% height of this wavelength. (**c**) Confirmation of lesion sensitivity. (**d**) Confirmation of scleral sensitivity. ※ The difference of sensitivity (dB) between c and d is used for the differential diagnosis of the lesion. (**e**) The lesion is suspected as retinal detachment because the difference in dB value is small. (**f**) The lesion assumed to be posterior vitreous detachment because the difference in dB value is large

marker line. At this time, decibel is called "scleral sensitivity" (Fig. 17.6d). The difference between these two sensitivities is used for differential diagnosis.

Retinal detachment is suspected when the difference is between 6 and 15 decibel. The wavelength of the difference between 16 and 19 decibel is considered as borderline, and the one with difference more than 20 decibel is suspected as posterior vitreous detachment.

Kinetic Echography

It is the method to examine the aftermovement (mobility) and the vascularity (spontaneous motion). The aftermovement is to observe the movement state of the lesion while stopping after repeated eye movement with a constant speed. Irregular and discontinuous posterior vitreous detachment or regular and continuous retinal detachment can be shown with the movement of the echo, but there is no motion in solid tumor.

Vascularity is a natural change of echo reflection caused by the intravascular blood flow. The presence or absence of vascularity can be assessed as one characteristic feature of the tumor lesion. When evaluating vascularity, the examination is performed in a stable state with no movement of the probe or eye. When the vascularity is present, the rapid and small-width multiple waveforms appear within the lesion.

Echography Method for Anterior Segment

In most cases, the anterior segment of the eyeball can be directly observed, so it is not usually necessary to perform an ultrasound examination. However, when the ultrasound examination is needed, the immersion technique should be used to observe details of the lesion. The scleral shell is placed between the eyelids, located on the eyeball, and filled with methylcellulose. The probe is immersed into the shell and the cornea, the anterior chamber, the iris, the lens, and the space behind the lens are examined.

17.1.5 Clinical Findings of Each Structure

17.1.5.1 The Lens

The information about the lens can be obtained by ultrasound examination when the medium in the anterior chamber becomes cloudy. In contact examination, the posterior capsule of the lens only appears on the image. However, when the cataractous change occurs, the whole lens may be observed and multiple intralenticular echo reflections can be seen. When the lens is liquefied and becomes hypermature cataract, the homogeneous ultrasonic finding of empty space like water can be observed. When the lens has fallen into the vitreous cavity, an image of the intravitreal elliptical shape can be seen.

17.1.5.2 The Vitreous

The normal vitreous usually appears as a vacant space due to no echo reflection in ultrasonography. However, if there are lesions such as hemorrhage, inflammation, and asteroid hyalosis, the echo reflection is seen. In case of posterior vitreous detachment, echo reflections are usually small, but with pathologic conditions, it could be hard to distinguish with retinal detachment because of large size and marked echo reflection. The incomplete posterior vitreous detachment connecting with the optic nerve head appears as seagull-like shape which is similar to the retinal detachment, but in case of the complete detachment, a U-shape appears, and aftermovement is large. Asteroid hyalosis shows multiple small and strong echo reflections due to fat deposits including calcium. Echo reflection is observed continuously when the gain is reduced, and aftermovement can be observed while the eyeball moves (Fig. 17.7).

Thick vitreous hemorrhage shows increased echo reflection in B-scan and higher reflectivity in A-scan. When the blood is organized, a large interface is formed, and it can be seen as a membranous surface in B-scan and a higher echo in A-scan.

17.1.5.3 The Retina

One of the most important purposes of ocular ultrasound examination is to assess the retina in patients with media opacification. Retinal detachment appears as the bright, continuous, and somewhat wrinkled membrane shape in B-scan. In the case of severe total retinal detachments, the optic nerve head and ora serrata are connected by the detached retina. In A-scan, the tissue sensitivity at the control point is 100% of the spike. The shape of retinal detachment appears in various forms from very shallow and smooth membrane shape to a bullous and folded funnel-shaped membrane. The aftermovement of retinal detachment appears diversely. After movement is very large in recently occurred bullous retinal detachment with large break, whereas there is little movement in long-lasting retinal detachment with proliferative vitreoretinopathy.

Posterior vitreous detachment is easily distinguished from retinal detachment due to good motility, but it may be difficult to distinguish posterior vitreous detachment from retinal detachment if the posterior vitreous remains attached to the optic disc. In this case, retinal detachment is indicated by high echo reflection both at the posterior pole and periphery in A-scan. If the echo reflections decrease from the center to the periphery, posterior vitreous

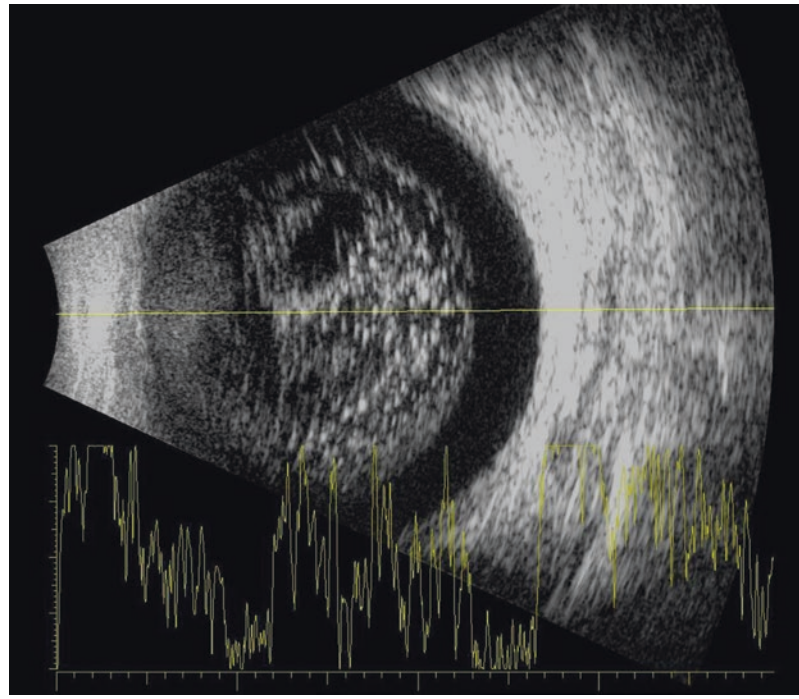

Fig. 17.7 The ultrasonographic finding of the asteroid hyalosis

detachment is suspected. However, this method only applies to the retinal detachment in the superior half of the eyeball. If it is difficult to distinguish by other methods, quantitative echography type 2 can be used to differentiate more accurately. Ultrasonography in diabetic retinopathy is useful to evaluate the progress of the disease, to determine the timing of surgery to localize the lesion, and to predict the prognosis of visual acuity. Retinoschisis is observed as thin and smooth hemispheric membrane in B-scan and is not usually connected to the optic disc. In A-scan retinoschisis displays 100% high spike. Retinoschisis shows more fine, localized, and smooth characteristics than retinal detachment.

17.1.5.4 The Choroid

Some layers of the eyeball are located very close, so during choroidal examination, lower sensitivity of control point has to be used to increase resolution. The increased choroidal thickness case shows echo reflection of various intensities in case of hypotony, uveitis, macular edema, etc. High and low echo reflection appear in Vogt-Koyanagi-Harada syndrome or sympathetic ophthalmia. Choroidal detachment shows characteristic features in ultrasonography. In B-scan, relatively smooth and thick hemispherical membrane located in periphery is observed, and because aftermovement is scarcely seen in kinetic echography, it is easy to distinguish from other diseases. In the A-scan, a thick and steeply rising 100% high spike is seen, and a double-peaked spike showing double-layered apex is observed.

17.1.5.5 The Optic Nerve

In general, ultrasound is not useful in examining the optic disc and retrobulbar optic nerve. In examining the optic disc, B-scan well expresses the morphology, and A-scan is used to measure the diameter of the retrobulbar optic nerve or to do differential diagnosis. Large optic disc cupping or large optic disc coloboma can be recognized well by axial scan. In small optic disc cupping, the transverse scan is used that allows the ultrasound to get through avoiding the lens. Optic nerve head drusen shows high echo reflection due to calcified nodules.

17.1.5.6 The Sclera

Ultrasonography is a very useful method for the diagnosis of posterior scleritis. B-scan shows that

sclera is thickened. Edema of Tenon's capsule and thickened choroid are also observed. The hypoechoic part of retrobulbar space intersects perpendicularly to the hypoechoic part of the optic disc, resulting in the characteristic T-sign of posterior scleritis. In A-scan, the thickened sclera has a uniform internal structure and shows strong echo though it is lower than the normal sclera.

17.1.5.7 The Tumor

Ultrasonography is essential to evaluate the presence, location, size, and shape of a tumor, when there is suspicion of an intraocular tumor with the media opacity such as a cataract or vitreous opacity or when serous retinal detachment is accompanied. Ultrasonography is also useful to measure the tumor size, to assess the histologic characteristics for the differential diagnosis, and to find out presence of the extrascleral metastasis. Tumors with a height greater than 0.4–0.75 mm can be diagnosed by ultrasonography. Furthermore the differential diagnosis is possible when the tumor is larger than 1.5–2.5 mm because the tissue characteristics can be evaluated.

Ultrasound can be used for differential diagnosis of choroidal melanoma. The characteristics of the tumor are collar button or mushroom shape in the B-scan, homogenous solid internal structure, lower than moderate echo reflection, and the internal vascularity (Fig. 17.8). Moreover, findings such as choroidal excavation, retinal detachment, hemorrhage, etc. may be observed.

Choroidal hemangioma is characterized by homogenous internal structure, high echo reflection, and internal vascularity. Metastatic choroidal tumor is characterized by a heterogeneous internal structure, higher reflective echo above the middle, and little internal vascularity.

17.1.5.8 Others

Insufficient Fluid Coupling

This is an artificial shade caused by the air between the B-scan probe and the eyeball. This is also caused by insufficient methylcellulose. It appears as strong echo reflections across the ultrasound image (Fig. 17.9).

Baum's Bumps

It often appeared in ultrasonic devices used in 1970s, but it is less common now. This is a pseudoelevation finding of the posterior fundus caused by the diffraction of the ultrasound when examination is performed through the lens.

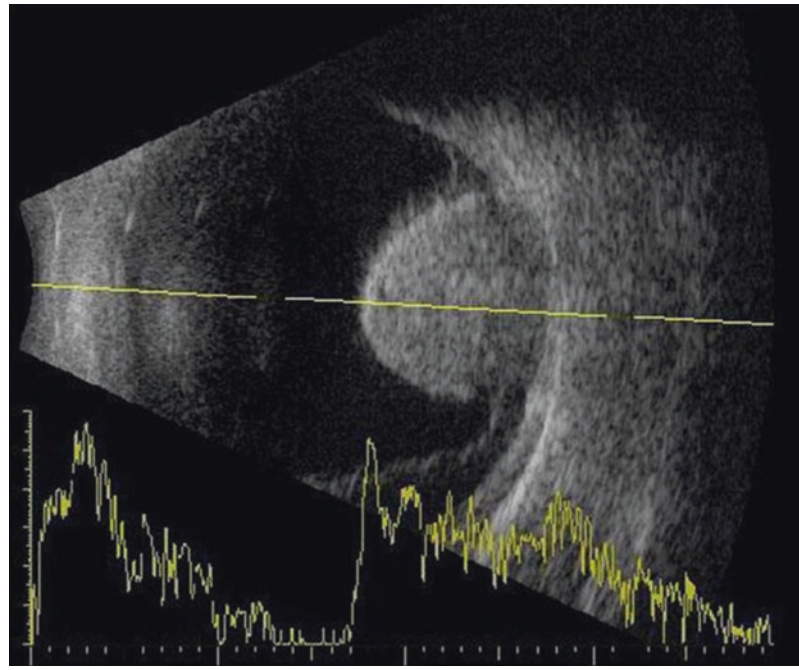

Fig. 17.8 Choroidal melanoma. B-scan shows a mushroom-shaped and solid homogeneous internal structure, and moderate-to-low echo reflection appears on A-scan

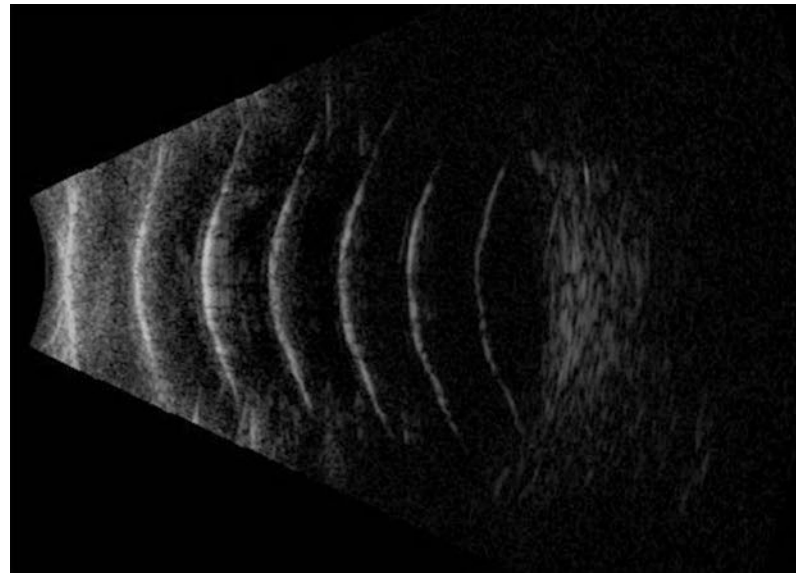

Fig. 17.9 Ultrasound findings when contact between probe and eyeball is improper

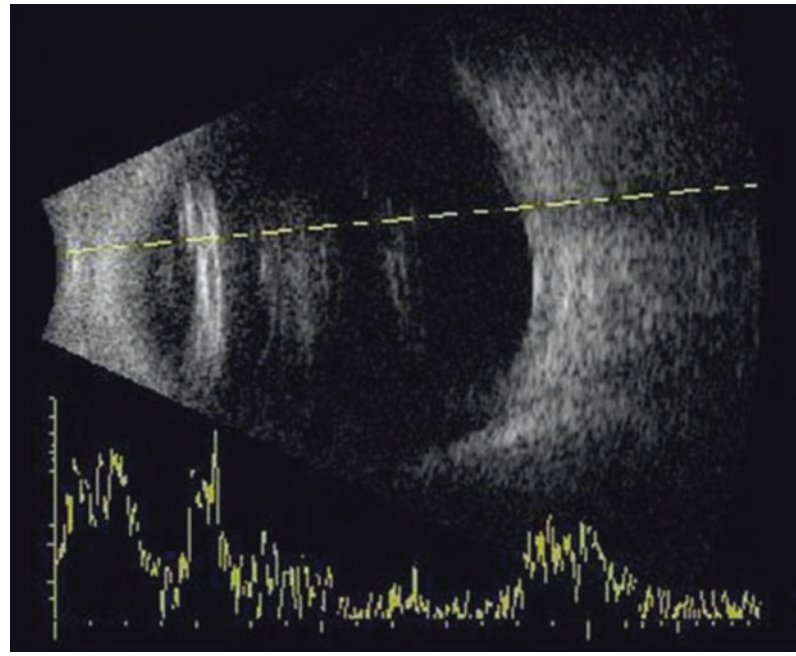

Fig. 17.10 Artificial shadow produced by ultrasound wave passing through the intraocular lens

Gas or Air Bubble

If the gas is filling the vitreous cavity or a large bubble is present, images cannot be obtained because the soundwave cannot penetrate. However, if a small gas bubble is present, the image can be obtained by moving the patient's head.

Multiple Signals

The lens capsule, intraocular lens, foreign body, air bubbles, etc. are often causes of miscellaneous signals. These occurred between the tip of the probe and the highly reflective intraocular contact surface (Fig. 17.10).

Scleral Buckling Procedure

Scleral buckling causes intrusion of the eyeball wall. Because the reflectivity of the material used for the sclera buckling procedure is very high and the sound wave severely reduced, the orbital shadow can be seen. The silicone sponge exhibits stronger echo reflection than the solid silicon material.

Silicone Oil

The speed of the sound wave is very low in the silicone oil compared to normal eye. Therefore, ultrasound images appear larger than normal. In addition, it is difficult to find the elevated posterior pole lesion.

17.2 Biometry

Biometry is the process of calculating the dioptric power of the intraocular lens inserted during cataract surgery. Important data for biometry are the accurately measured axial length, the mean value of the keratometric diopter, the intrinsic constant of each intraocular lens (the A constant), anterior chamber depth constant, and a surgeon factor.

17.2.1 The Axial Length Measurement

The axial length measurement methods for the biometry are the A-scan and the partial coherence interferometer (IOLMaster, Zeiss Humphrey). Both methods are widely used. In A-scan, the sound wave passes through the ocular tissue, and the reflected waves are graphically represented. The distance from the cornea to the orbit can be measured by calculating the interval between each of the reflected wave. The distance from the front of the cornea to the retina in the measured graph is used as the axial length of the eye.

17.2.1.1 The Examination Method

There are immersion and contact techniques to measure axial length by placing an ultrasonic probe parallel to the optical axis of the eyeball.

Immersion Technique

Lay the patient down and drop a topical ophthalmic anesthetics.

An immersion shell is inserted between the upper and lower eyelids to contact the sclera and the shell is filled with 1% methylcellulose or balanced salt solution carefully not to create bubbles, because bubbles can affect the speed of the ultrasonic wave and generate noise in the pattern of the graph.

If the ultrasonic probe is immersed in the solution and aligned with the ocular axis spacing 5–10 mm from cornea avoiding contact with the cornea, four reflection echoes are generated including the anterior surface of the cornea, the anterior surface of the lens, the posterior surface of the lens, and the anterior surface of the retina.

In the most appropriate graph, the distance measurement value from the anterior surface of the cornea to the anterior surface of the retina is the axial length of the eye.

The Measurement Method for Corneal Refractive Power

An error of about 1 diopter of the corneal refractive power causes about 1 diopter of postoperative refractive error. There are manual and automatic corneal refractive power measurement methods. After refractive errors in the vertical and horizontal meridian are measured, the average of these two values is used. Since the constant of refractive index used to convert the measured radius of corneal curvature to the refractive power in each device is different, the measured value may vary slightly depending on the equipment.

The Constant

Each formula for calculating the diopter of intraocular lens requires a constant depending on the characteristics of the intraocular lens. The constant A is used in SRK, SRK II, and SRK-T formulas; the anterior chamber depth constant is used in the Binkhorst, Binkhorst II, Hoffer, Hoffer-Q, and Olsen formulas; and the surgeon factor is additionally used in the Holladay formula. Each of these constant is determined by the type of the intraocular lens and may affect the postoperative results.

Formulas for Power Calculation

Early theoretical formulas: In 1967, Fyodorov calculated the power of intraocular lens using A-scan and the corneal curvature based on the geometric optics, and since then, Thijssen, Van der Heijde, and Binkhorst et al. have published theoretical formulas, which were based on geometric optics and were using theoretical constants of the model eye.

Regression formulas: In the 1980s, Sanders, Retzlaff, and Kraff made the SRK formula which calculates the intraocular lens power conversely using the statistical research of the postoperative refractive errors, and this formula was once used by 82% of American ophthalmologists.

$$P = A - 2.5L - 0.9K$$

A, a constant; *L*, axial length; *K*, average of the corneal refractive power

Second-generation formulas: The initial theoretical formulas and the regression formulas were correct for normal eye with axial length of 22–24.5 mm. However, in the initial theoretical formula, the diopter power was calculated to be higher in eyes with short axial length and lower in eyes with long axial length. In the regression formula, the diopter power was calculated reversely. In order to correct this, the second-generation formulas such as SRK II and the SRK-T were developed since 1981.

Second-generation theoretic formulas: The postoperatively expected anterior chamber depth is used in the calculation, and the formulas using this method are Binkhorst, Binkhorst II, Hoffer, Hoffer-Q, and Olsen.

Second-generation empiric formulas: These formulas include TMB, DKG, Kora, and SRK II formulas.

Modified second-generation formulas: The Holladay formula is the method that determines the position of the intraocular lens using the axial length and the corneal refractive power and uses the surgeon factor as a constant. The SRK-T formula was developed by Sanders, Retzlaff, and Kraff, which not only determines the position of the intraocular lens but also considers the retinal thickness correction factor in the axial length.

Comparison of the second-generation formulas: The result of SRK-T and Holladay formula is similar and accurate for all patients. When the axial length is short (<22 mm), it has accuracy in the order of SRK-T, SRK II, and Holladay formula. In moderate-sized eyes (>24.5 mm, <27 mm), the SRK-T and Holladay are correct, and in long eyes (>27 mm, <28.4 mm) SRK II and SRK-T are correct. If the axial length is very long (>28.4 mm), the SRK-T has the correct value. Overall, the SRK-T formula shows very high accuracy in all cases, and many people are using this formula in practice.

Determination of the Intraocular Lens Diopter for Insertion

The postoperative dioptric power for the patient is determined in consideration of the patient's age, lifestyle habits, and working environment. The refractive error and visual acuity of the other eye also have to be considered. In order to eliminate the errors and to increase the accuracy, the operator should check the test result again. If there is a difference between test results of both eyes, the test should be retried. The diopter of intraocular lens to be inserted should be selected by the operator.

The SRK-T formula is considered for the long or short axial length. Nevertheless, postoperative error within 1 diopter may occur. Since the method of determining the diopter of intraocular lens is not absolute, the individual characteristics of each patient should be considered. In people with a lot of outdoor activity, it is targeted to be emmetropia, and in people working with sitting position, it is targeted to be mild myopia. In case of eye with high hypermetropia, it is recommened that it become postoperative emmetropia. In case of eye with high myopia, it is helpful to become postoperative mild myopia. In addition, if the difference in refractive error between both eyes is severe after surgery, an anisometropia may cause inconveniences. When detemining of the intraocular lens power in case of large difference of refractive error between eyes, it is better to remain some refractive error in the target eye rather than strict emmetropic result to avoid anisometropia.

17.3 Ultrasound Biomicroscopy

This system uses ultrasonic waves with high frequencies of 50–100 MHz and has a penetration depth of 5 mm and a resolution of 20–60 μm, so it is possible to obtain the image of the anterior segment that could not be described by a conventional ultrasonic diagnostic apparatus (Figs. 17.11 and 17.12). This equipment's name is ultrasound biomicroscopy because it can acquire detailed ultrasound images and information of the anterior segment similar to the performance of a slit lamp microscope in the resolution and the detail discription. It is possible to observe the shape of the iris root, the posterior chamber, and the ciliary body. It is also possible to perform a quantitative measurement. In 50 MHz frequency, the corneal epithelium cannot be seen because the image consists of the coarse spots, but in 80 MHz frequency, it is possible to observe the corneal epithelium because the image with excellent sharpness can be obtained. In addition, ultrasound biomicroscopy has advantage of being able to distinguish the mechanism of the angle closure glaucoma because it can observe the ciliary body, the structure behind the iris, and the posterior chamber that cannot be observed with the gonioscopy or anterior segment optical coherence tomography. The filtering bleb created after the trabeculectomy or the aqueous drainage device implantation can be observed as well (Fig. 17.13).

Anterior Chamber Angle Examination for the Patient with Shallow Anterior Chamber

It is necessary to perform this procedure in order to differentiate the mechanism in all diseases with shallow anterior chamber or in diseases requiring anterior chamber angle examination. Primary angle closure glaucoma, malignant glaucoma, lens-induced glaucoma, and plateau iris can be distinguished. It is also

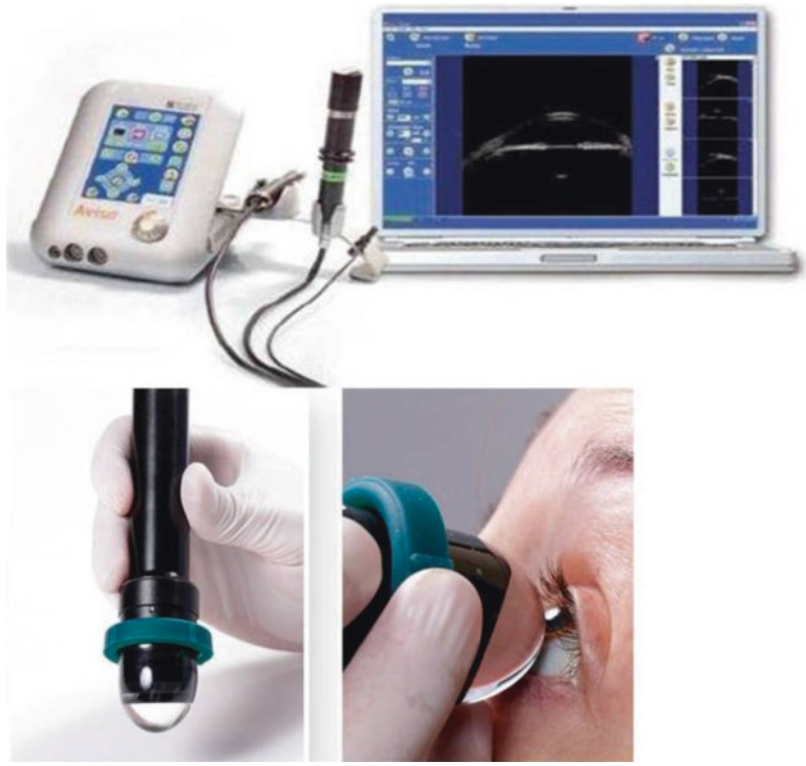

Fig. 17.11 Ultrasound biomicroscopy machine and probe with water balloon

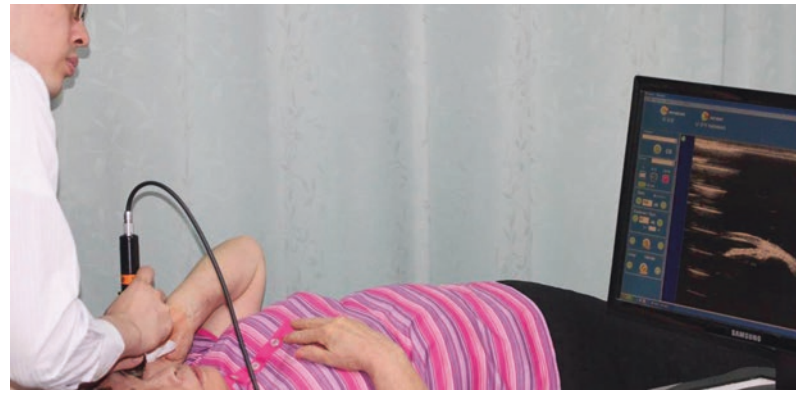

Fig. 17.12 Ultrasound biomicroscopy examination scene

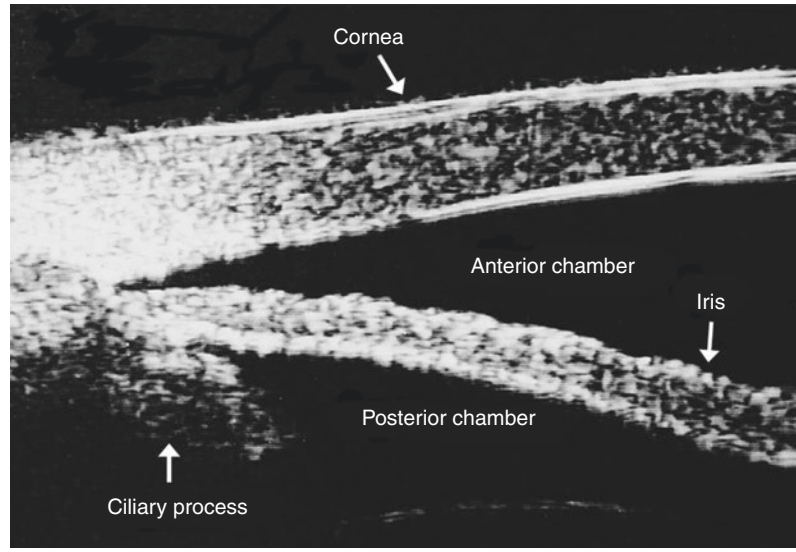

Fig. 17.13 The findings of utrasound biomicroscopy examination shows the reflection from anterior and posterior surface of the cornea, iris, and ciliary body

possible to perform examination for diseases in which anterior chamber angle examination is impossible due to corneal opacity. It is also possible to perform the measurement of the anterior chamber depth and the angle of anterior chamber and to do anterior chamber angle closure provocative test.

Anterior Segment Trauma: Post-ophthalmic Surgery
Angle recession after ocular trauma, ciliochoroidal effusion, and cyclodialysis (Fig. 17.14)

In Suspicious Case of Ciliary Body Abnormality
Plateau iris, tumor, cyst, dialysis in pars plana, Vogt-Koyanagi-Harada disease, and ciliochoroidal effusion after topiramate use (Fig. 17.15)

The Differential Diagnosis of Secondary Glaucoma Due to Lens
Diagnosis of lens subluxation, confirmation of fixation status of the intraocular lens

Others
Measurement of the size or thickness of the cornea, iris, and ciliary body and identification of the filtering bleb condition after glaucoma surgery (Fig. 17.16).

17.3.1 Method

After topical anesthesia, insert a shell for probe is located in the palpebral fissure and fill the methylcellulose or normal saline into the shell while preventing air from entering.

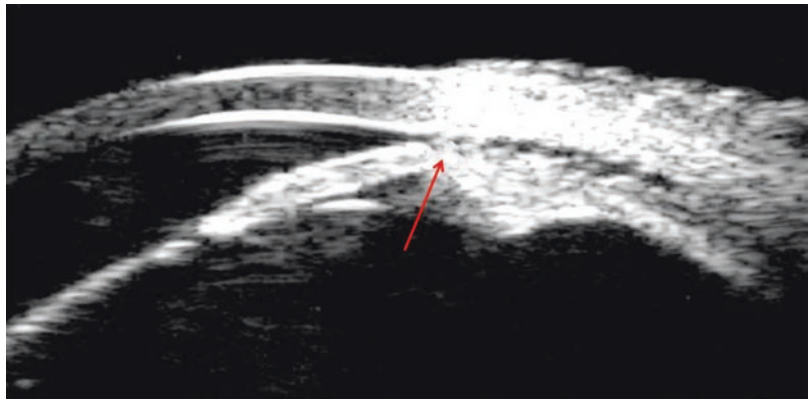

Fig. 17.14 Cyclodialysis (arrow) occurred in a 14-year-old male patient with juvenile glaucoma after trabeculectomy

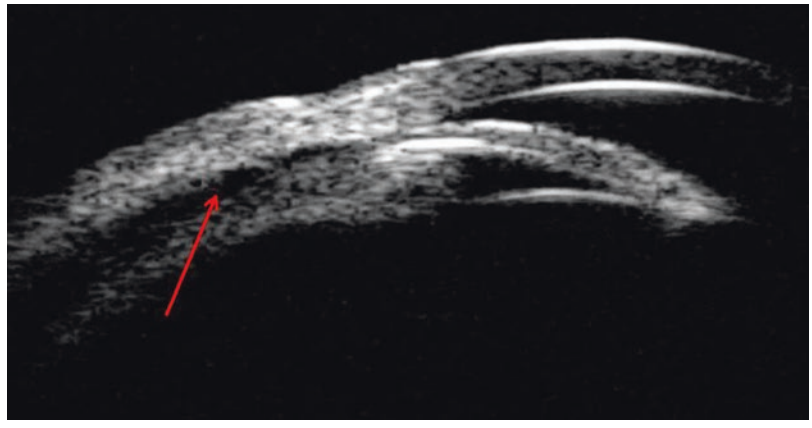

Fig. 17.15 The ultrasound biomicroscopic photography of a 27-year-old female patient with acute angle closure occurred after administration of oseltamivir (Tamiflu®). Ciliochoroidal exudation (arrow) which extended to scleral pole is observed

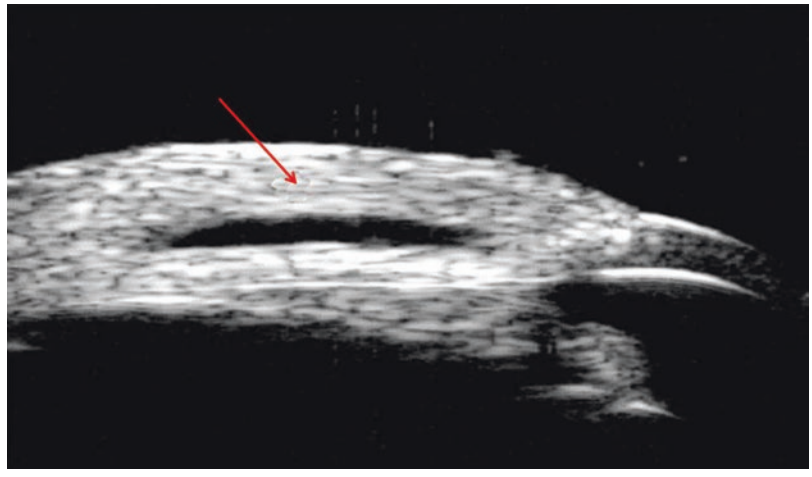

Fig. 17.16 The ultrasound biomicroscopic photography of a 46-year-old man with neovascular glaucoma after 2 years of trabeculectomy. The filtering bleb is observed as a high echo (arrow) over the hypoechoic space

Place the methylcellulose on the tip of probe.

The probe is slowly approached to the eyeball and the examination is initiated begins the examination. If the probe is approached too close to the eyeball, the beep will sound and the probe will stop working.

The image is displayed on the monitor in real time. When the appropriate findings appear, press the foot plate to stop and save the image.

In order to acquire the clear image, the eyeball or probe is moved so that the probe is perpendicular to the target tissue (a topographic image of the cornea, iris, ciliary body, and lens). It is important that the anterior and posterior surface of cornea appears as sharp and bright lines (Fig.17.17).

17.3.2 Evaluation of the Results

Confirmation of Normal Findings

The anterior and posterior surface of the cornea, the scleral surface, and the anterior and posterior surface of iris appear brightly in ultrasonography. The cornea and iris parenchyma and ciliary body appear dark. The end of white line of the posterior surface of cornea is the Schwalbe line. The most anterior part of the border connecting the sclera and ciliary body is the scleral spur. In normal subjects, the iris is flat and the ciliary sulcus is clearly visible between the ciliary process and the iris. To observe the ciliary process, the scanning is performed in the tangential direction of the cornea.

The normal depth of anterior chamber is 3128 ± 372 μm. Anterior chamber depth less than 2500 μm is diagnosed as shallow anterior chamber. The pupillary block is determined by the degree of the forward bowing of the iris (Fig. 17.18).

The plateau iris is suspected when the ciliary process is located anterior to the normal position, and the ciliary sulcus is not observed even if the iris surface is flat and the sulcus is not present on ultrasound biomicroscopy (Fig. 17.19).

The ciliary process turned anteriorly pushes the peripheral iris toward the anterior chamber angle. Although the ciliary body is observed (red arrow), the ciliary sulcus (white arrow) is not clearly seen which is observed in cases of Figs. 17.17 and 17.18.

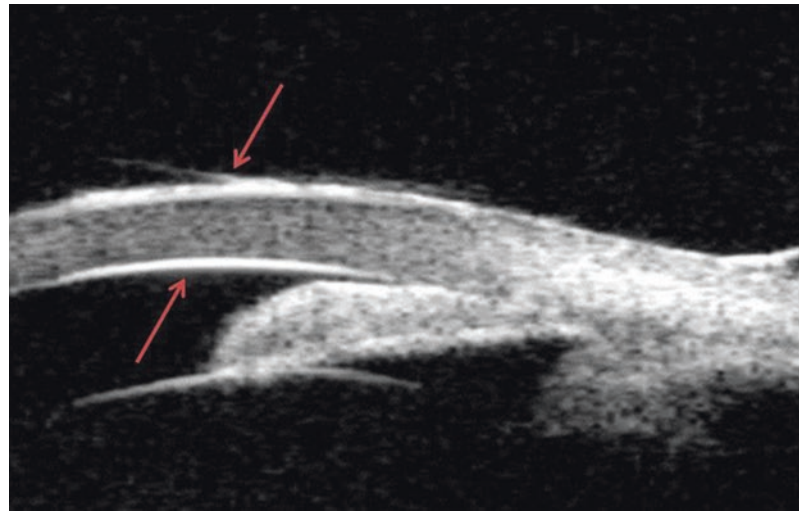

Fig. 17.17 The ultrasound biomicroscopic photography obtained by appropriate position of the probe. A clearly reflected line can be observed from the anterior and posterior surface of the cornea (arrow)

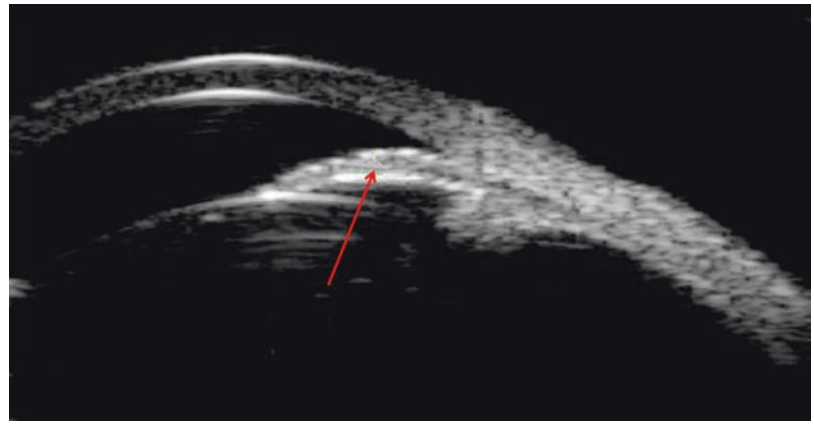

Fig. 17.18 The ultrasound biomicroscopic photography of a 61-year-old female patient with primary angle closure glaucoma (arrow). It shows that the mechanism of angle closure glaucoma is relate to pupillary block

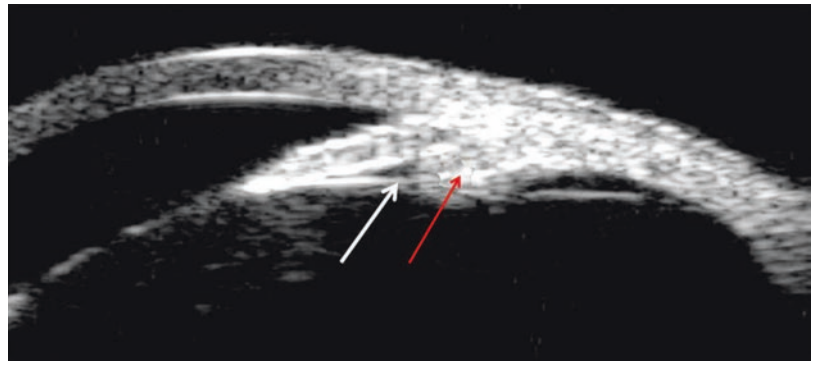

Fig. 17.19 The ultrasound biomicroscopy shows that the ciliary process is located anterior to the normal position and the ciliary sulcus is not observed in a 56-year-old female patient with plateau iris

Bibliography

Atta HR. Ophthalmic ultrasound; a practical guide. 1st ed. New York: Churchill Livingstone; 1996.

Byrne SF, Green RL. Ultrasound of the eye and orbit. 1st ed. St. Louis: Mosby; 1992.

DiBernardo CW, Greenberg EF. Ophthalmic ultrasound; a diagnostic atlas. 2nd ed. New York: Thieme Medical Publishers; 2007.

Fledelius HC. Ultrasound in ophthalmology. Ultrasound Med Biol. 1997;23(3):365–75.

Green RL, Btme SF. Diagnostic ophthalmic ultrasound. In: Ryan SJ, editor. Retina. 5th ed. Amsterdam: Elsevier; 2013. p. 265–350.

Guthoff RF, Labriola LT, Stachs O. Diagnostic ophthalmic ultrasound. In: Ryan SJ, editor. Retina. 5th ed. Amsterdam: Elsevier; 2013. p. 227–84.

Pavlin CJ, Harasiewicz K, Sherar MD. Clinical use of ultrasound biomicroscopy. Ophthalmology. 1991;98:287–95.

Silverman RH. High-resolution ultrasound imaging of the eye – a review. Clin Exp Ophthalmol. 2009;37(1):54–67.

Thijssen JM. The history of ultrasound techniques in ophthalmology. Ultrasound Med Biol. 1993;19(8):599–618.

Optical Coherence Tomography

18

Ji-Eun Lee, Je-Hyun Seo, and Young-Min Park

Optical coherence tomography (OCT) is a tool to visualize a cross section of the ocular tissue as difference of the reflectivity by measuring interference of the backscattered light. OCT provides images of the tissue at a very high resolution close to a histologic examination. Like ultrasound images, a cross-sectional OCT image is called B-scan and composed of multiple A-scans. As the ocular media is transparent, incident light enters the eye and is backscattered from the tissue. The reflectivity is shown as spectrum of gray scale or pseudo-color coding.

The older model of time domain OCT (TD-OCT), such as Stratus OCT (Carl Zeiss), has a slower scanning speed and lower axial resolution. The later OCT machines adopted spectral domain technology, which has faster speed and higher resolution. Recently, swept-source OCT (SS-OCT) machines were introduced to the market. SS-OCT is even faster than spectral domain OCT (SD-OCT) and uses a longer wave length that allows deeper penetration into the choroid.

TD-OCT has various scanning protocols to compensate the slow speed. Radial scan protocol is commonly used to obtain map data of the macula (Fig. 18.1a). The faster machines (SD- or SS-OCT) have basically two protocols: a volume scan and a line scan of high resolution. A volume scan acquires the data of a cube area by performing multiple B-scans densely. The most popular protocol is 512 × 128 scans, which consists of 128 B-scans that has 512 A-scans each (Fig. 18.1b). The whole area of the macula can be scanned by performing this protocol in a 6 × 6 mm area centered at the fovea. This raster scan protocol has several advantages compared to the radial scan protocol of TD-OCT. A small lesion can be detected more accurately. The volume data can be processed to provide a thickness map, a three-dimensional image, or an en face image (Fig. 18.2a–c). Especially a thickness map is very useful quantitative analysis to detect and follow up macular edema. However, a B-scan of a volume scan does not provide the maximal resolution for a qualitative assessment. As longer scan time increases the chance of the artifact caused by the eye movement, the density of A- and B-scan is limited in a volume scan.

A line scan provides a high-resolution image for qualitative analysis by performing highly dense A-scans (more than 1000) or by averaging multiple B-scans repeated at the same location

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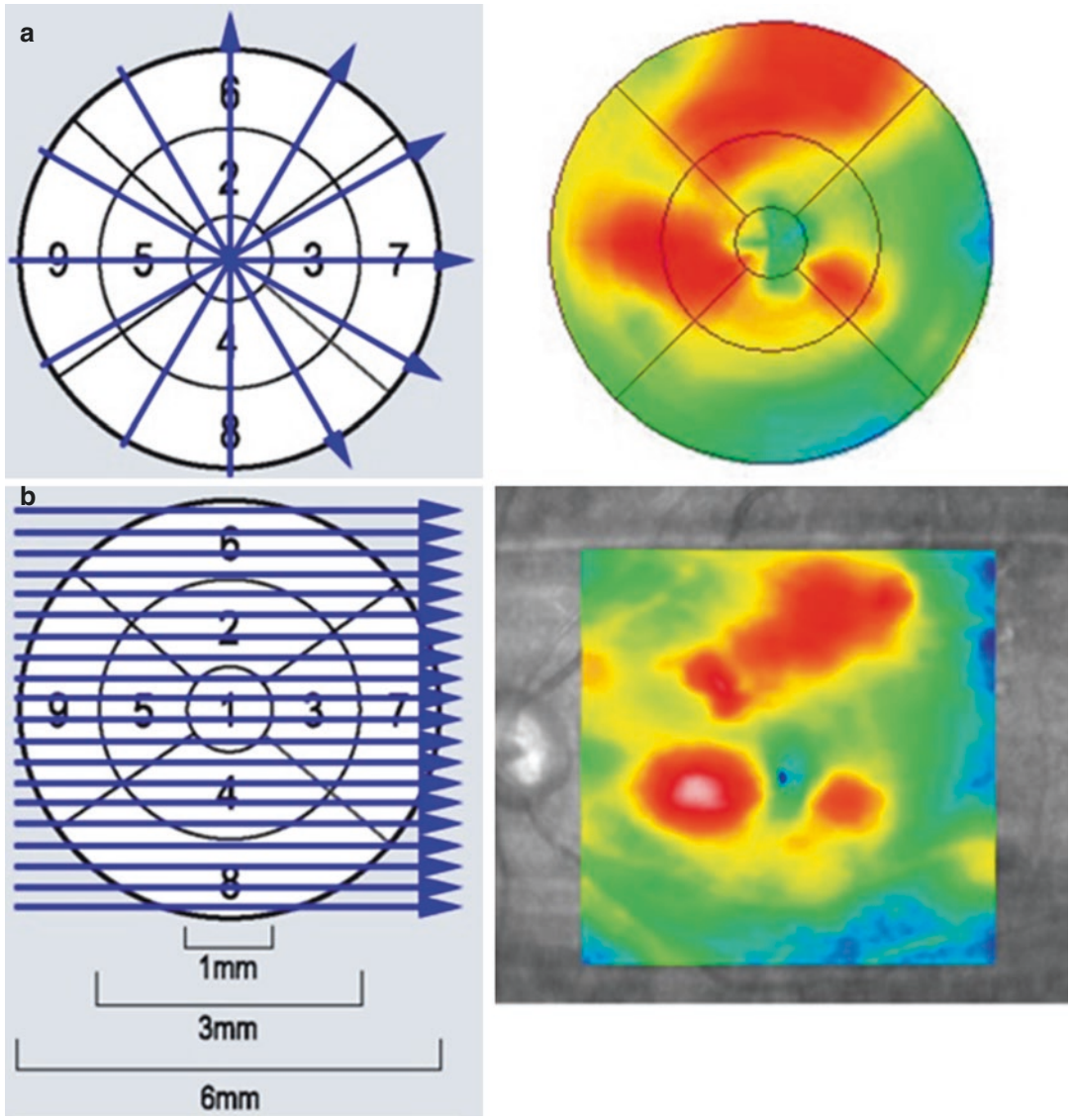


Fig. 18.1 Time domain optical coherence tomography (OCT, Stratus OCT, Carl Zeiss Meditec) versus spectral domain OCT (Cirrus HD-OCT, Carl Zeiss Meditec). (**a**) Due to the slow scanning speed, time domain OCT uses the radial scan protocol to generate a thickness map. (**b**) Spectral domain OCT may perform a raster scan, which shows more detailed status of macular edema and has a lower chance of missing a small lesion

(Fig. 18.2d, e). Axial resolution is determined by wave length of the scanning beam, and lateral resolution is limited by the spot size of the scanning beam at the target tissue. However, many factors such as aberration or opacity decrease signal-to-noise ratio (SNR) resulting in lower image quality. Increasing A-scan density or summation of repeated scans may increase SNR to make the resolution approach to the theoretical maximum. The examiner must know this procedure cannot improve the image quality or resolution limitlessly. The more scanning time also increases a chance of artifact and usually repeating scans less than 20 times is preferred.

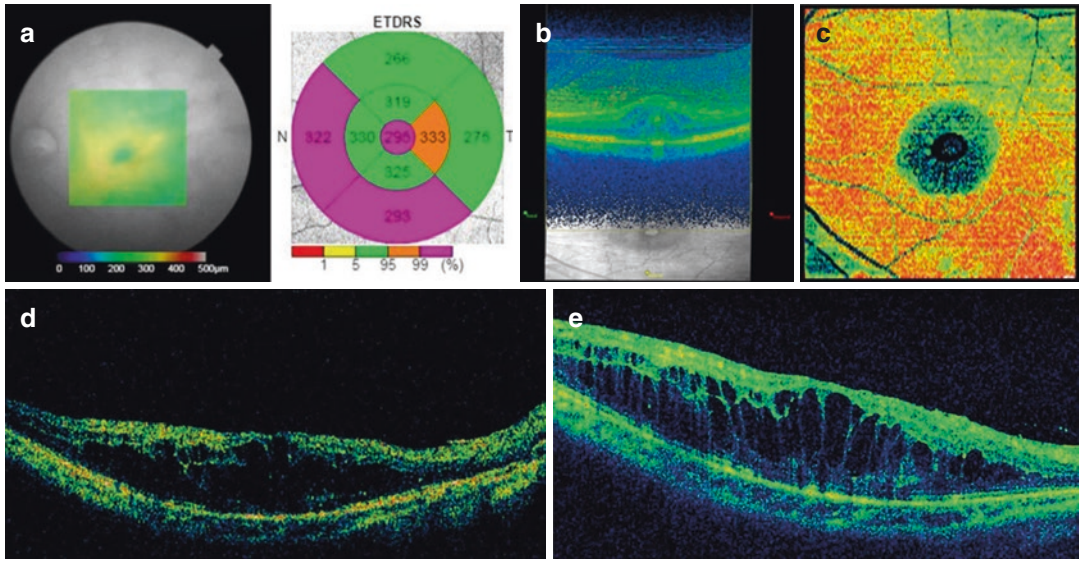


Fig. 18.2 Various processed images of optical coherence tomography. (**a**) Thickness map, (**b**) three-dimensional render, (**c**) en face image, (**d**) conventional B-scan image composed of 512 A-scans, (**e**) high-resolution image composed of 4096 A-scans (eight times higher than the conventional B-scan). *a; Atlantis DRI-OCT (Topcon), b to e; Cirrus HD-OCT (Carl Zeiss Meditec)

18.1 Imaging the Retina

18.1.1 Indications

The OCT examination may be useful in almost all the disease of the posterior segment, including uveitis and choroidal diseases.

Macular edema can be assessed qualitatively and quantitatively in diabetic retinopathy, retinal vein occlusion, choroidal neovascularization, and uveitis. OCT provides essential information for treating macular edema and evaluating the treatment results.

Vitreoretinal interface diseases, including macular hole, epiretinal membrane, and vitreomacular traction syndrome, are diagnosed most accurately by an OCT examination, which may differentiate full-thickness macular hole from pseudohole and assess the preoperative status as well as the postoperative results.

Subretinal fluid can be detected sensitively in OCT images for rhegmatogenous and non-rhegmatogenous retinal detachment, including proliferative diabetic retinopathy, central serous chorioretinopathy, and Vogt-Koyanagi-Harada disease.

Choroidal neovascularization and its activity are assessed best by OCT, which is very useful in age-related macular degeneration, polypoidal choroidal vasculopathy, degenerative myopia, angioid streak, and idiopathic choroidal neovascularization.

To diagnose pachychoroid diseases, such as central serous choroidopathy and polypoidal choroidal vasculopathy, measurement of the choroidal thickness and identification of dilated large choroidal vessels compressing the inner choroid are helpful.

18.1.2 Examinations

A typical OCT machine is composed of the imaging-acquiring device, computer, monitor, and

printer, and some of them may be integrated as a single device. The followings are general descriptions. The details of the OCT examination should follow the operation manual provided by the manufacturer.

Check the pupil. It is recommended that the diameter of the pupil is larger than 3 mm. Better image quality can be obtained when the pupil is dilated pharmacologically. Secure the position of the patient's head on the head-chin rest. Make the face straight to the device. Adjust the chin rest to match the height of the eye and the device lens. Maneuver the joystick or buttons to align the eye and the device lens to show the anterior segment in the monitor. Following the light from the pupil, move the device forward till the fundus is visualized. Adjust the focus to compensate the refractive error. These processes may be performed automatically in some device. Optimize the image. Several other procedures may be required to enhance the image quality according to the device. Check image quality and repeat the above procedures if required. Select the protocols depending on the purpose and the physician's preference. Commonly a combined protocol of volume scan of 6x6 mm area for the macula and additional line scans of a higher resolution is preferred. In TD-OCT, radial scans should be performed for the thickness map. For imaging of the choroid, enhanced-depth imaging (EDI) option is selected unless the OCT machine is SS-OCT. According to the device, many parameters such as scan length or scan density can be changed. Tell the patient to blink once or twice. Then instruct the patient to open the eye wide and to keep looking at the fixation light. Start capturing the image while reminding the patients to maintain focus on the fixation target without blinking. When the capture is completed, let the patient rest and check the scan quality. The signal strength is recommended to be 6 (of 10) or higher. Repeat the scan, if required. Bright and contrast may be adjusted to enhance the image quality. Save the scan. The standard output provides the results of basic analysis, such as macular thickness map and a cross-sectional image of B-scan. Usually the manufacturer provides the online viewer that can analyze the saved data using the various methods in the clinic.

18.1.3 Basic Interpretation

An OCT image depicts the intensity of the light reflected from the tissue as brightness of the pixel. The reflectivity can be shown using pseudo-color which represent higher reflectivity as warm colors from white to red and yellow and lower reflectivity as cold colors of green, blue, and black. These colors are coded arbitrarily and do not correspond to microscopic findings. There are no differences in sensitivity or specificity of interpretation between a black-white image and a pseudo-color image.

The tissues with high reflectivity have the structures irregular or arranged perpendicularly (horizontally) to the scanning beam, including the nerve fiber layer (NFL), plexiform layer, ellipsoid zone, retinal pigment epithelium (RPE), and choriocapillaris (Fig. 18.3). Lower reflectivity represents the tissue having regular structure or arranged vertically, such as the

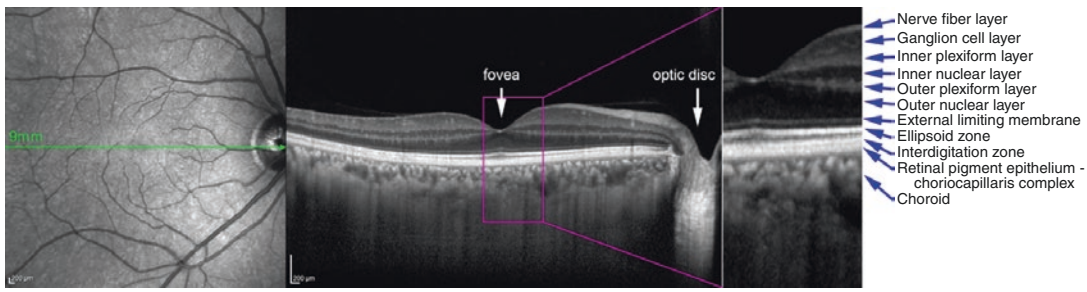


Fig. 18.3 Optical coherence tomography image of a normal macula (Spectralis OCT, Heidelberg engineering)

vitreous, nuclear layer, and outer segment of the photoreceptors. The RPE and choriocapillaris is the most distinct band having high reflectivity.

The OCT image of the normal macula is shown in Fig. 18.3. The fovea or the center of the macula is concave and the parafoveal area is thickest. The upside is toward the center of the eyeball. The multiple layers of the retina are visualized as hyper- or hypo-reflective bands. An OCT image of high resolution reveals four hyperreflective bands in the outer retina at the fovea. The outermost brightest band is the RPE-choriocapillaris complex. The next brightest band represents the ellipsoid zone (EZ), which was previously recognized as the junction of the inner and outer segment of the photoreceptors (IS-OS junction). Between the above two bands, thin band may be seen representing the interdigitation zone between the photoreceptors and RPE, although the debates exist. The inner most or the fourth band represents the external limiting membrane (ELM).

Hemorrhage and lipid exudates have high reflectivity, whereas intraretinal or subretinal fluid has lower reflectivity. Abnormal lesions

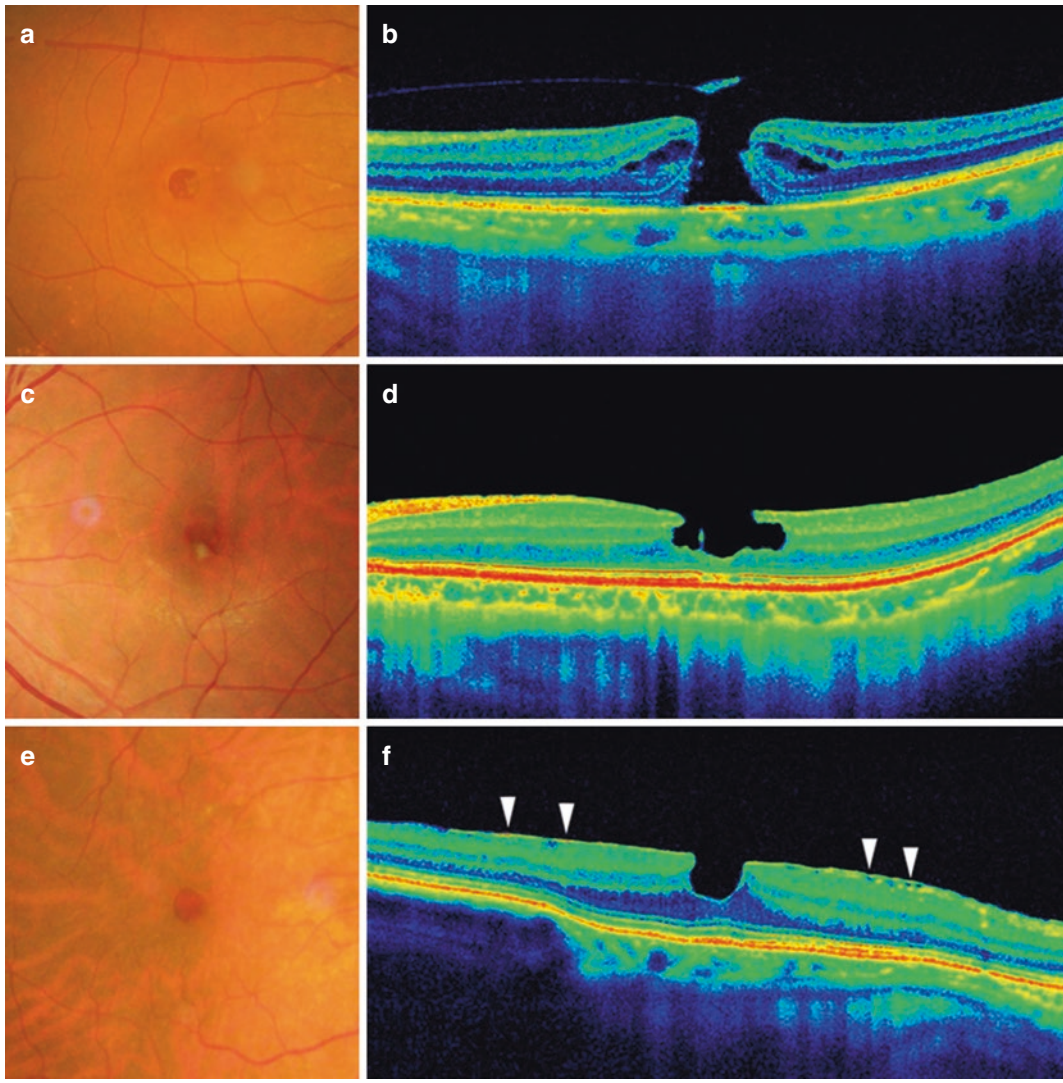


Fig. 18.4 Changes of the foveal configuration observed in optical coherence tomography (**a**, **b**) Full-thickness macular hole. (**c**, **d**) Lamellar hole. (**e**, **f**) Pseudohole (Cirrus HD-OCT, Carl Zeiss Meditec)

with an irregular structure may cause shadowing of the outer tissue. The large retinal vessels in the inner retina have low reflectivity with shadowing.

18.1.4 Composed Images of Multiple B-Scans

18.1.4.1 Retinal Thickness Map

Thickness of the retina provides invaluable information regarding macular edema or atrophy. Especially quantitative assessment of the macular thickness is essential for diagnosis, treatment, and follow-up of macular edema in diabetic retinopathy, choroidal neovascularization, retinal vein occlusion, epiretinal membrane, and other macular diseases.

The retinal thickness map of the macula can be obtained using raster or radial scan. The denser the B-scans, the lower is the chance of missing a small lesion. A scan of lower density has a merit of saving time for examination and data storage.

The grid of early treatment of diabetic retinopathy study (ETDRS) is the most popular form of presentation that has three circles with the diameter of 1, 3, and 6 mm (Fig. 18.2a). The middle and outer rings are divided into four sectors of superior, nasal, inferior, and temporal. Consequently, the ETDRS grid consisted of nine sectors. The most OCT machines provide the results of comparison to a normative data of normal population according to the age and sex.

If the thickness map is obtained using a raster scan, the centration error due to poor fixation of the patient can be corrected by moving the grid center. The retinal layers may be segmented, and thickness of each layer or combined layers can be shown as a map. Thickness of the nerve fiber layer or combined thickness of the NFL and ganglion cell layer is important in glaucoma patients.

18.1.4.2 Three-Dimensional Rendering

The scanned volume data can be processed to generate the 3-D rendered image (Fig. 18.2b), which may provide some additional information in vitreoretinal interface diseases, such as vitreomacular traction syndrome and myopic traction maculopathy.

18.1.4.3 En Face Image

The volume data can be processed to present data in a slab area at a specific level to the reference plane as a fundus photo, so-called en face image (Fig. 18.2c). The results are extremely variable according to the reference plane and the thickness of the slab. This is an essential process to visualize the vascular plexus at different level separately in OCT angiography. An en face image is also useful to identify area of serous detachment in central serous chorioretinopathy or defects of the EZ in white dot syndrome or other macular diseases. Follow the manufacturer's manual for the details.

18.1.5 Interpretation of Retinal OCT

Interpretation of an OCT image must include validation of the proper acquisition of the image. Quality of image, signal strength, and presence of artifact should be checked. Qualitative assessment of B-scan is essential, and quantitative assessment in thickness map is supplemental.

Verify the configuration of the macula. The normal macula is concave at the center, thickest in the paracentral area, and then thinner in the periphery. The inner layers (from the outer plexiform layer to the NFL) are missing in the fovea normally. If the inner layers exist in the center, confirm the centration of the scan or presence of a lesion causing deformation of the inner retina. Missing foveal tissue suggests macular hole (Fig. 18.4a), which commonly accompanies the surrounding edema. Lamellar hole refers to partial loss of the foveal tissue (Fig. 18.4b). Pseudohole implies that epiretinal membrane on the perifoveal area makes fundus findings mimicking macular hole without any tissue loss (Fig. 18.4c).

Verify the retinal thickness, which decreases in retinal atrophy and increases in macule edema, retinal detachment, or presence of tractional membrane. Presence of intraretinal fluid is an

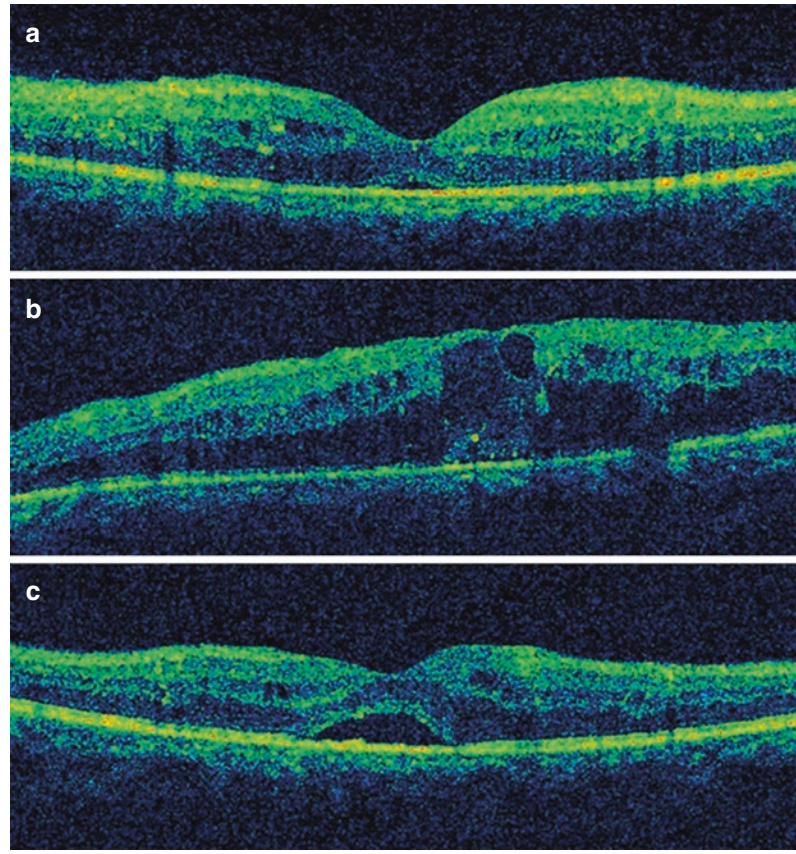


Fig. 18.5 Macular edema. (**a**) Diffuse macular edema. (**b**) Cystoid macular edema. (**c**) Subretinal fluid (Cirrus HD-OCT, Carl Zeiss Meditec)

important sign of macular edema. Average thickness is shown in the retinal thickness map, and thickness at a specific point also can be measured manually or automatically according to the software.

Macular edema can be categorized as three types (Fig. 18.5), although two or more may exist concurrently in a single eye. Diffuse edema shows thickening of the retina with sponge-form intraretinal fluid and reduction of reflectivity. It develops usually in the outer retina. Cystoid macular edema refers to the accumulation of fluid in cystoid spaces, which typically occurs in the foveal area. Macular hole accompanies cystoid edema around the hole. Subretinal fluid may be observed in macular edema. The neural retina is separated from the choroid, and intervening low reflective space exists representing subretinal fluid.

Search the presence of membrane on the retinal surface (Fig. 18.6). Common causes of membrane are epiretinal membrane, proliferative diabetic retinopathy, and vitreo-macular traction syndrome. When membrane adheres to the retinal surface globally without intervening space, it looks like the thickened internal limiting membrane with high reflectivity and the other sections should be reviewed. The low reflective space between the membrane and the internal limiting membrane confirms epiretinal membrane (Fig. 18.6a, arrows). Vitreo-macular traction syndrome has partially detached posterior hyaloid membrane that attaches to the fovea causing traction and retinal edema (Fig. 18.6b).

Check subretinal lesions (Fig. 18.7). Review the sections other than the central cross not to miss extrafoveal lesion.

Small round elevation of the RPE layer indicates drusen, and large elevation is called pigment epithelial detachment (PED). PED may have various components such as serous, hemorrhagic,

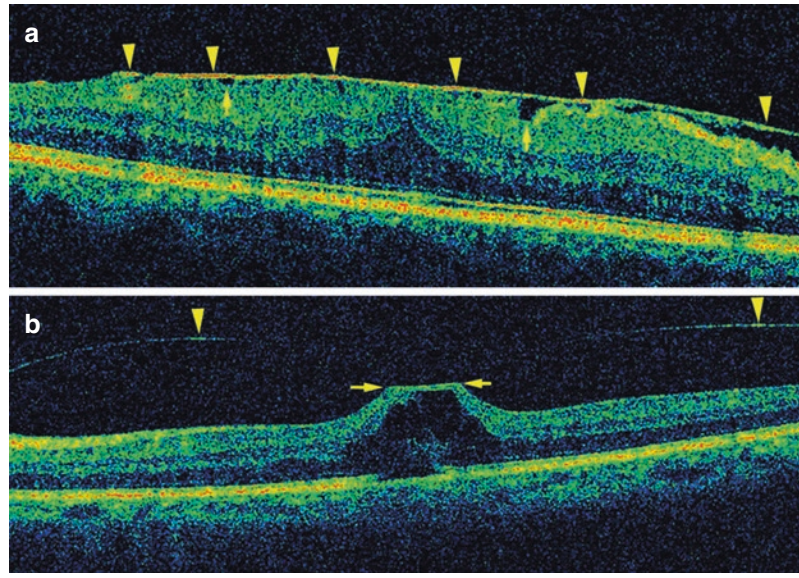


Fig. 18.6 (**a**) Epiretinal membrane. (**b**) Vitreo-macular traction syndrome

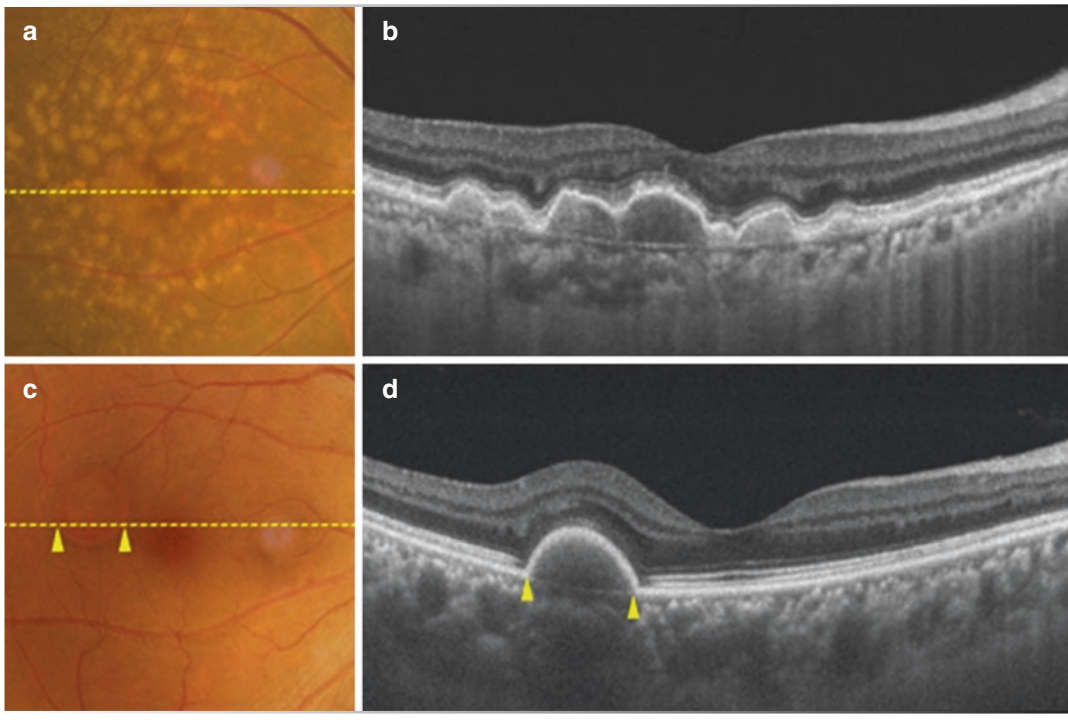


Fig. 18.7 Subretinal lesions observed in optical coherence tomography. (**a**, **b**) Drusen. (**c**, **d**) Pigment epithelial detachment. (**e**, **f**) Type 1 neovascularization. (**g**, **h**) Type 2 neovascularization. (Atlantis DRI-OCT, Topcon)

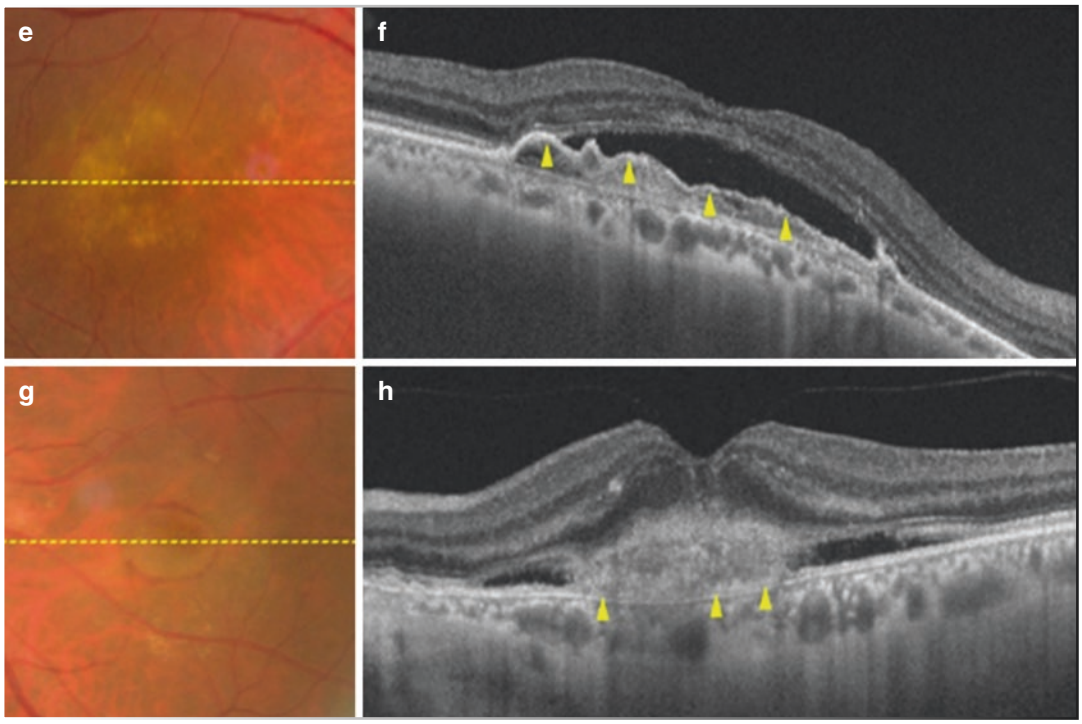


Fig. 18.7 (continued)

fibrovascular, and drusenoid. Serous PED has lowest internal reflectivity and smooth elevation. Hemorrhagic PED has usually smooth elevation having higher internal reflectivity. Fibrovascular component has inhomogeneous high reflectivity with irregular contour. Drusenoid PED refers to very large drusen or PED filled with materials of drusen (lipofuscin). A single eye may have multiple PED components at the same time.

Findings of choroidal neovascularization (CNV) are extremely various. Type 1 neovascularization refers to new vessels under the RPE layer (Fig. 18.7f, arrowheads) and is practically synonymous with occult CNV or fibrovascular PED. Type 2 neovascularization indicates that CNV is between the sensory retina and RPE (Fig. 18.7h, arrowheads) and is sometimes a synonym with classic CNV. Active CNV may accompany exudative findings of subretinal hemorrhage, subretinal/intraretinal fluid, and serous/hemorrhagic PED.

Check integrity of the outer retina (Fig. 18.8). The EZ band best represents the integrity of the photoreceptor layer. In a normal eye, the EZ band is observed as the second brightest band above the RPE-choriocapillaris band. Occasionally, the center is slightly elevated and looks broken (Fig. 18.3), but these are normal findings. Attenuation or defects of the EZ band indicate the damaged photoreceptor.

Review the choroid (Fig. 18.9). The choroid is thickened in so-called pachychoroid diseases, including central serous chorioretinopathy and polypoidal choroidal vasculopathy, where dilated large choroidal vessels are observed in the thickened choroid (Fig. 18.9a). Thin choroid indicates choroidal atrophy, which is seen in dry age-related macular degeneration, geographic atrophy (Fig. 18.9b), and retinal angiomatous proliferation. Dark choroid with folding suggests choroiditis that is a typical finding of Vogt-Koyanagi-Harada disease (Fig. 18.9c).

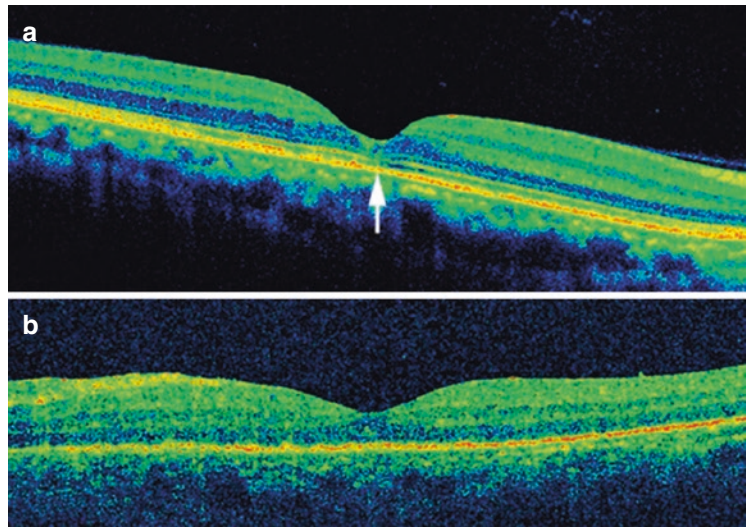


Fig. 18.8 Defects of the outer retina. (**a**) Focal disruption of the ellipsoid zone band (arrow) in solar retinopathy. (**b**) Diffuse loss of the outer retinal bands in ocular syphilis (Cirrus HD-OCT, Carl Zeiss Meditec)

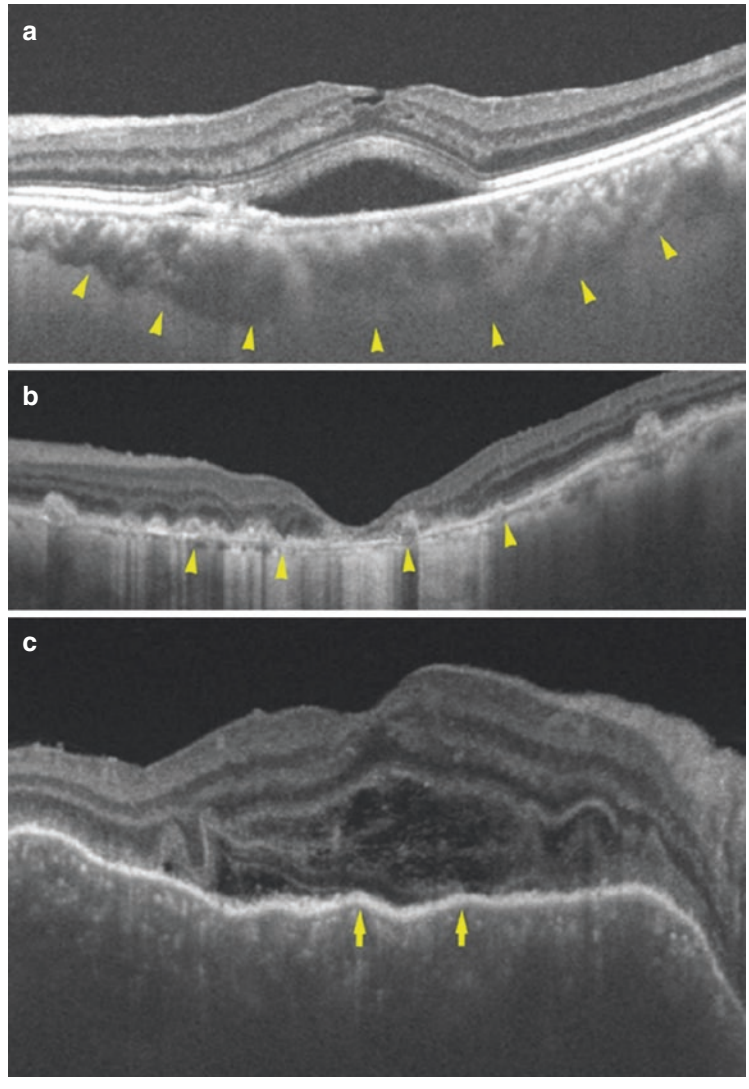


Fig. 18.9 Abnormal thickness of the choroid. (**a**) Thickened choroid (arrowheads) in central serous chorioretinopathy. Dilated large choroidal vessels are noted in the outer choroid or the Haller layer. (**b**) The choroid is extremely thin (arrowheads) in dry age-related macular degeneration. The vertical lines of hyper-reflectivity indicate increased transmission due to geographic atrophy. (**c**) Choroiditis in Vogt-Koyanagi-Harada disease. Choroidal folding is noted (arrows). The choroidal vascular structures and the outer border are not identified (Atlantis DRI-OCT, Topcon)

18.2 Optical Coherence Tomography Angiography in Retina

18.2.1 Indications

The purpose of OCT angiography (OCTA) examination is to detect and follow up vascular abnormality in retinal vascular diseases. OCTA is extremely useful in macular ischemia.

Another purpose of OCTA examination is to detect and follow up CNV. Its sensitivity is lower than conventional indocyanine green angiography to CNV, especially when CNV is active with exudative changes. However, OCTA is more sensitive to depict inactive type I neovascularization in shallow PED.

18.2.2 Mechanism

OCTA is a relatively new technology and developing rapidly. OCTA depicts blood flow by detecting movements of the red blood cell based on the difference of multiple OCT images obtained at the same locations (Fig. 18.10). The calculated difference is called a decorrelation signal. OCTA has several advantages over conventional fluorescein angiography. Invasive procedure of dye injection is not required. High contrast and resolution make the small capillary visualized more clearly. An en face image using different segmentations enables layered analysis of three-dimensional vascular structures (Fig. 18.11).

However, OCTA has disadvantages as well. It cannot detect breakdown of the blood-retinal

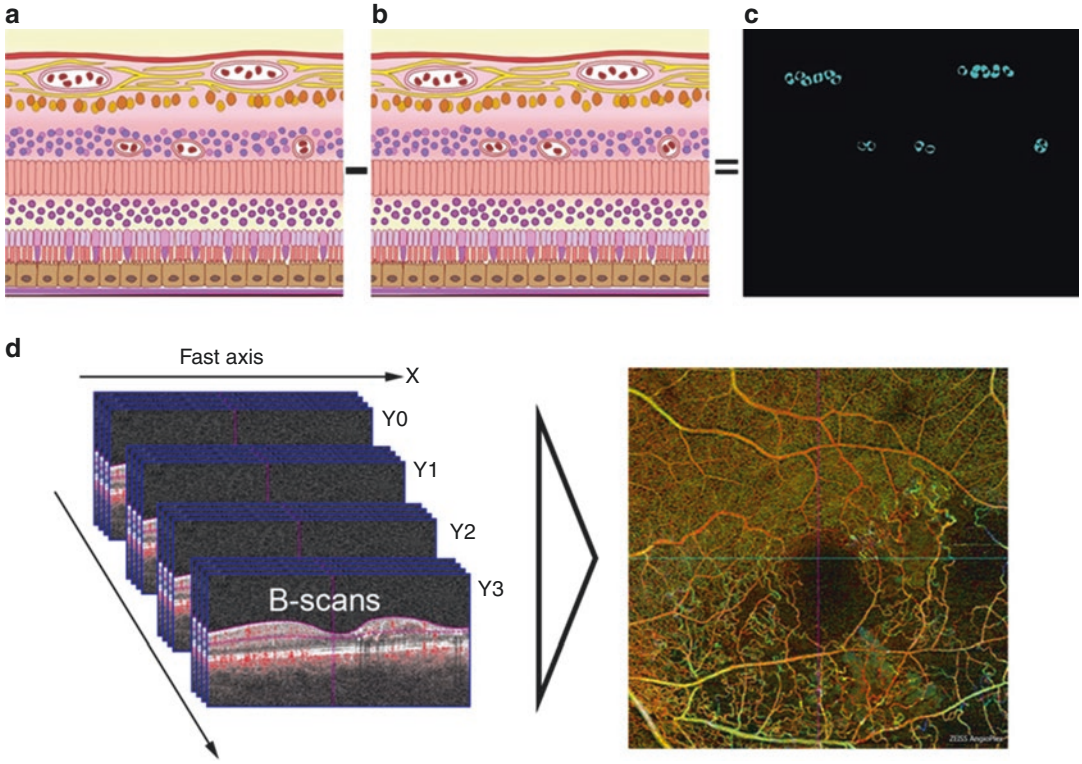


Fig. 18.10 Mechanism of optical coherence tomography angiography (OCTA). (**a**, **b**) Movement of the red blood cells makes differences in the consecutive scans at a predetermined location. (**c**) The difference is decorrelation signal. (**d**) Decorrelation signal is shown with red color in the B-scan image. The en face image showing decorrelation signal from the raster B-scans depicts the retinal vessels having blood flow inside

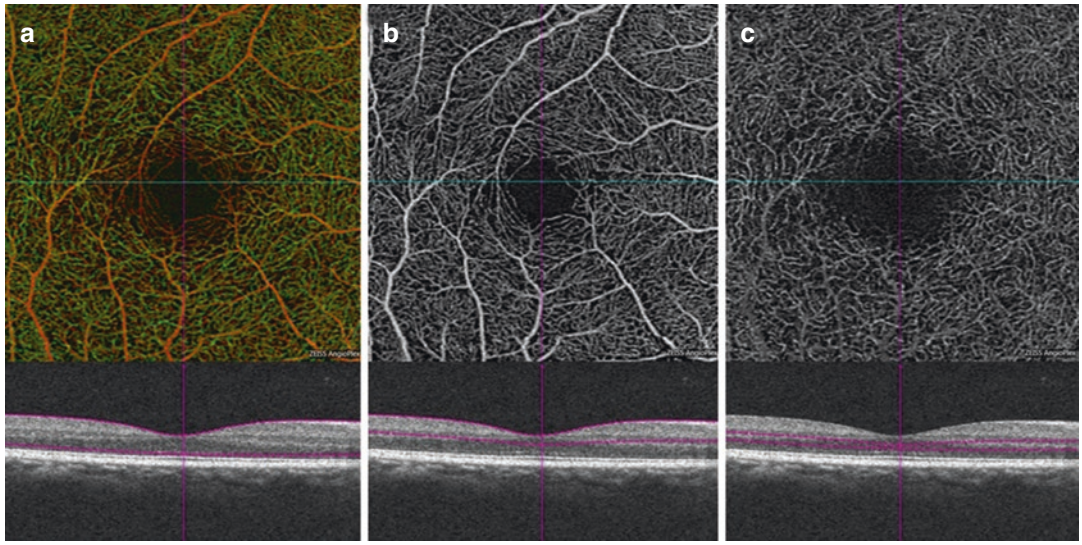


Fig. 18.11 Optical coherence tomography angiography obtained in 3 × 3 mm area of a normal macula. Red dashed lines indicate segmentations to define the specific slab to generate the en face image. (**a**) Full slab with depth coding. (**b**) Superficial capillary plexus. (**c**) Deep capillary plexus

barrier that is demonstrated as leakage of dye in conventional fluorescein angiography. Longer acquisition time, frequent segmentation error, and many artifacts reduce its practical uses. The physicians must get familiar with OCTA artifacts to avoid misinterpretation.

18.2.3 Examinations

Acquisition of OCTA images is essentially same with OCT images but takes more time as more scans are required to detect a decorrelation signal. Accordingly, it is more prone to artifact caused by eye movements.

An OCTA scan is commonly performed in 3 × 3 mm or 6 × 6 mm area. The former has a narrower field but a higher resolution.

18.2.4 Interpretation of OCTA

The reader must understand that OCTA depicts the movement of blood cells, not the vascular structure itself. Loss of blood vessel in OCTA does not necessarily indicate absence of the blood vessel, as OCTA fails to show the vessel in which the blood flow is below the detection threshold.

To interpret OCTA image, a cross-sectional image of structural OCTA with the segmentations must be reviewed together. A structural OCT coded with decorrelation signal is called an angio-B image, which is very useful to rule out projection artifact. The segmentations demonstrate the slab where an en face image of OCTA is obtained. As segmentation errors are common, a manual adjustment is sometimes required for a good-quality image. All the retinal vessels are visualized when a full slab is applied from the RPE to internal limiting membrane segmentation. The depth of the vessels can be coded using different colors (Fig. 18.11a).

The retinal capillaries have two distinct plexus – deep and superficial (Fig. 18.11b, c). The superficial capillary plexus is in the ganglion cell layer and nerve fiber layer. The deep capillary plexus is beneath the inner plexiform layer. By changing the set of segmentations, each plexus can be analyzed.

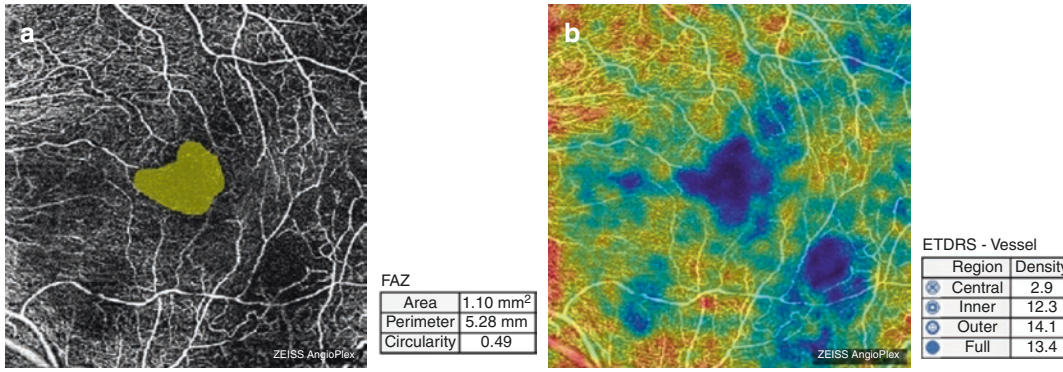


Fig. 18.12 Quantitative analysis of optical coherence tomography angiography obtained in ischemic maculopathy complicated with diabetic retinopathy. (**a**) Assessment of foveal avascular zone. (**b**) Measurement of vascular density

To optimize visualization of the targeted vessels, the segmentation can be changed or moved up and down. Especially to visualize CNV, the optimization is very important to reduce the signal from the normal vessels in the retina and choroid.

The embedded software of some machines provides analyzing tool for measuring vascular density and area of the foveal avascular zone (Fig. 18.12).

18.2.5 Artifacts in OCTA

18.2.5.1 Projection Artifact

A projection artifact requires high attention for OCTA interpretation. Even a well-trained retinal specialist may misinterpret the artifact as a meaningful signal. An OCTA image is acquired based on the reflected light from the moving blood cells. However, some of the light passes through the blood cells and is reflected from the tissue below the blood vessels. The moving blood cells make changes on the light passing through the vessels; the light reflected from the tissue also have a decorrelation. As a result, the projection artifact generates a vascular image in the layer deeper than the real location.

Vascular images may be seen in nonvascular tissue due to projection artifact (Fig. 18.13a, b). For example, the retinal vessel may be projected to the nonvascular pigment epithelial detachment. This would lead to misdiagnosis of CNV. When the vascular pattern shown in the RPE layer coincides with the retinal vascular pattern, projection artifact is confirmed.

As the intensity of decorrelation signal depends on the reflectivity, sometimes projection artifact is stronger than the real signal. This is useful to detect CNV having weak reflectivity. Moving the slab to the superficial choroid below the actual location may visualize the CNV more clearly. These suggest that the reader must be cautious to determine the location of CNV based on an OCTA image.

The recent software provides tool to remove projection artifact. However, the artificial removal of the artifacts makes another artifact. To overcome the secondary artifact, the function may be turned on and off by the reader.

18.2.5.2 Eye Movement

OCTA technology is based on detection of changes in successive repeated image. Various motions of ocular tissues may cause changes in images other than blood flow. Several strategies are used to reduce the effects of movements, but nothing is perfect. Sometimes the correction algorithm may generate other artifacts, such as loss of detail, doubling of the vessels, and a linear defect (Fig. 18.13d).

Breaks of the vessels and white line defects are caused by eye movements such as a microsaccade. If an image is aligned by comparing vertical and horizontal scans, checkerboard defect or quilting defect may be seen.

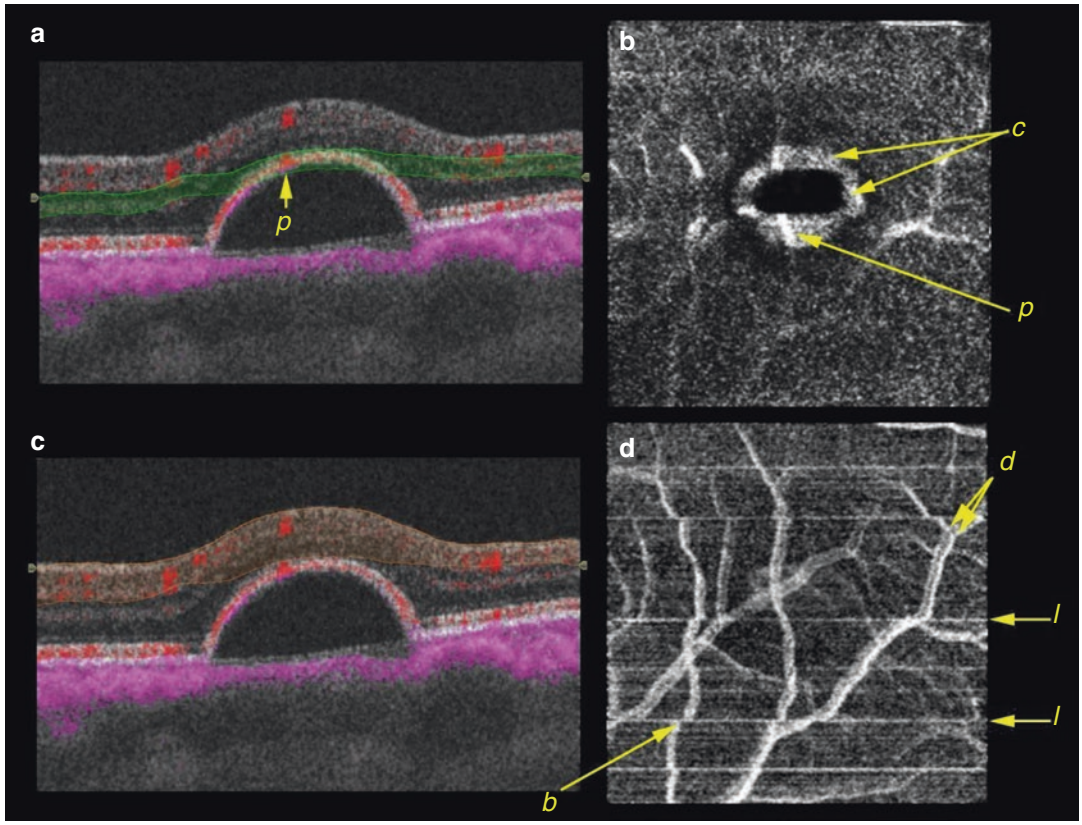


Fig. 18.13 Artifact in optical coherence tomography angiography observed in an eye with serous pigment epithelial detachment (PED). (**a**) Angio-B image shows the slab of the deep capillary plexus. Red color indicates decorrelation signal. Nonvascular pigment epithelial detachment has decorrelation signal projected from the retinal vessel in the superficial capillary plexus (p). (**b**) En face image of the deep capillary plexus demonstrates the round artifact due to anteroposterior movement of the PED wall caused by cardiac pulsation (**c**). Projection artifact is also noted (p). (**c**) Angio-B image shows the slab of the superficial capillary plexus. (**d**) En face image of the superficial capillary plexus shows various artifacts; d, doubling; l, white line defects; b, breaks of the vessel

Movement of reflective tissues may have decorrelation strong enough to cause the false-positive signal. Axial movement of the choroid due to cardiac pulsation can generate a false-positive decorrelation signal along the edge of pigment epithelial detachment. This must not be misinterpreted as a CNV (Fig. 18.13b).

18.3 Optical Coherence Tomography in Glaucoma

Optical coherence tomography has been used for glaucoma diagnosis and progression detection. The various protocols in OCT were used for glaucoma.

- Optic nerve head analysis
- Retina nerve fiber layer thickness
- Guided progression analysis
- Macular thickness
- Lamina cribrosa
- OCT angiography

18.3.1 Scan Protocol in Glaucoma (Fig. 18.14)

The scan protocols, which are conducted for glaucoma, can be divided into optic nerve head analysis and retinal nerve fiber layer thickness analysis. Of time domain optical coherence tomography

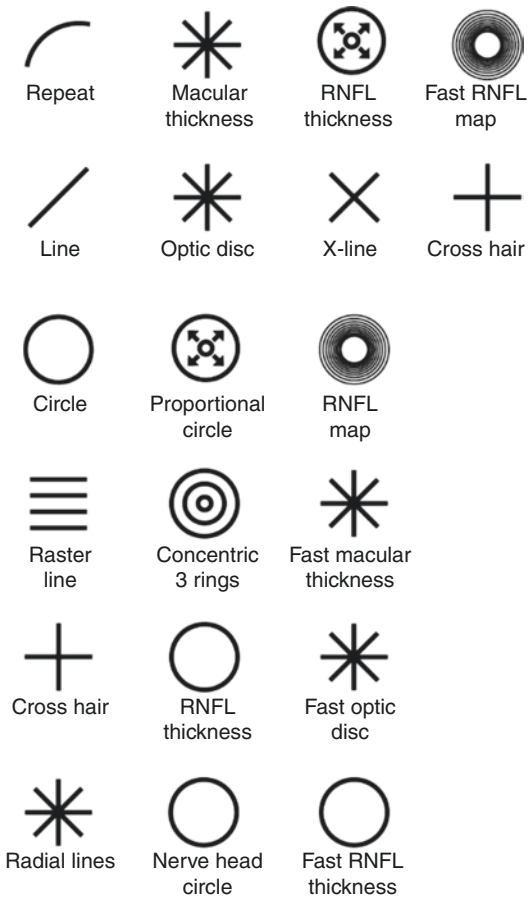


Fig. 18.14 Various exam protocols (Stratus optical coherence tomography, Carl Zeiss)

(TD-OCT), Stratus OCT was a popular model. Recently, the latest model, spectral domain optical coherence tomography (SD-OCT), was introduced. These SD-OCTs provide various protocols to evaluate glaucoma. Typical protocols for glaucoma diagnosis are described below:

Fast Optic Disc Scan: This is a protocol used in Stratus OCT. It measures 6 lines crossing the center of the optic nerve head and performs an optic nerve head analysis using a fixed scan length of 4 mm.

Fast RNFL Thickness Scan: This is the protocol used in the Stratus OCT. Three circle scans with a radius of 1.73 mm scan the optic nerve head to measure the thickness of the retinal nerve fiber layer.

Optic Disc 200x200 Cube Scan: This is a scan provided by Cirrus OCT, which is one of SD-OCT models. It consists of 200 A scans per one B scan in a 6x6 mm cube, and a total of 200 B scans are performed.

18.3.2 Analysis of Optic Disc and Retinal Nerve Fiber Layer

18.3.2.1 Optic Nerve Head Analysis

With the (fast) optic disc scan, the 4 mm lines divide the optic disc into six equal parts. The optic nerve head analysis automatically divides the retinal pigment epithelium and choroidal capillary layers during the scan. Thereafter, the baseline is determined to be parallel (upward) 150 μm above the line connecting the two retinal pigment epithelium layers facing the optic nerve. The area above this baseline is set as the neuroretinal rim, and the area below this baseline is defined as cup. In addition, since the diameter of the optic disc is determined based on the end of the retinal pigment epithelium, unlike other devices, it is hardly affected by tilted discs. The measurement value of vertical and horizontal optic disc cup ratios, optic disc area, volume and volume of disc space, and area and volume of optic disc space are displayed in printout (Fig. 18.15).

18.3.2.2 Retinal Nerve Fiber Layer Analysis

For RNFL analysis, OCT acquires a scan with radius 1.73 mm centered on the optic disc. In the form showing the result, the temporal is defined as 0°, and the result is shown in the clockwise direction (temporal, superior, nasal, inferior again temporal; TSNIT graph) in the right eye. On the other hand, in the left eye, OCT provides a linear graph that continuously shows changes in retinal nerve fiber thickness in a counterclockwise direction. Also, there are pie charts showing RNFL thickness divided by quadrant analysis and 12-clock hour analysis.

Average RNFL Thickness

Three scans with the same radius around the optic nerve head were performed and the results are shown as mean values for the thickness of the retinal nerve fiber layers (Fig. 18.16).

Quadrant Analysis and 12-clock hour Analysis

Glaucomatous optic nerve fiber layer (RNFL) defect is a type of glaucomatous optic neuropathy

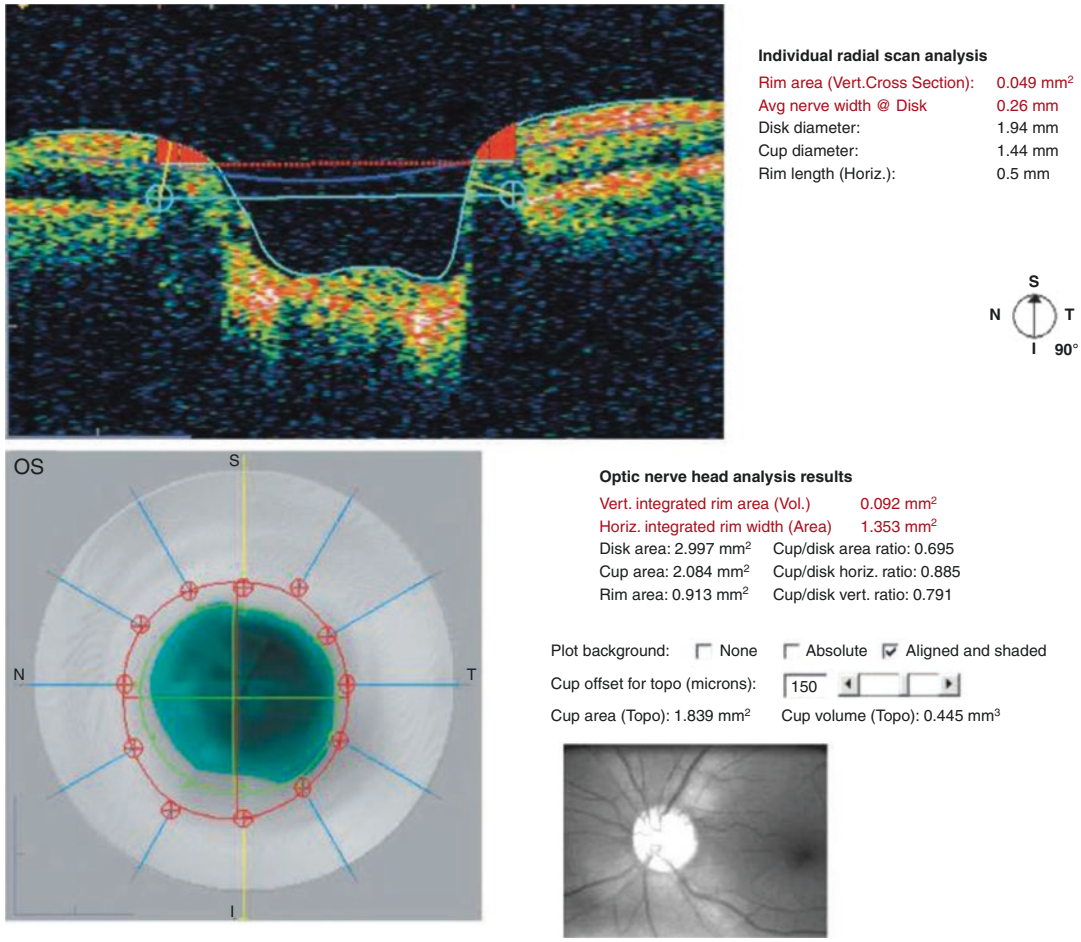
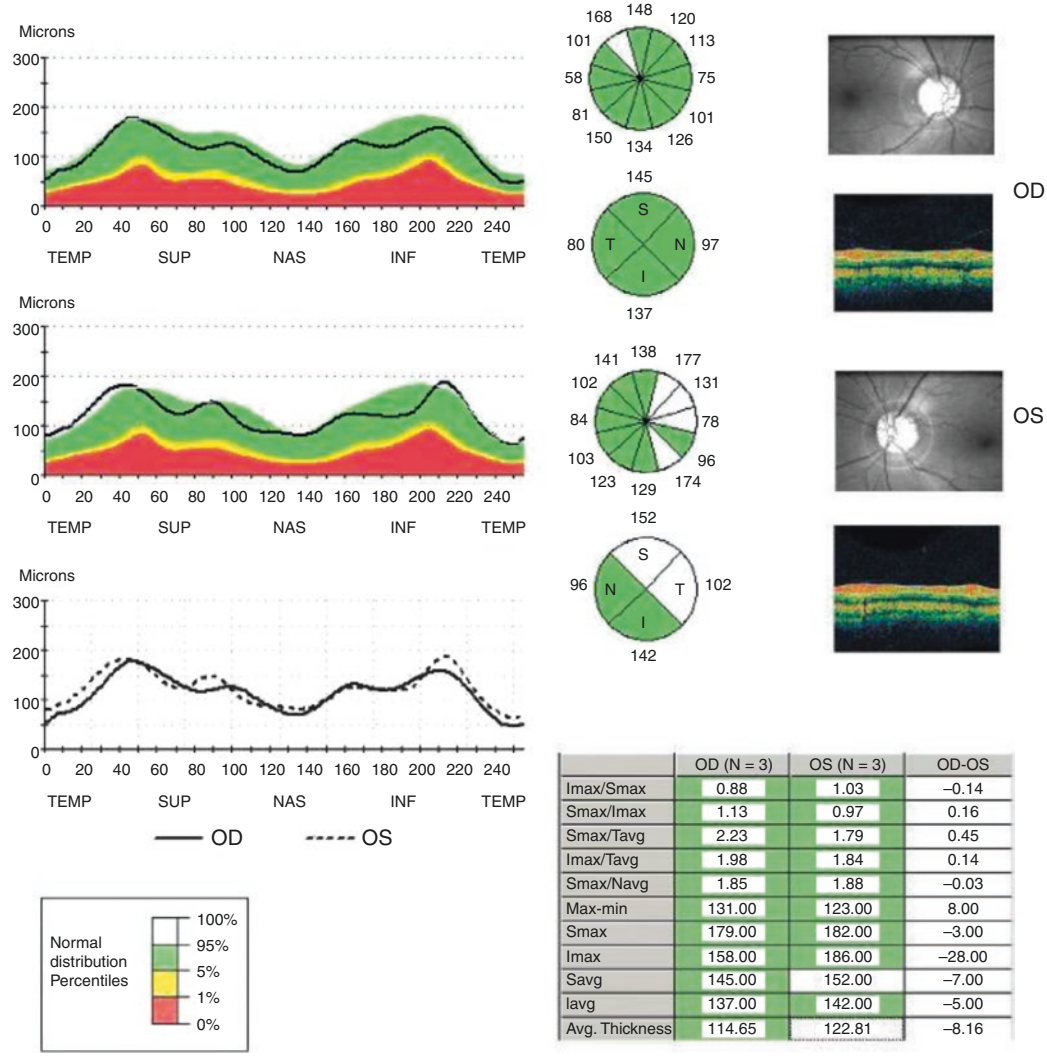


Fig. 18.15 Optic nerve head analysis of Stratus OCT

that occurs in the superotemporal or inferotemporal side of the optic nerve fiber layer and it requires information on the location and extent of RNFL defect for detect glaucoma development and progression. To do this, use quadrant analysis and 12-clock hour analysis.

Other Minor Parameters

The bottom right box of Fig. 18.3 shows the other parameters provided by the Stratus OCT. It consists of Smax (maximal superior RNFL thickness), Imax (maximal inferior RNFL thickness), the ratio of the two variables (Imax/Smax and Smax/Imax), Imax /Tavg (Imax is divided by average temporal RNFL thickness), Smax/Navg (Smax is divided by average nasal RNFL thickness), Max-Min, Savg (average superior RNFL thickness), and Iavg (average inferior RNFL thickness). When it is abnormal, it shows yellow or red. It also shows the difference between the right eye and the left eye of the parameters shown by the OCT. The reason for this parameter is that the RNFL and optic nerve is symmetrical in the normal eye. When asymmetry is observed, it would be helpful to the diagnosis of glaucoma, as the asymmetry of each quadrant is seen in early glaucoma.



	OD (N = 3)	OS (N = 3)	OD-OS
Imax/Smax	0.88	1.03	–0.14
Smax/Imax	1.13	0.97	0.16
Smax/Tavg	2.23	1.79	0.45
Imax/Tavg	1.98	1.84	0.14
Smax/Navg	1.85	1.88	–0.03
Max-min	131.00	123.00	8.00
Smax	179.00	182.00	–3.00
Imax	158.00	186.00	–28.00
Savg	145.00	152.00	–7.00
Iavg	137.00	142.00	–5.00
Avg. Thickness	114.65	122.81	–8.16

Fig. 18.16 RNFL thickness analysis of Stratus OCT

18.3.3 Interpretation of Optic Nerve Head Analysis and Retinal Nerve Fiber Layer Thickness

Optic disc scan and RNFL thickness scan are used to examine optic disc and retinal nerve fiber layer in patients with glaucoma; there is a high risk of errors due to fixation errors in patients who are time-consuming and whose vision is poor. In TD-OCT, fast optic disc scan and fast RNFL thickness scan are used most often. In a recent SD-OCT, optic disc cube scan is performed simultaneously with optic nerve and retinal nerve fiber layer thickness. When reading out the results of optical coherence tomography, it is necessary to check the scanned area and check the signal strength. If the scanned region is included in the peripapillary atrophy in the high myopia, RNFL thickness can be measured thinly even if it is not glaucoma. If the scanned region is not in the center of the optic nerve, false positive

may occur. If there is severe clouding of the cataract or vitreous hemorrhage, it may be inaccurate if the signal intensity is less than 7.

18.3.3.1 Optic Nerve Head Analysis

The results of the optic nerve head examination revealed the vertical and horizontal optic disc ratio, optic disc area, optic cup, and area and volume of the neuroretinal rim. In the eye with glaucomatous optic disc damage, optic disc cup ratios increase and the area and volume of neuroretinal rim decrease. In addition, pathological information can be obtained through comparison of both eyes (Fig. 18.17).

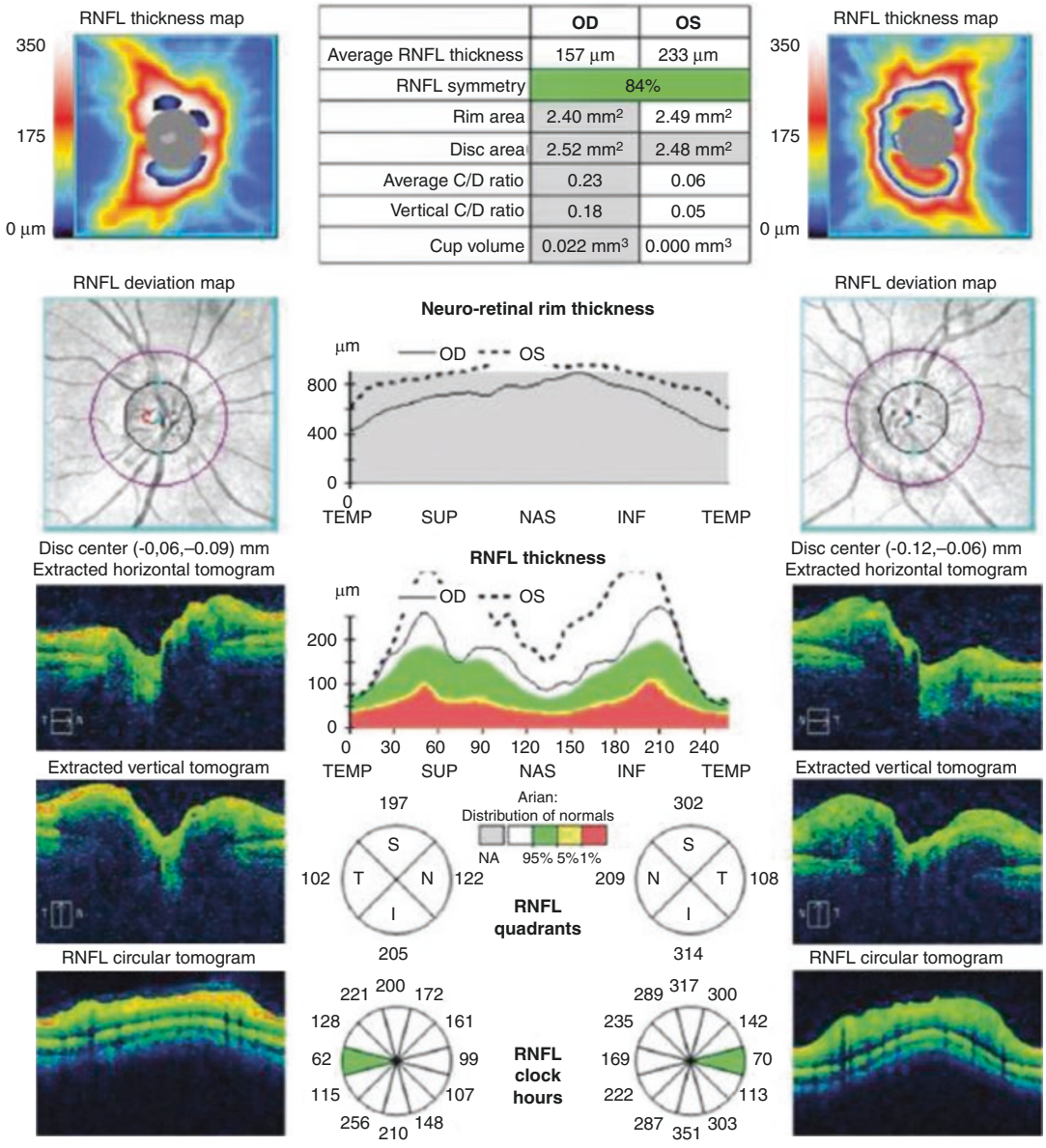


Fig. 18.17 Spectral domain optical coherence tomography with optic disc edema. The TSNIT graph shows a higher RNFL thickness than normal

18.3.3.2 Retinal Nerve Fiber Thickness Analysis

Retinal nerve fiber layer (RNFL) had been carefully examined to detect glaucoma damage before OCT era. Firstly, for interpreting of RNFL analysis, RNFL thickness changes need to be found. In glaucomatous RNFL atrophy, RNFL thickness was thinner than normal RNFL thickness. According to several references, the mean value of RNFL thickness in normal subjects is 100–120 μm, the initial glaucoma patient is 80 μm or less, moderate glaucoma patients is around 60 μm, and the advanced glaucoma patient is 40 μm. To detect glaucoma, the normal range of RNFL thickness should first be defined. Depending on the type of OCT machine, the normal range according to age and race is stored in the OCT machine. This is called "normative data." The data are stored at age 18 or older than 18 years of age and show normal values according to age. The normal retinal nerve fiber layer has a double-hump pattern structure on the superotemporal side and the inferotemporal side. Especially in early glaucoma, the disappearance or change of these patterns should be observed carefully when viewing the TSNIT graph. In normative data, each part is calculated and displayed in color. White represents the upper 5% of normal, green represents the lower 5–95% of the normal, yellow indicates the lower 1–5% of the normal, and red indicates the lower 1% of the normal. Under 18 years of age does not show any color because there is no normal data. In general, white and green are normal, yellow is the borderline, and red is interpreted as having an abnormality. It is noteworthy that even if all areas are displayed in white and green, the average thickness of each area should be checked and the difference between the two eyes should be evaluated to determine the possibility of early glaucoma (Fig. 18.16). In addition, RNFL thickness in optic neuritis or Leber's hereditary optic neuropathy (LHON) may be thicker than normal when there is optic disc edema in the early stage of the disease (Fig. 18.17). Therefore, even if the RNFL thickness is normal (white color sign shown in the printout) in OCT, it may not be actually normal. In the clinical setting, glaucoma is often difficult to determine in myopic eye, and at this time, the OCT may show false-positive results even if the thickness of the retinal nerve fiber layer is normal. One may be confused by the red color sign of OCT when the scan site includes the optic disc peripapillary atrophy. For other reasons, the position of the double hump shifts to the temporal position in the myopia, and the deviation from the normative data is possible. In this case, it is helpful to identify the height of the hump. On the other hand, localized RNFL defects may show false negative results in quadrant analysis and clock-hour analysis. It is also necessary to confirm whether there is a decrease in the TSNIT graph where the RNFL defect is suspected.

18.3.3.3 Deviation from Normal Map (Fig. 18.18)

The location of the RNFL defect is shown in a similar way as RNFL photograph. Based on the RNFL thicknesses calculated with a cube scan around the optic nerve, it is shown as yellow if RNFL thickness is between 1% and 5% of the normative data. It is shown as red if RNFL thickness is less than 1% of the normative data. It can be used to determine the glaucomatous damage as an adjunct to the gold standard method (RNFL photography).

18.3.4 Guided Progression Analysis (Fig. 18.19)

Guided progression analysis (GPA™)-RNFL is a method to compare the RNFL thickness measurements of optic disc cube 200 × 200 scans over time using three or more scans (three to eight scans) to determine if there is a statistically significant change. This analysis included the time sequence of the RNFL thickness map and the RNFL thickness change map, the average RNFL thickness graph showing the rate of change, and

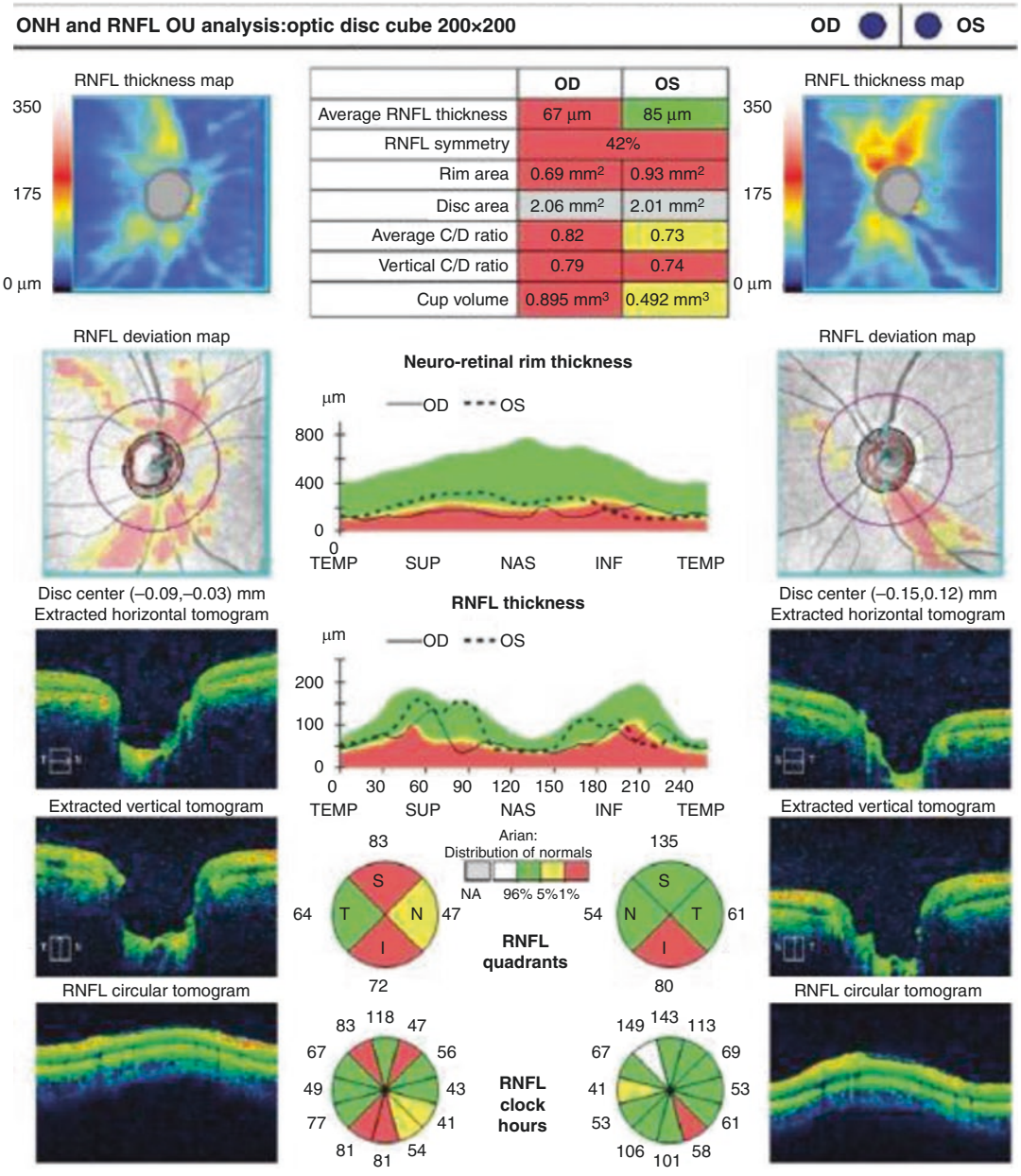


Fig. 18.18 RNFL deviation map of spectral domain OCT

the RNFL thickness profile comparing the current test to the reference test. However, GPA method alone does not confirm progression of glaucoma. Glaucoma progression can be confirmed only after a comprehensive review of changes in a variety of clinical parameters including the optic disc shape and visual field. In addition, in the guided progression analysis, an optic nerve head may be used as a similar concept, but it is an ancillary method.

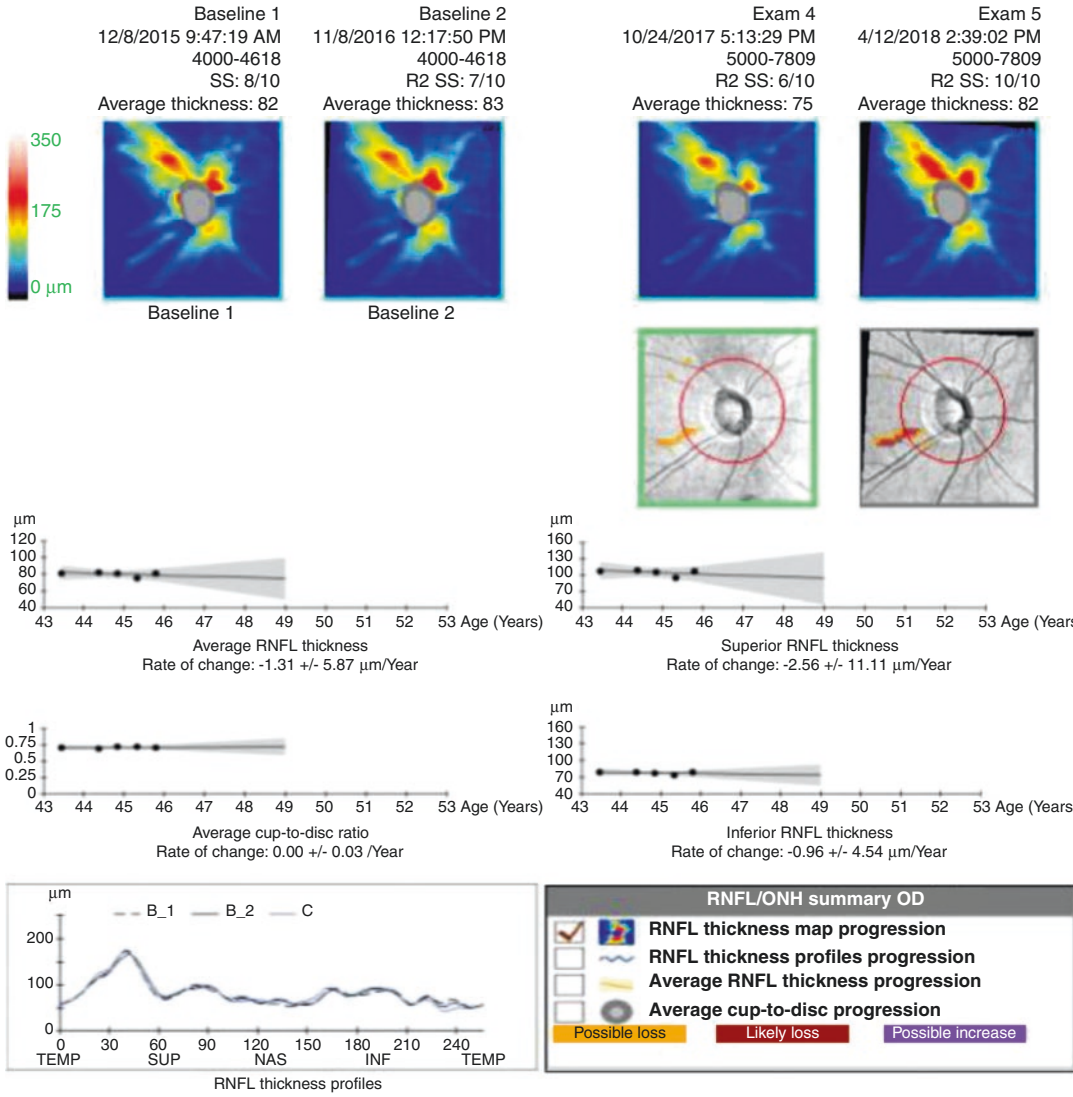


Fig. 18.19 Guided progression analysis. In this case, deterioration in inferotemporal RNFL thickness is suspected

18.3.5 Macular Thickness

18.3.5.1 Ganglion Cell/Inner Plexiform Layer Thickness Analysis (Fig. 18.20)

Since ganglion cell damage is observed in glaucoma, it is a concept that observation of ganglion cell damage by OCT may be helpful in the diagnosis of glaucoma. Ganglion cell/inner plexiform layer thickness analysis of OCT provides a thickness for the sum of the ganglion cell layer and the inner plexiform layer. Thick topography implements a circular six-sector analysis in the form of a 6 mm × 6 mm cube. As compared with the normal range, the green color sign indicates the thickness between 5% and 95% of the

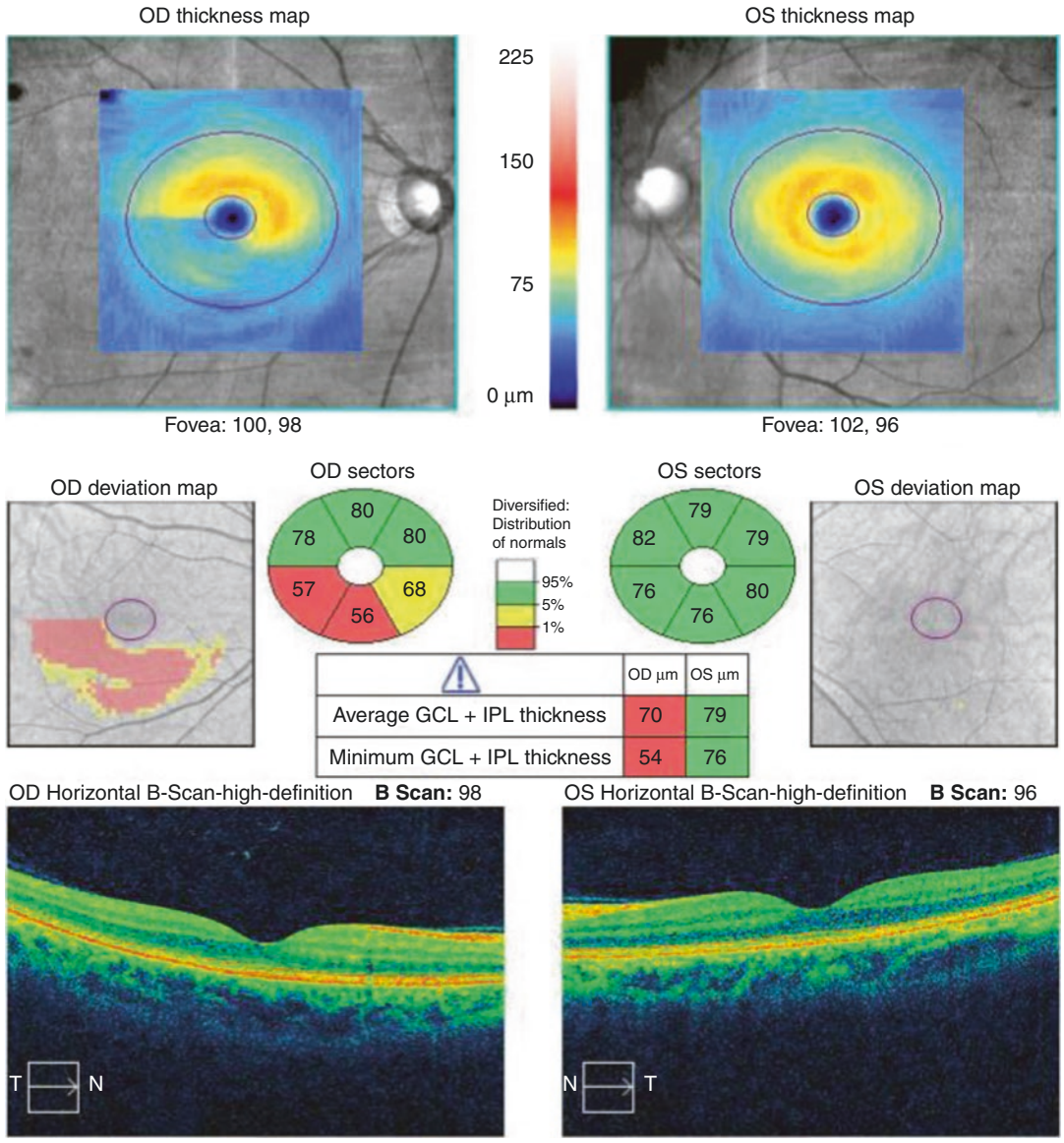


Fig. 18.20 Ganglion cell/inner plexiform layer thickness analysis. The ganglion cell/inner plexiform layer thickness is decreased in inferotemporal and inferior sectors in right eye

normative data base, the yellow color sign indicates thickness between 1% and 5%, and the red color sign indicated thickness less than 1%.

18.3.5.2 Posterior Pole Asymmetry Analysis (Fig. 18.21)

As retinal ganglion cell damage is detected in glaucoma, the thickness of the ganglion cell layer will be decreased in glaucoma and this change result in retinal thickness changes. In comparison with the binocular and upper and lower retinal hemisphere, we can compare them likewise in the glaucoma hemifield test and the visual field test. The significance of this test is helpful in the assumption that bilateral retinal thickness or GCIPL thickness is similar. Hence, if asymmetry is observed, comparing the difference between the upper and lower retinal thickness and the left and right retinal thickness may be helpful in the diagnosis of early glaucoma.

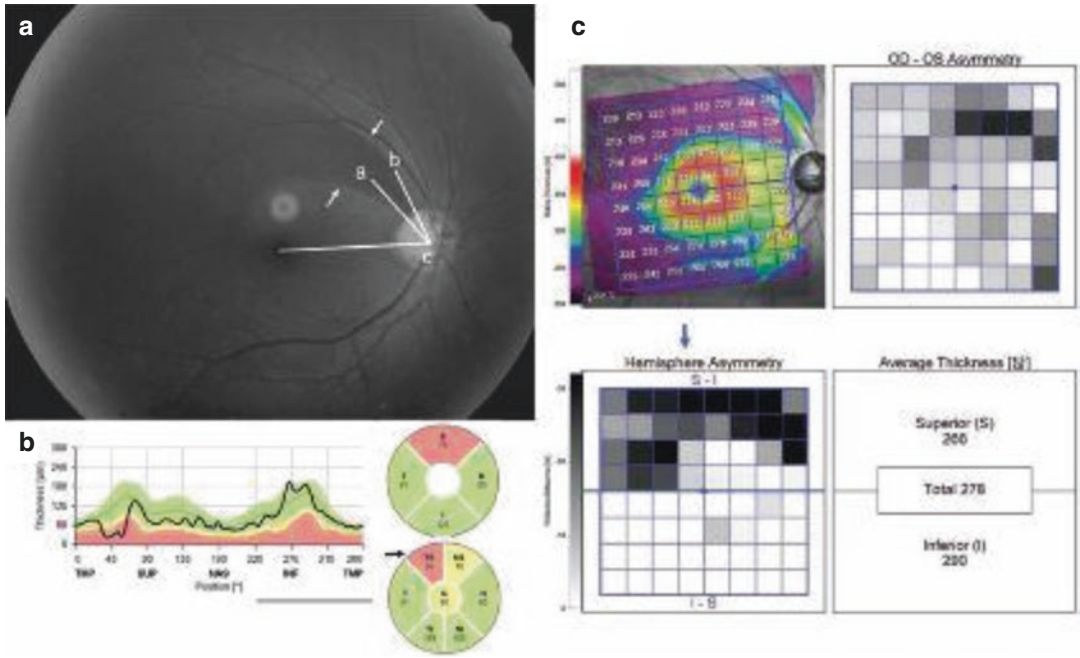


Fig. 18.21 Posterior pole asymmetry analysis (**a**) Retinal nerve fiber defect is observed in retinal nerve fiber layer photograph. (**b**) OCT RNFL thickness defect is observed in the area where nerve defect is observed. (**c**) Posterior pole asymmetry analysis shows that the defect is observed

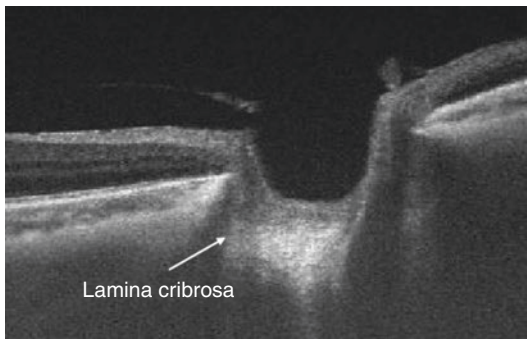


Fig. 18.22 Example of lamina cribrosa in swept-source OCT

18.3.6 Lamina Cribrosa (Fig. 18.22)

18.3.6.1 Significance of Lamina Cribrosa Imaging Using OCT

The lamina cribrosa (LC) is the putative site of primary axonal injury in glaucoma. Distortions within the LC are thought to promote the blockade of axoplasmic flow within the optic nerve fibers that contributes to glaucomatous optic neuropathy. Recently, developed enhanced-depth imaging (EDI) spectral domain-optical coherence tomography (SD-OCT) or swept-source OCT had demonstrated that the LC moves anteriorly (reduction of LC depth) after IOP lowering in glaucoma patients. These findings together indicate that increase of the LC posterior displacement is a principle component of glaucomatous optic neuropathy, and LC depth may vary in relation with IOP-related stress in human glaucoma patients. Moreover, it has been demonstrated that the displacement of the LC may precede early surface-detected structural damage and early retinal nerve fiber layer loss in experimental glaucoma. Some studies have found that disc hemorrhage is related with LC defect.

18.3.6.2 BMO-MRW (Bruch's Membrane Opening Minimum Rim Width) (Fig. 18.23)

Minimum distance from the inner opening of the BMO to the internal limiting membrane (ILM) is defined as BMO-MRW. It provides stable borders

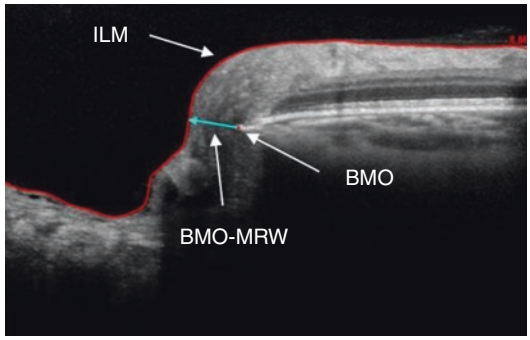


Fig. 18.23 Example of BMO-MRW. It is defined as minimum distance from the inner opening of the BMO to the ILM

and a geometrically more accurate assessment of neuroretinal rim tissue. Recent studies on BMO-MRW provide better diagnostic performance for glaucoma than conventional neuroretinal rim parameters. Moreover, it has been reported that BMO-MRW had a stronger association with visual field than other optic disc parameters or RNFL thickness.

18.3.7 Optical Coherence Tomography Angiography in Glaucoma

OCTA is used to find micro-blood vessels by detecting OCT images twice in the same area to find red blood cell-like particles and converting them into signals. The OCTA is expected as a noninvasive device showing the blood vessels of the retina and the choroid. And it can be potentially a good way to tell how blood disorders are involved in the onset and progression of glaucoma.

18.3.7.1 Pathologic Significance of Blood Flow Observed in OCTA (Fig. 18.24)

Recently, several studies have documented a decrease in microvascularity in the retina and microvascular loss in the peripapillary choroid of OCTA. It is not known whether these disorders occur before or after glaucoma, and this may be the result of a longitudinal study.

18.3.7.2 Diagnostic Usefulness of Microvascular Reduction of Retinal Layer

The decrease in retinal blood vessel density around the peripapillary and macula is reported to be similar to or slightly less than the decrease in thickness of peripapillary RNFL or macular retinal ganglion layer using OCT. Therefore, OCTA might not replace OCT for evaluation of glaucomatous damage.

18.4 Optical Coherence Tomography in Anterior Segment

With the optical coherence tomography (OCT), cross-sectional images of the cornea and anterior segment structures are produced with optical backscattering of light in fashion similar to B-scan ultrasound examination. Scattering is a fundamental property of a heterogeneous medium and occurs because of variations in the refractive index within the tissue. The time delay of the returning light and intensity differences of the infrared light in OCT is determined indirectly by the method of low-coherence interferometry. Optical interferometry is the technique of superimposing two or more waves to detect difference between them and is used to determine the distance to reflective structures within the eye. As the OCT uses a non-contact image acquisition method, this technique is efficient and noninvasive (Fig. 18.25).

Anterior segment OCT systems are categorized by wavelength of light sources. Due to the different light sources, there are some differences between the two groups. A longer wavelength system of 1310 nm wavelength provides deeper penetration, which result in reduced scattering and less signal loss in opaque media, and allows deeper penetration through sclera and limbus for the visualization of the scleral spur and iridocorneal angle (Visante OCT, Carl Zeiss Meditec, Dublin, CA; SL-OCT, Heidelberg Engineering, Heidelberg, Germany; CASIA, Tomey, Nagoya, Japan). On the contrary, a shorter wavelength

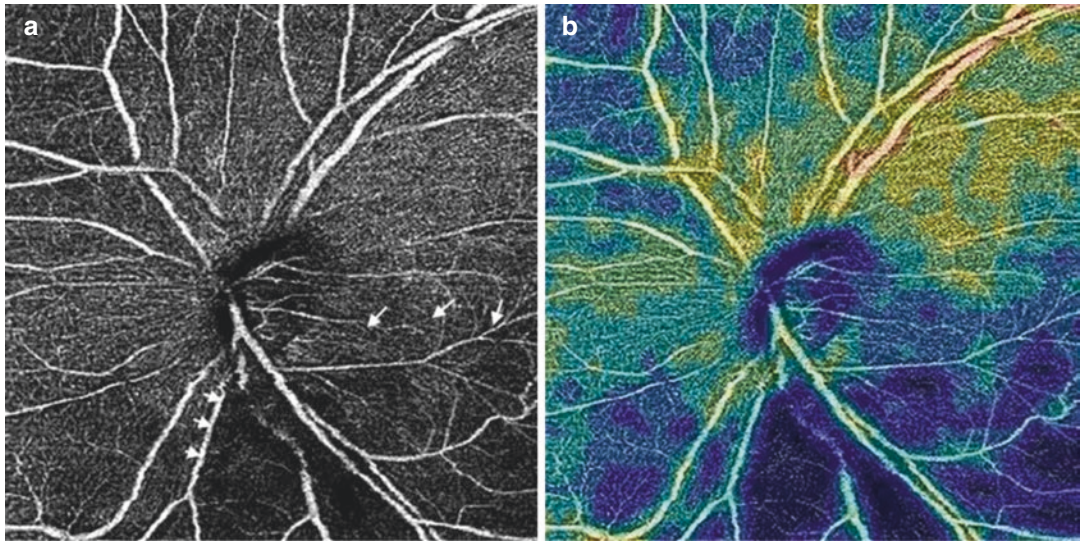


Fig. 18.24 A case of inferior microvascular decrease in glaucoma patient using OCT angiography. (**a**) Radial peripapillary capillary network image by OCTA, white arrows indicate inferior microvascular decrease in RNFL layer. (**b**) Vascular density map shows microvascular decrease in the area corresponding to the area with RNFL defect

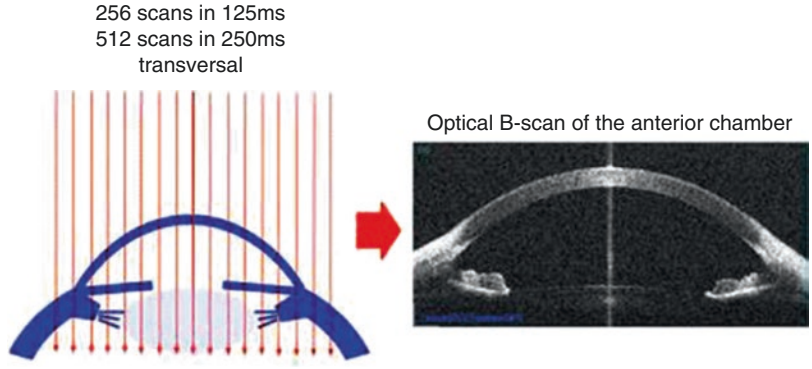


Fig. 18.25 Image acquisition principle of anterior segment optical coherence tomography (OCT)

system is converted from a retinal scanner using 830 nm and provides a higher axial resolution, but its imaging depth is limited (Spectralis, Heidelberg Engineering GmbH, Heidelberg, Germany; RTVue, Optovue, Inc., CA, USA; Cirrus OCT, Carl Zeiss Meditec, Oberkochen, Germany).

Anterior segment OCT can be also categorized by its platforms, time domain OCT (Visante OCT, Carl Zeiss Meditec, Dublin, CA; SL-OCT, Heidelberg Engineering, Heidelberg, Germany) and spectral domain OCT (Spectralis, Heidelberg Engineering GmbH, Heidelberg, Germany; RTVue, Optovue, Inc., CA, USA; Cirrus OCT, Carl Zeiss Meditec, Oberkochen, Germany). Unlike spectral domain OCT being freed from the limitations of a moving reference mirror, image capture speed of time domain OCT is limited by the velocity of mechanical movement of the reference mirror, which results in 10 to 100 times faster image acquisition speed in spectral domain OCT. On the other hand, time domain OCT enables wider area of capture in a single image, whereas spectral domain OCT processes only a small area of the anterior segment.

Recently, ultrahigh-resolution OCT with resolution of 1–4 μm and scan width of 5–12 mm has been introduced. Improved axial resolution was

attained by using a light source with a broad bandwidth of more than 100 μm which enables the precise imaging of the individual corneal and conjunctiva layers and a spectrometer that can detect the fringes reflected from both reference and sample arms.

Anterior segment OCT provides higher image resolution compared to high-frequency ultrasound biomicroscopy (UBM). Image resolution is approximately less than 10 um, compared to 35–70 μm for UBM. The scanning process is much faster compared to the UBM, 400 frames per second (fps) versus 8 fps. The image acquisition time is less than a few seconds and does not require an expert examiner. The software of recent anterior segment OCT system enables easy measurement of anterior segment structures, including anterior chamber depth, anterior angles, and anterior chamber diameter. Like the topography system, OCT is designed to assist a cataract and refractive practice, as well as a glaucoma practice.

The image acquisition in anterior segment OCT is similar to traditional retinal OCTs. The examination is performed with the patient in a sitting position. Because of non-contact procedure, topical anesthesia is unnecessary. To get a high-quality scan, particularly in vertical scans, wide palpebral apertures are required. Sometimes it is necessary to lift the eyelid to enlarge the palpebral apertures to get an OCT scan unobstructed. The OCT machine provides an internal fixation. The patient is asked to look at the imaging aperture, which will always be straight ahead, and focus on the center of fixation point. Center the pupil by using the X-Y controls to move the chin rest or clicking controls in the internal software. After the patient's distance adjustment is made, the desired scan is taken. The corneal images are subsequently analyzed by the software of each device.

When scanning the anterior chamber structures, the patient is asked to fixate on the external fixation target. This moves the eye position to expose the limbus optimally. Further adjust the eye position to reveal the corneoscleral junction. Center the scan on the corneal limbus. OCT image should show the top of the cornea and should be almost horizontally aligned. A slight tilt is acceptable and can improve visualization of angle structures (Figs. 18.26 and 18.27).

For the anterior segment examination with Spectralis OCT, it requires of an add-on lens (Spectralis OCT anterior segment module) and dedicated software

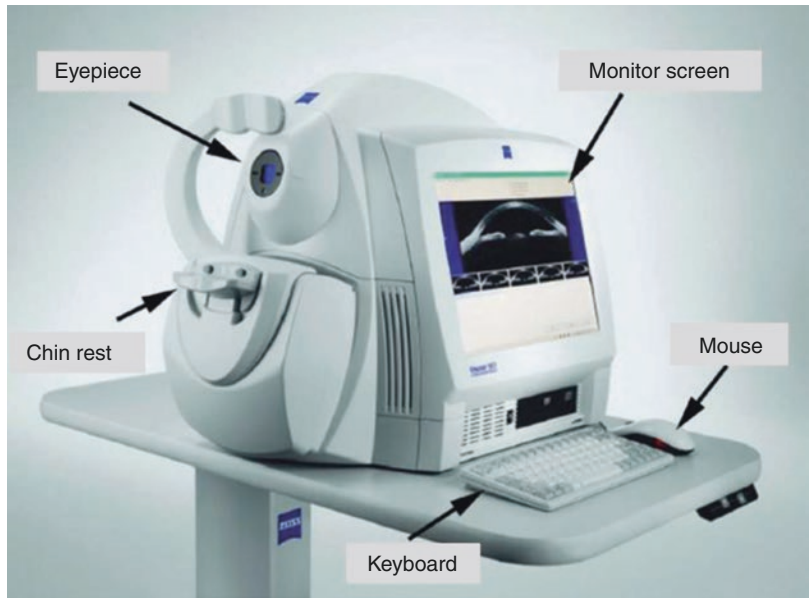


Fig. 18.26 External configuration of anterior segment OCT, Visante OCT (Carl Zeiss)

First, replace the preexisting module to the Spectralis OCT anterior segment module. Fix the adjustment knob to 0 mm. Set the internal mode according to the ocular part to be examined (cornea, sclera, or anterior segment structures). As the slit-lamp microscopy, align the patient's forehead and chin with the height of the imaging aperture and position the face direction and eye position properly. Use the control stick to adjust the patient's anterior segment to the monitor image and then adjust the central bright light centered to the pupil. Use "line scan" and "volume scan" to set scan length, tilting, volume width, and height. Make sure that the line of the corneal edge and the line of the pupil edge are at the center, and if the image appears clearly, acquire and store the image for the analysis.

18.4.1 OCT Section of the Normal Cornea

Figure 18.28 shows the horizontal OCT section of the normal cornea. The ophthalmologist can easily distinguish the eye structures including corneal epithelium (a), Bowman's layer (b), corneal stroma (c), Descemet's membrane (d), and endothelium (e)

Fig. 18.27 Anterior segment module for Spectralis OCT

18.4.2 Refractive Surgery and Ectatic Disorders

Preoperative evaluation of refractive patients shows exquisite detail of the anterior segment, particularly of the cornea, iris, and anterior chamber angle. Limbus to limbus pachymetry provides important information of a patient for refractive surgery (Fig. 18.29).

In postoperative patients, the "flap tool" is used to measure the thickness of LASIK flap and residual stromal bed. Residual stromal bed thickness provides the surgeon valuable information to avoid corneal ectasia (Fig. 18.30), and flap tool is also important to visualize the LASIK flap, flap interface (flap-stroma relationship), and flap displacement (Fig. 18.31).

The quantitative evaluation of the cornea using anterior segment OCT before intrastromal ring segment implantation reduces postoperative corneal complications such as epithelial stromal breakdown or implant perforation into the anterior chamber. Anterior segment OCT allows the determination of the precise depth and position of the intrastromal corneal ring segments when placing the implants in patients with keratoconus.

Recently, corneal collagen cross-linking has become the principal method to increase corneal stiffness and stabilize the ectatic cornea leading to inhibition of progression for keratoconus

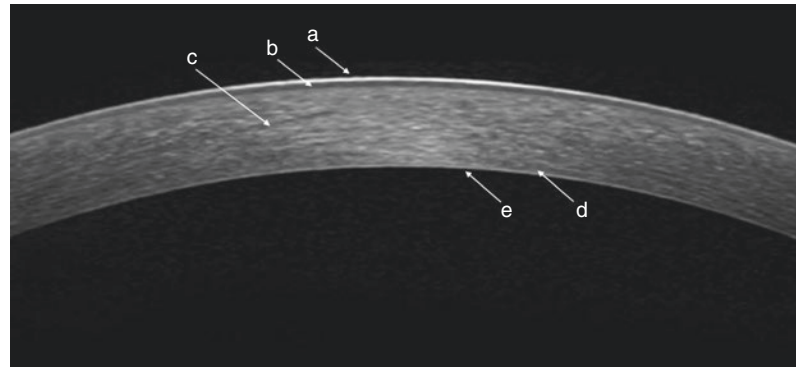


Fig. 18.28 OCT cross-sectional image of the normal cornea: epithelium (**a**), Bowman's layer (**b**), corneal stroma layer (**c**), Descemet's membrane (**d**), and endothelium (**e**)

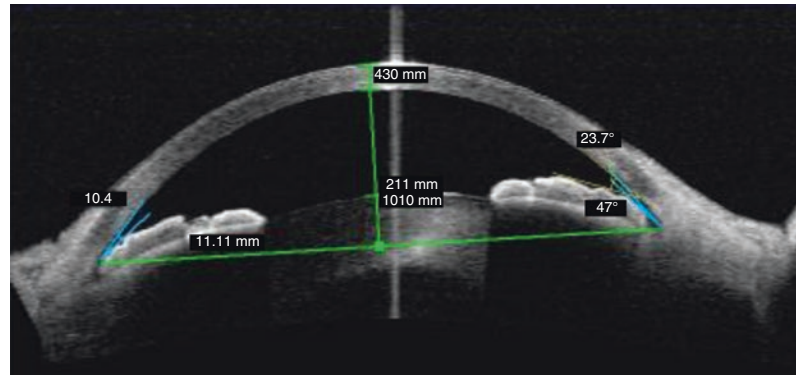


Fig. 18.29 Anterior segment OCT showing detailed parameters of the anterior segment. Vertical green line shows central corneal thickness, anterior chamber depth, and the lens vault, respectively. Horizontal green line implies anterior chamber width (scleral spur to scleral spur). Angle between two yellow lines indicates anterior chamber angle

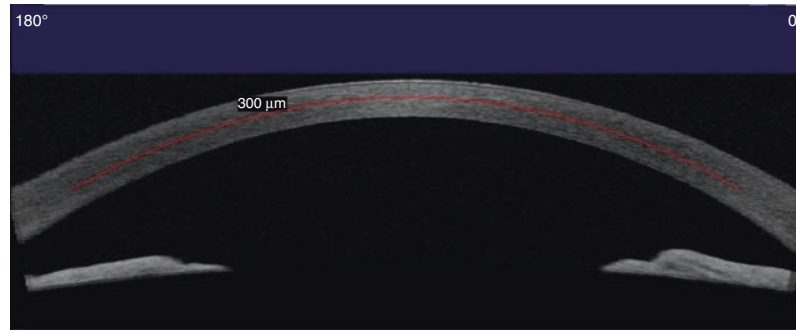


Fig. 18.30 Anterior segment OCT provides expected residual stromal bed thickness before the surgery. Red line indicating expected residual stromal thickness as 300 um

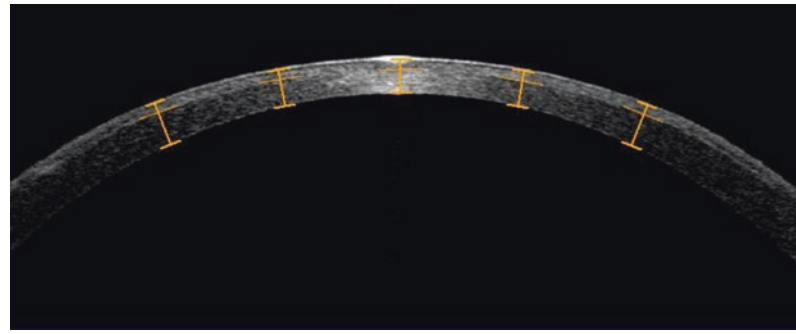


Fig. 18.31 Anterior segment OCT shows detailed image of LASIK flap and flap interface

and postoperative refractive surgery ectasia. A corneal stromal demarcation line after corneal collagen cross-linking indicates the cross-linked anterior corneal stroma and the untreated posterior stroma. Anterior segment OCT enables visualization of the demarcation line that represents the "effective depth of corneal collagen cross-linking" as hyperreflective line.

18.4.3 Assessment of Descemet's Membrane

Descemet's membrane detachment is considered as one of the major causes of corneal edema after intraocular surgery or ocular trauma (Fig. 18.32). Anterior segment OCT provides detailed status of the Descemet's membrane.

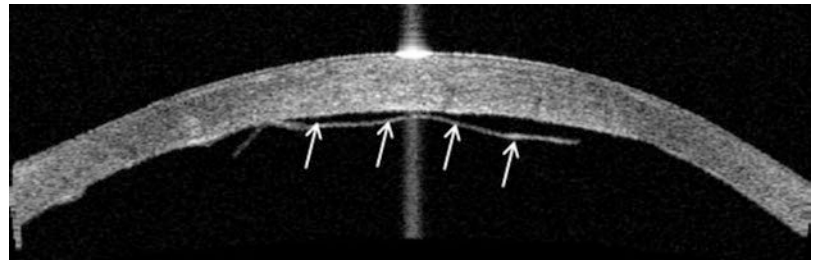


Fig. 18.32 Descemet's membrane detachment (arrows) after cataract surgery

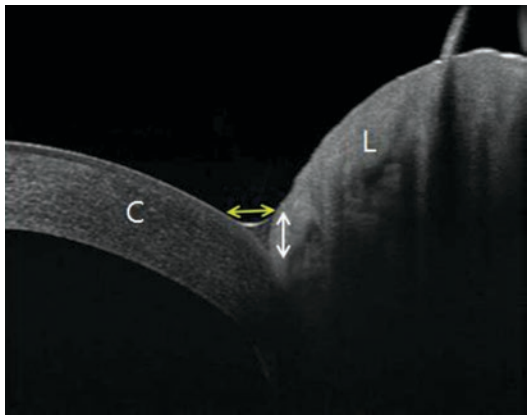


Fig. 18.33 Tear meniscus measurement. Anterior segment OCT image of the lower tear meniscus showing the tear meniscus height (yellow arrow) and depth (white arrow) (C, cornea; L, lower lid)

18.4.4 Tear Meniscus Measurement

Most of the conventional tests concerning dry eye, including the Schirmer test or corneal fluorescein staining, are invasive and are affected by the examiner. Tear meniscus measurement using anterior segment OCT is a noninvasive test, and it provides objective results compared to the conventional dry eye tests. The tear meniscus height, tear meniscus depth, and tear meniscus area can be examined and analyzed by the anterior segment OCT (Fig. 18.33).

18.4.5 Keratoplasty Patient Evaluation

Anterior segment OCT gives detailed information about the cornea after keratoplasty surgeries, including penetrating keratoplasty, deep anterior lamellar keratoplasty (DALK), Descemet's membrane endothelial keratoplasty (DMEK), and Descemet's membrane stripping automated endothelial keratoplasty (DSAEK). Especially, anterior segment OCT is an effective tool for the detection of an early graft detachment after DMEK or DSAEK that needs early postoperative managements (Fig. 18.34). In addition, "flap tool" may be used to measure precut endothelial keratoplasty in storage media or to follow up of the postoperative patients.

In DALK, anterior segment OCT allows precise evaluation of the corneal depth to achieve an optimal descemetic or pre-descemetic dissection.

18.4.6 Phakic Refractive Implant Patient Evaluation

Anterior segment OCT is particularly useful in phakic refractive implant patients such as implantable collamer lens (ICL) or iris-claw phakic intraocular lens. Distance from the corneal endothelium to the anterior surface of lens, anterior chamber angle width, white-to-white measurement, and sulcus-to-sulcus measurement is important especially in iris-claw phakic intraocular lens implanted patients (Fig. 18.35).

Anterior segment OCT has the ability to calculate the degree of lens vault over the crystalline lens after ICL implantation (Fig. 18.36). Excessive vaulting of a posterior chamber may cause the iris diaphragm to bulge forward, leading to the anterior chamber angle narrowing. On contrary, the lack of ICL vaulting may result in

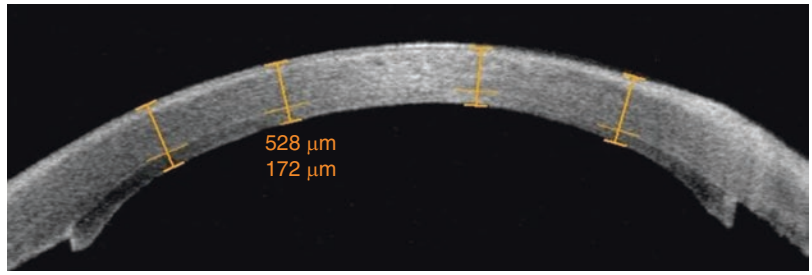


Fig. 18.34 Anterior segment OCT provides detailed status of the endothelial graft. Anterior segment OCT shows that the 172 μm thickness endothelial graft is well attached and the thickness of the cornea is 528 μm

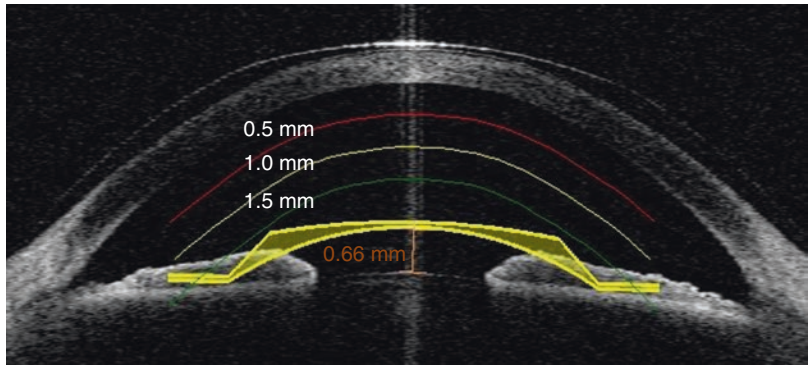


Fig. 18.35 Distance from the corneal endothelium to the expected location of the phakic refractive implant, measured by anterior segment OCT. The yellow boundary indicates iris-claw phakic intraocular lens. Vault to crystalline lens is automatically calculated as 0.6 mm. The distance from the corneal endothelium to the implant is indicated in units of 0.5 mm (safety rainbow)

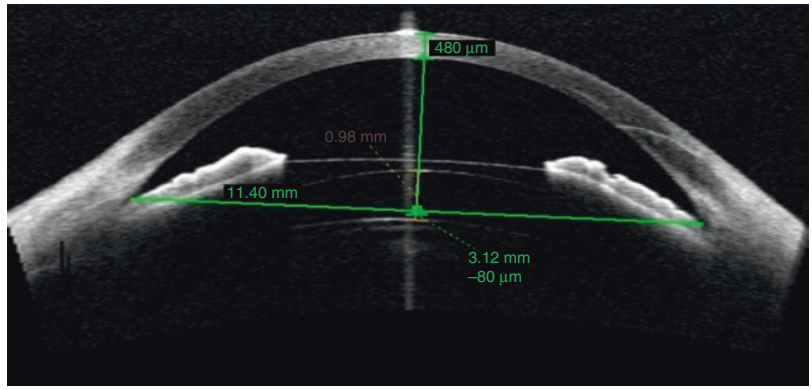


Fig. 18.36 Measurement of lens vault over the crystalline lens after ICL implantation. Vertical green line shows central corneal thickness and the anterior vault (3.12 mm). Vertical pink line indicates the vault of implanted ICL as 0.98 mm

an anterior subcapsular cataract. The recommended vault over the crystalline lens of the ICL is approximately 350 μm in myopia and 250 μm in hyperopia.

Suggested Reading

Bald M, Li Y, Huang D. Anterior chamber angle evaluation with fourier-domain optical coherence tomography. J Ophthalmol. 2012;2012:103704.

Bujak MC, Yiu S, Zhang X, Li Y, Huang D. Serial measurement of tear meniscus by FD-OCT after instillation of artificial tears in patients with dry eyes. Ophthalmic Surg Lasers Imaging Retina. 2011;42:308–13.

Cheung CY, Liu S, Weinreb RN, et al. Dynamic analysis of iris configuration with anterior segment optical coherence tomography. Invest Ophthalmol Vis Sci. 2010;51:4040–6.

Chow VW, Agarwal T, Vajpayee RB, Jhanji V. Update on diagnosis and management of Descemet's membrane detachment. Curr Opin Ophthalmol. 2013;24:356–61.

Czajkowski G, Kaluzny BJ, Laudencka A, Malukiewicz G, Kaluzny JJ. Tear meniscus measurement by

spectral optical coherence tomography. Optom Vis Sci. 2012;89:336–42.
DeLeón-Ortega JE, Arthur SN, McGwin G, Xie A, Monheit BE, Girkin CA. Discrimination between glaucomatous and nonglaucomatous eyes using quantitative imaging devices and subjective optic nerve head assessment. Invest Ophthalmol Vis Sci. 2006;47(8):3374–80.
Goldsmith JA, Li Y, Chalita MR, et al. Anterior chamber width measurement by high-speed optical coherence tomography. Ophthalmology. 2005;112:238–44.
Han SB, Liu YC, Noriega KM, Mehta JS. Applications of anterior segment optical coherence tomography in cornea and ocular surface diseases. J Ophthalmol. 2016;2016:4971572.
Harizman N, Zelefsky JR, Ilitchev E, Tello C, Ritch R, Liebmann JM. Detection of glaucoma using operator-dependent versus operator-independent classification in the Heidelberg retinal tomograph-III. Br J Ophthalmol. 2006;90(11):1390–2.
Hee MR, Puliafito CA, Wong C, et al. Optical coherence tomography of macular holes. Ophthalmology. 1995;102:748–56.
Hee MR, Maumal CR, Puliafito CA, et al. Optical coherence tomography of age-related macular degeneration and choroidal neovascularization. Ophthalmology. 1996;103:1260–70.
Hong JX, Sun XH. Clinical applications and limitations of anterior segment optical coherence tomography. Zhonghua Yan Ke Za Zhi. 2010;46:476–80.
Huang D, Li Y, Radhakrishnan S. Optical coherence tomography of the anterior segment of the eye. Ophthalmol Clin N Am. 2004;17:1–6.
Izatt JA, Hee MR, Swanson EA, et al. Micrometer-scale resolution imaging of the anterior eye in vivo with optical coherence tomography. Arch Ophthalmol. 1994;112:1584–9.
Kiernan DF, Mieler WF, Hariprasad SM. Spectral-domain optical coherence tomography: a comparison of modern high-resolution retinal imaging systems. Am J Ophthalmol. 2010;149:18–31.
Knecht PB, Kaufmann C, Menke MN, Watson SL, Bosch MM. Use of intraoperative Fourier-domain anterior segment optical coherence tomography during Descemet stripping endothelial keratoplasty. Am J Ophthalmol. 2010;150:360–5. e2.
Kymionis GD, Grentzelos MA, Plaka AD, et al. Evaluation of the corneal collagen cross-linking demarcation line profile using anterior segment optical coherence tomography. Cornea. 2013;32:907–10.
Lang SJ, Cucera A, Lang GK. Applications of optical coherence tomography in the anterior segment. Klin Monatsbl Augenheilkd. 2011;228:1086–91.
Leite MT, Rao HL, Zangwill LM, Weinreb RN, Medeiros FA. Comparison of the diagnostic accuracies of the Spectralis, Cirrus, and RTVue optical coherence tomography devices in glaucoma. Ophthalmology. 2011;118:1334–9.
Li H, Leung CK, Cheung CY, et al. Repeatability and reproducibility of anterior chamber angle measurement with anterior segment optical coherence tomography. Br J Ophthalmol. 2007a;91:1490–2.
Li Y, Netto MV, Shekhar R, Krueger RR, Huang D. A longitudinal study of LASIK flap and stromal thickness with high-speed optical coherence tomography. Ophthalmology. 2007b;114:1124–32.
Lim SH. Clinical applications of anterior segment optical coherence tomography. J Ophthalmol. 2015;2015:605729.
Lim LS, Aung HT, Aung T, Tan DT. Corneal imaging with anterior segment optical coherence tomography for lamellar keratoplasty procedures. Am J Ophthalmol. 2008;145:81–90.
Lisboa R, Leite MT, Zangwill LM, Tafreshi A, Weinreb RN, Medeiros FA. Diagnosing preperimetric glaucoma with spectral domain optical coherence tomography. Ophthalmology. 2012;119(11):2261–9.
Maeda N. Optical coherence tomography for corneal diseases. Eye Contact Lens. 2010;36:254–9.
Manassakorn A, Nouri-Mahdavi K, Caprioli J. Comparison of retinal nerve fiber layer thickness and optic disk algorithms with optical coherence tomography to detect glaucoma. Am J Ophthalmol. 2006;141(1):105–15. e1.
Moutsouris K, Dapena I, Ham L, Balachandran C, Oellerich S, Melles GR. Optical coherence tomography, Scheimpflug imaging, and slit-lamp biomicroscopy in the early detection of graft detachment after Descemet membrane endothelial keratoplasty. Cornea. 2011;30:1369–75.
Nagy ZZ, Filkorn T, Takacs AI, et al. Anterior segment OCT imaging after femtosecond laser cataract surgery. J Refract Surg. 2013;29:110–2.
Narayanaswamy A, Sakata LM, He MG, et al. Diagnostic performance of anterior chamber angle measurements for detecting eyes with narrow angles: an anterior segment OCT study. Arch Ophthalmol. 2010;128:1321–7.
Pallikaris IG, Kymionis GD, Astyrakakis NI. Corneal ectasia induced by laser in situ keratomileusis. J Cataract Refract Surg. 2001;27:1796–802.
Puliafito CA, Hee MR, Lin CP, et al. Imaging of macular diseases with optical coherence tomography. Ophthalmology. 1995;102:217–29.
Radhakrishnan S, Goldsmith J, Huang D, et al. Comparison of optical coherence tomography and ultrasound biomicroscopy for detection of narrow anterior chamber angles. Arch Ophthalmol. 2005;123:1053–9.
Ramos JL, Li Y, Huang D. Clinical and research applications of anterior segment optical coherence tomography - a review. Clin Exp Ophthalmol. 2009;37:81–9.
Randleman JB, Woodward M, Lynn MJ, Stulting RD. Risk assessment for ectasia after corneal refractive surgery. Ophthalmology. 2008;115:37–50.
Reinstein DZ, Archer TJ, Gobbe M. Comparison of residual stromal bed thickness measurement among very high-frequency digital ultrasound, intraoperative handheld ultrasound, and optical coherence tomography. J Refract Surg. 2012;28:42–7.
Reus NJ, Lemij HG. Diagnostic accuracy of the GDx VCC for glaucoma. Ophthalmology. 2004;111(10):1860–5.
Reus NJ, Colen TP, Lemij HG. Visualization of localized retinal nerve fiber layer defects with the GDx with individualized and with fixed compensation

of anterior segment birefringence. Ophthalmology. 2003;110(8):1512–6.

Rio-Cristobal A, Martin R. Corneal assessment technologies: current status. Surv Ophthalmol. 2014;59:599–614.

Rosas Salaroli CH, Li Y, Huang D. High-resolution optical coherence tomography visualization of LASIK flap displacement. J Cataract Refract Surg. 2009;35:1640–2.

Rosas Salaroli CH, Li Y, Zhang X, et al. Repeatability of laser in situ keratomileusis flap thickness measurement by Fourier-domain optical coherence tomography. J Cataract Refract Surg. 2011;37:649–54.

Sommer A, Katz J, Quigley HA, Miller NR, Robin AL, Richter RC, et al. Clinically detectable nerve fiber atrophy precedes the onset of glaucomatous field loss. Arch Ophthalmol. 1991;109(1):77–83.

Spaide RF, Fujimoto JG, Waheed NK. Image artifacts in optical coherence tomography angiography. Retina. 2015a;35:2163–80.

Spaide RF, Klancnik JM Jr, Cooney MJ. Retinal vascular layers imaged by fluorescein angiography and optical coherence tomography angiography. JAMA Ophthalmol. 2015b;133:45–50.

Sung MS, Yoon KC. Evaluation of graft-host interface after penetrating keratoplasty using anterior segment optical coherence tomography. Jpn J Ophthalmol. 2014;58:282–9.

Wang BS, Wang NL. Applications of anterior segment optical coherence tomography in ophthalmology. Zhonghua Yan Ke Za Zhi. 2008;44:185–8.

Wilkins JR, Puliafito CA, Hee MR, et al. Characterization of epiretinal membranes using optical coherence tomography. Ophthalmology. 1996;103:2142–51.

Wollstein G, Ishikawa H, Wang J, Beaton SA, Schuman JS. Comparison of three optical coherence tomography scanning areas for detection of glaucomatous damage. Am J Ophthalmol. 2005;139(1):39–43.

Yeh RY, Quilendrino R, Musa FU, Liarakos VS, Dapena I, Melles GR. Predictive value of optical coherence tomography in graft attachment after Descemet's membrane endothelial keratoplasty. Ophthalmology. 2013;120:240–5.

Electrophysiologic Test

19

Jae-Jung Lee and Sung-Who Park

The electrophysiological examination is to record the electrical phenomena of the visual pathway and to determine whether the path from the retina to the visual cortex is abnormal. There are the full-field flash electroretinogram (ERG), the multifocal electroretinogram (mfERG), the pattern electroretinogram (pattern ERG or PERG), the electrooculogram (EOG), and the cortical-derived visual evoked potential (VEP). There was a lot of confusion in the interpretation of the results due to the difference in the examination environment and setting depending on the model or laboratory. Recently, the International Society of Clinical Electrophysiology for Vision (ISCEV) has provided standards for the electrophysiological examinations of the machine, the measurement method, and the interpretation and makes the examination and the reading improved in the area of ophthalmology. This chapter focuses on specific testing methods. Detailed specifications for each procedure may be found in the appropriate ISCEV standards in the homepage of www.iscev.org.

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19.1 Electroretinography, ERG

Retinal function of eyes incapable of fundus exam because of corneal opacity, cataract, iris synechiae, and vitreous opacity could be evaluated by electroretinogram.

Differential diagnosis of night blindness whether progressive or non-progressive, differentiation of retinopathy similar to retinitis pigmentosa, diagnosis of non-pigmented retinitis pigmentosa, differential diagnosis of other retinal degenerations (multiple evanescent white dot syndrome, congenital stationary night blindness), and distinction between optic nerve disease and retinal disease could be evaluated by electroretinogram.

B-wave and oscillatory potential are sensitive to retinal blood circulation. Implicit time of oscillatory potential could be delayed at early phase in diabetic retinopathy. Amplitude of oscillatory potential and b-wave would be decreased in central retinal artery occlusion. Abnormality of a-wave would be helpful for discrimination of ophthalmic artery occlusion.

Generalized or localized abnormality, rod cell or cone cell abnormality, and outer retinal defect or inner retinal defect could be calculated by electroretinogram.

Visual disturbance may appear before the abnormal findings on the fundus examination, for example, the early phase of retinitis pigmentosa, drug toxicity, and diabetic retinopathy. Electroretinogram could be helpful for young

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children and psychotic. Electroretinogram is very objective test so abnormality in this test means impairment of the retina.

19.1.1 Principle and Methods

Electroretinogram detects the development of electric potentials in the retina when it is stimulated by the light (Fig. 19.1). Regardless of the conformity of the eyeballs, there is always a stationary electric current made by anode of corneal plane and cathode of posterior pole. This stationary electric current is converted to active potential by light stimulation in the retina. Serial changes of active potentials of retina could be recorded as a waveform in electroretinogram. This wave could be changed by adaptation state of the retina, angle and color of stimulated light, and duration and the location of stimulation. Amplitude of active potential is proportional to the area of the normal retina.

Sufficient pupil dilatation should be needed. Uniform stimulation to the entire retina should be motivated using Ganzfeld stimulator (Fig. 19.2). Light stimulation of 0.01 and 3.0 cd•s/m^2 is

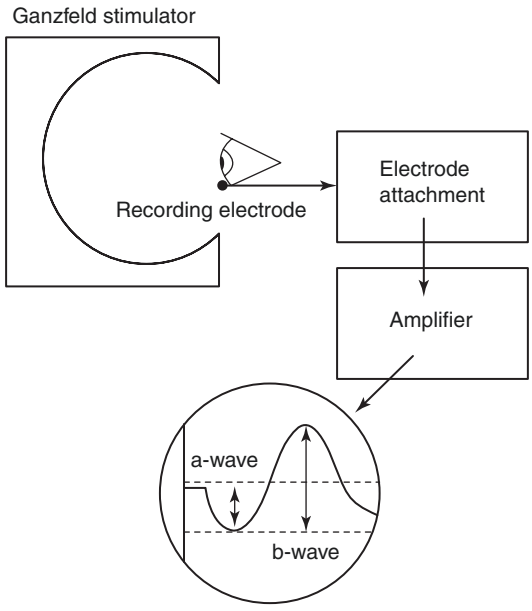


Fig. 19.1 Diagram of ERG

Fig. 19.2 Ganzfeld stimulator of ERG machine

ISCEV standards. To evaluate specific retina lesion, direct stimulator is needed for localized light stimulation. The distance between the light source and the eye should be kept constant because the intensity of the stimulated light is inversely proportional to the square of distance.

There are recording electrode, reference electrode, and ground electrode. There are many types of recording electrodes which record the change of electroretinogram by contact to the cornea or conjunctiva (Fig. 19.3). Among them, Burian-Allen contact lens is the most popular one for its safety and ease of use. Disturbance of eyelid movement is minimized because speculum and recording electrode are integrated. Reference electrode is not needed because reference electrode is attached to recording electrode. However, Burian-Allen contact lens is so expensive that it should be reused many times after disinfection. It is difficult to use for people with small eyelid gaps because the lens is large. Disposable recording electrodes called ERG jet are also widely used. It is affected by eyelid movement and has the disadvantage that the contact lens can move during the examination. Common problems for contact lens-type

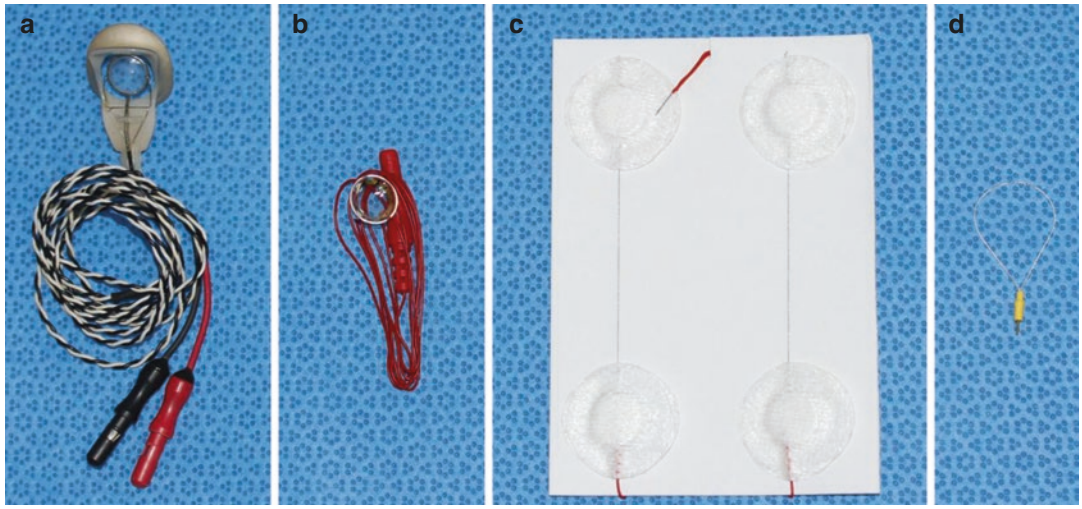


Fig. 19.3 Recording electrodes of ERG: (**a**) Burian-Allen electrode, (**b**) ERG jet, (**c**) DTL electrode, and (**d**) H-K loop

electrode are corneal abrasion and impossibility for pattern electroretinogram because of poor clarity. DTL electrode and skin electrode could be used for children.

Full dilatation of the pupil is needed. Smoking is prohibited during examination because it affects the waveform. Children with poor cooperation should be put to sleep while testing. Alcohol or Skinpore is applied to the skin for removal of oily material, and electrode is attached tightly with electrode glue. Reference electrode as anode is placed at both lateral canthal areas where ISCEV recommends. Ground electrode is attached to the forehead or earlobe. Electrode should be blocked against the light because of photoelectric effect.

Dark adaptation should be done sufficiently 20 min or more. Over 30 min of dark adaptation is needed if the patient is tested immediately after being in bright outdoors. After dark adaptation, cathode contact lens is applied with methylcellulose after topical anesthesia under dim red light. For children, pediatric corneal electrode or skin electrode should be prepared. Dark-adapted 0.01 ERG, dark-adapted 3.0 ERG, and dark-adapted 3.0 oscillatory potential are recorded respectively. Light adaptation should be done over 10 min. Light-adapted 3.0 ERG and light-adapted 3.0 flicker ERG are recorded.

19.1.2 Characteristics of ERG Waveform and Its Origin

Electricity flows through resistance by voltage difference. Electricity in ERG develops in retinal cells. Extracellular fluid and vitreous play a role as resistance (Fig. 19.4). Photoreceptor consists of cone and rod cell and its characteristics are shown in Table 19.1. Standard ERG waveform, amplitude and the definition of implicit time are noted in Fig. 19.5.

19.1.2.1 A-Wave

A-wave is the first negative wave which reflects the function of photoreceptors. Rod cell potential is not shown in ERG because it decreases and recovers so slowly that it is obscured by b-wave. Cone cell potential decreases and increases so rapidly that definite negative wave is recorded on the 3.0 cd•s/m^2 stimulation. Amplitude of a-wave is defined as the difference between reference potential and the peak of negative potential (Fig. 19.5).

19.1.2.2 B-Wave

B-wave is positive wave which appears after a-wave originates from bipolar cell. Amplitude of b-wave is defined as difference between the trough of the a-wave and the peak of the b-wave (Fig. 19.5).

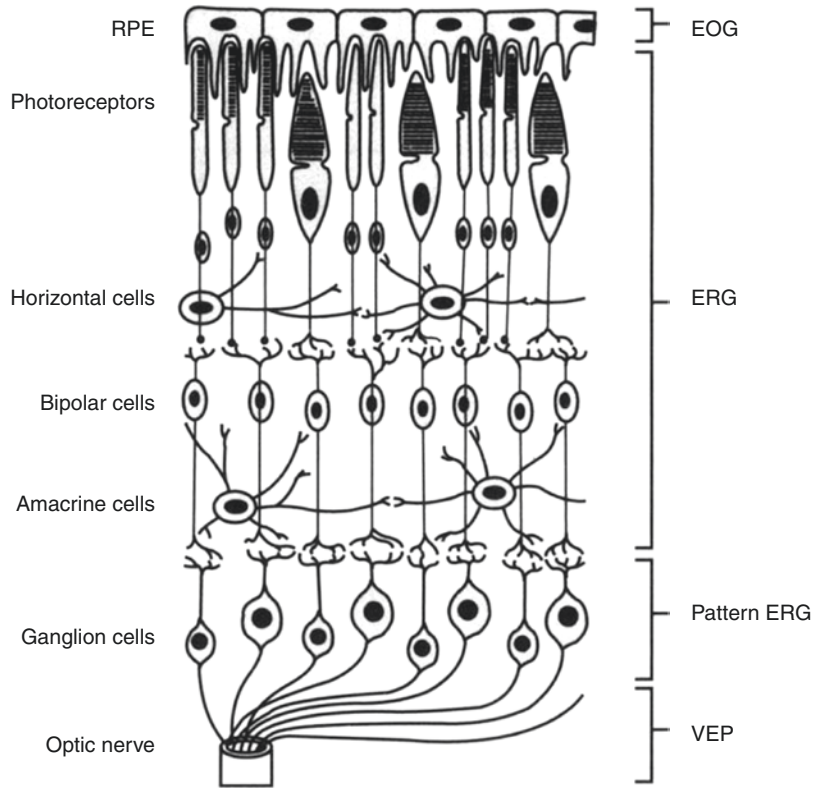


Fig. 19.4 Retinal layers and the origin of development of each electric potential

Table 19.1 Characteristics of cone and rod cell

	Cone cell	Rod cell
Color	Recognition	Unrecognition
Vision in darkness	Bad	Good
Maximal intensity location	Fovea	15–20° from the fovea
Number of cells	7,000,000	120,000,000
Sensitivity difference according to stimulus direction	Recognition	Unrecognition
Maximal sensitivity wavelength	555 nm	510 nm
Stimulus frequency of fused flicker	High	Low

19.1.2.3 Oscillatory Potential

Oscillatory potential is a duplicated wave shown at the elevation part of b-wave. It can be separated by filtering high-frequency wave and low-frequency wave. This small wavy electricity is induced from inner plexiform layer and originated from negative feedback by amacrine cell. It is clearly shown when cone cell and rod cell are simultaneously stimulated by 3.0 cd•s/m^2 stimulation in dark adaptation (Fig. 19.5).

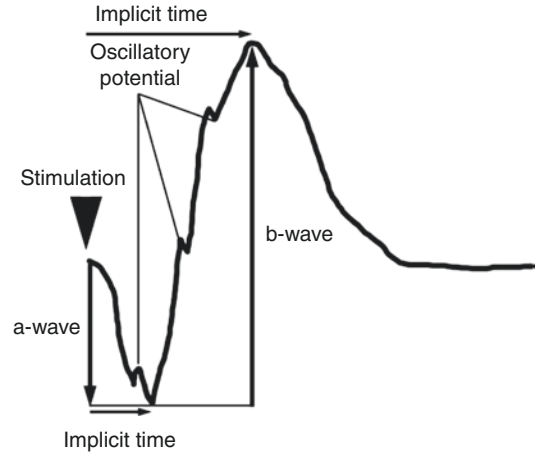


Fig. 19.5 ERG a- and b-wave, amplitude, and implicit time

19.1.2.4 Early Receptor Potential

When the stimulated light is very strong, minute potential change derived from outer segment of photoreceptor at the beginning downward part of a-wave is observed. It is not shown in standard ERG and is confused with wave generated by photoelectric effect using metallic recording electrode.

19.1.2.5 C-Wave and Off-Effect

With long stimulation light, c-wave appears after b-wave, and off-effect of c-wave is recorded at the end of light stimulation.

19.1.3 Standard Electroretinogram (ISCEV 2015)

Standard ERG is performed in dome-shaped visual field stimulation device. Uniform light is illuminated to central retina 120° and the following five tests are performed (Fig. 19.6).

19.1.3.1 Dark-Adapted 0.01 ERG

Dark-adapted 0.01 ERG is previously called as scotopic ERG. This is the examination for detection of rod response. Minimum 20 min of dark adaptation is needed, and 0.01 cd•s/m^2 white flash light lower than the threshold of cone cell is evoked. Interval between flash lights is minimum 2 s. A-wave is not shown and large b-wave appears.

19.1.3.2 Dark-Adapted 3.0 ERG

Dark-adapted 3.0 ERG is also called as maximal combined response. When 3.0 cd•s/m^2 white flash light is applied after dark adaptation, a-wave including cone cell and rod cell and maximal b-wave are acquired. Interval between stimulation is minimum 10 s.

19.1.3.3 Dark-Adapted 10 ERG

In comparison with the dark-adapted 3 ERG, the dark-adapted 10 ERG is characterized by a larger a-wave with better definition of peak time, greater distinction of negative ERG waveforms, and enhanced oscillatory potential amplitudes. In addition, this ERG may give more reliable responses in patients with opaque media or immature retinae. The dark-adapted 10 ERG should be recorded after the dark-adapted 3.0 ERG, with an interval of at least 20 s between strong flash stimuli.

19.1.3.4 Dark-Adapted Oscillatory Potential

Dark-adapted oscillatory potential is simply called as oscillatory potential. After dark adaptation, cone cell and rod cell are simultaneously stimulated with 3.0 cd•s/m^2 white flash light, and interval between stimulations is minimum 15 s. Duplicated wave which appears at upper line of b-wave is separated by electric filter.

19.1.3.5 Light-Adapted 3.0 ERG

Light-adapted 3.0 ERG is called as photopic ERG or single flash cone response. After light adaptation, rod cell response is suppressed by 30 cd/m^2 background light, and 3.0 cd•s/m^2 white flash light is used for recording.

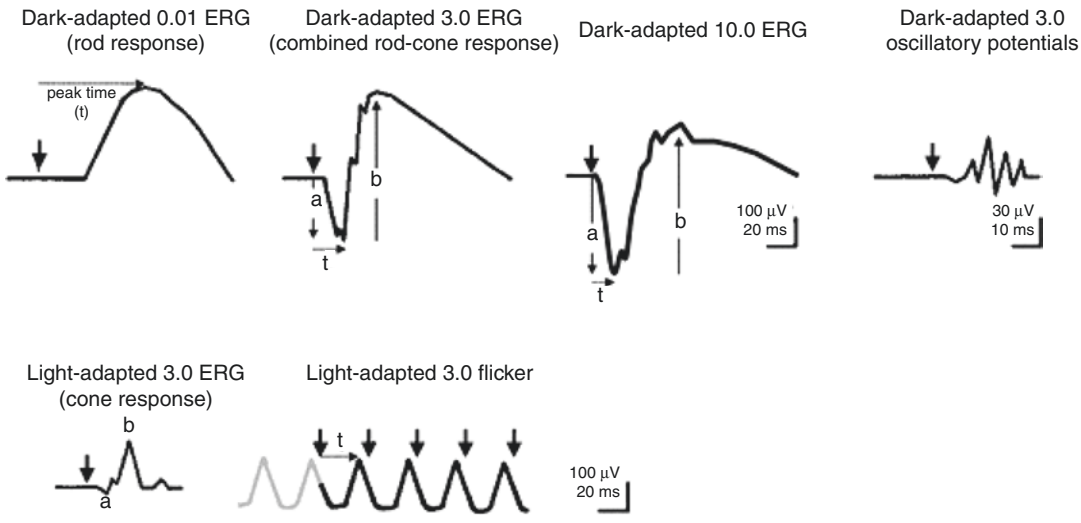


Fig. 19.6 ISCEV standard (ISCEV standard 2015 update)

19.1.3.6 Light-Adapted 3.0 Flicker

Light-adapted 3.0 flicker is previously called 30 Hz flicker. Rod cell can respond to stimulation below 20 Hz but cannot respond to stimulation over 30 Hz. Cone cell response can be selectively assessed by this feature. Classic sign waveform is shown, and a-wave and b-wave are not distinguished.

19.1.4 Abnormal Findings

The activity of nerve fiber layer and efferent inhibitory fiber of optic nerve are not recorded in ERG. Retinal vascularity and various nerve fiber circuits should be considered when analyzing ERG. ERG recording is the result from the entire retinal response, not localized response that lesion larger than 3 disc diameter is needed for changing recordings in ERG. B-wave and oscillatory potential may show abnormalities if there is photoreceptor abnormality, even if the bipolar cells or amacrine cells in the inner retina are normal.

Noise can be developed by poor attachment of electrode or problem with connecting electrode. Non-recordable waveform could be pathologic, but connecting status of electric line, problem with recording, or mechanical problem should be checked. Eyeball movement and photoelectric effect could make disturbed waves.

Strong stimulation light makes increment of amplitude and shortens implicit time. Dark adaptation time can affect the result but no change after 15 min. Effect of pupil diameter increases in weak stimulation. Ganzfeld stimulator is recommended for uniform stimulation on large area because the size of stimulated area can influence the result. Refractive error could be neglected except severe high myopia. Age can affect the result, and infant and old people show decrease of amplitude in a- and b-wave and elongation of implicit time.

19.1.4.1 Types of Abnormal ERG (Fig. 19.7)

Currently used ERG classification is determined according to relative relationship between a-wave

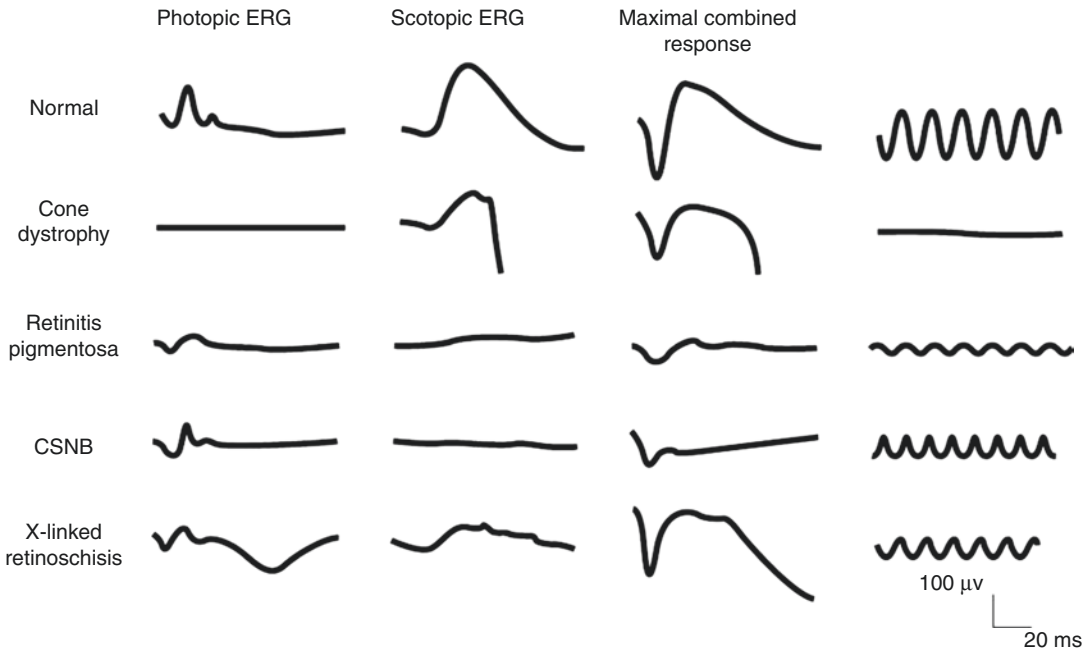


Fig. 19.7 Various ERG findings according to the type of disease

and b-wave. B-wave is selectively decreased in inner plexiform layer diseases.

Supernormal means that b-wave enlarged abnormally. This includes early phase of siderosis bulbi, hypertensive retinopathy, use of hallucinating drugs, and optic nerve atrophy.

Subnormal means that amplitudes of all waves are decreased over 30% difference compared to normal response and over 0.18 mV difference between both eyes. Diffuse retinal abnormality such as retinitis pigmentosa and localized retinal detachment shows subnormal.

Negative ERG means amplitude of b-wave is larger than a-wave (b/a < 1). Positive wave after a-wave cannot reach to early potential. Severe abnormality in middle retinal layer including bipolar cell shows negative ERG. This includes X-linked retinoschisis, central retinal artery occlusion, congenital stationary night blindness, quinidine toxicity, and Oguchi disease.

Non-recordable means no retinal function. This includes end-stage retinitis pigmentosa, total retinal detachment, ophthalmic artery occlusion, and Leber congenital night blindness.

Cone cell dystrophy shows subnormal scotopic ERG, but photopic ERG and flicker are selectively decreased or lost. Oscillatory potential abnormality represents decrease or loss of oscillatory potential or elongation of implicit time. This includes diabetic retinopathy and retinal artery occlusion.

19.1.5 Others

19.1.5.1 Focal ERG

Seven percent of cone cell presents in central macula that full-field ERG in age-related macular degeneration shows normal. Localized stimulation to macula is needed for analyzing macular function. Specific stimulator retinoscopy is used for examining posterior pole. First, rod cell is suppressed outside 10° from the fovea by bright light, and then 42 Hz rapid flickering white flash light is given to 4° area around the fovea. Hundreds of small focal ERG are recorded and analyzed in general.

19.1.5.2 Strong Flash ERG

Light stimulus stronger than standard flash is used for examination, and it is useful for eyes with media opacity.

19.2 Multifocal ERG, mfERG

In general, electroretinogram (ERG) is the response of the entire retina to stimulated light that it is not appropriate for the evaluation of localized retinal lesions. Focal ERG was developed to examine the localized retinal lesion to compensate for these shortcomings, but it is not commonly used because of difficulties in recording. Therefore, a new method known as VERIS (Visual Evoked Response Imaging System) to simultaneously record the multiple focal lesions on the retina was developed by Sutter et al. This device stimulates the posterior pole of retina with pre-calculated pattern at the same time, and focal ERG at each retinal lesion is computed and separated in a short time. The extent of disability is measured objectively in a short time.

The measured visual field is about 40–50° in diameter and 61 or 103 hexagonal stimuli are used in general. Two hundred forty-one hexagonal stimuli are used for very accurate result, but proper cooperation is needed because the examination time is very long. Half the black and white on the hexagon, it looks irregular but stimulates according to pre-defined rules (pseudo-random), and ERG of each hexagon is calculated from this current signal (Fig. 19.8). The area of the hexagon is small in the center and large in the periphery for the same amplitude of the recorded focal ERG in each region of the normal person.

Electric potential of corresponding macular lesion is not directly measured and obtained by calculation that the result can be affected by variable factors. Therefore, ISCEV standard was published in 2011.

Multifocal ERG can be used for the following diseases.

Retinal disease without fundus changes: Hereditary retinal diseases are occult macular dystrophy and Stargardt disease. Acquired retinal diseases are acute zonal occult outer retinopathy

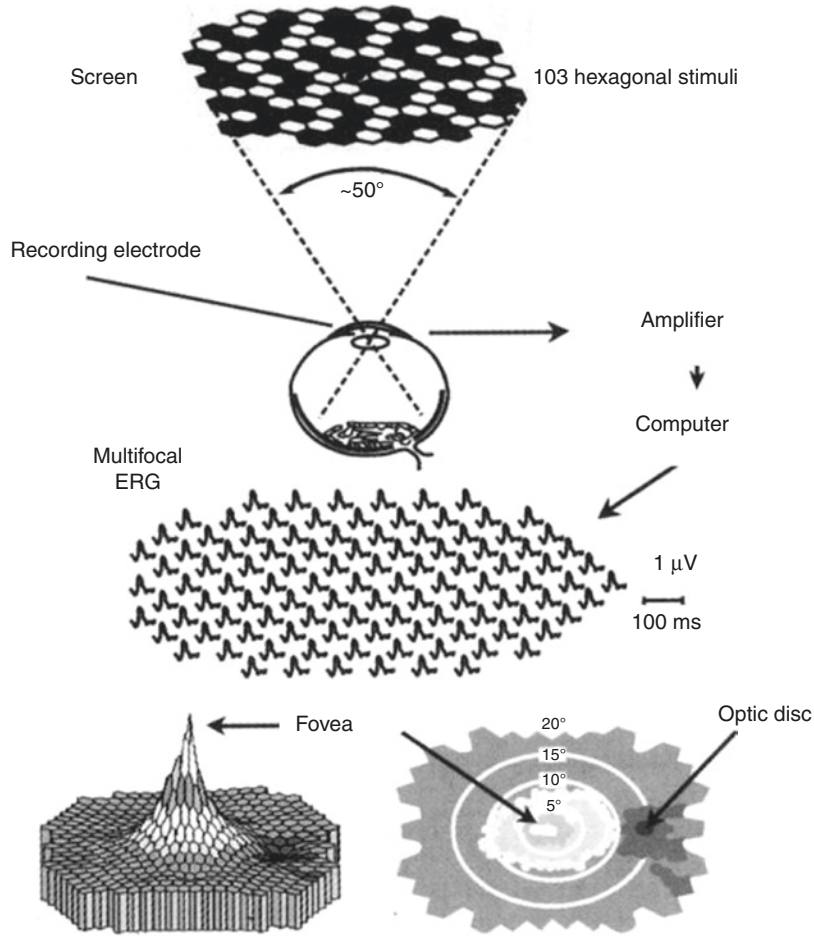


Fig. 19.8 Multifocal ERG wave, amplitude, and implicit time

(AZOOR), white dot syndrome, and acute idiopathic blind syndrome.

- Differentiation between optic nerve disease and retinal disease
- Evaluation of visual function before and after surgery of macular disease
- Evaluation of localized cone cell function in various retinal diseases

19.2.1 Method

After pupil dilatation, dedicated contact lens electrode is applied with local anesthesia. The contralateral eye should be occluded.

Correct visual acuity with refractive lens while the contact lens electrode is applied.

Finely adjust examination distance with corrected visual acuity.

Reference electrode is attached to both lateral canthal areas except anode recording electrode. Ground electrode is attached to the ipsilateral earlobe.

Patient's face is placed on the chin rest and center point of the monitor should be watched.

After starting the exam, the patient should keep watching the center point even though the stimulus of the monitor changes rapidly.

Total examination time takes about 4 min but the inspection process is difficult, and it is not easy to maintain concentration. Patient usually rests every 30 s and test is divided into eight sessions.

Test should be done again if there are a lot of noises due to eye movements or eye flicker.

19.2.2 Interpretation

Multifocal ERG is based on the response of cone cell. Standard waveform is two negative waves (N1, N2) and one positive wave (P1) (Fig. 19.9a). ERG corresponding to each hexagonal stimulus is shown with corresponding visual field test.

The amplitude of P1 and implicit time are shown as a three-dimensional (3D) topographic map. 3D topographic map of amplitude provides the amplitude of retina as height/area. The center area has the highest amplitude, whereas the peripheral area has lower amplitude because the area of the central hexagon is the smallest in normal individual. It must be interpreted by referring the trace array in which individual waveforms are recorded because noise can be displayed in a 3D topographic map. The difference between the normal value and the patient's result can be displayed as a topographic map depending on the model. Depressed region means decreased retinal function. ERG abnormality corresponding to abnormal visual field is assumed that the visual field defect is due to retinal disease (Fig. 19.10). If the result is normal, optic nerve or central nervous system (CNS) disease would be suspicious rather than retinal disease.

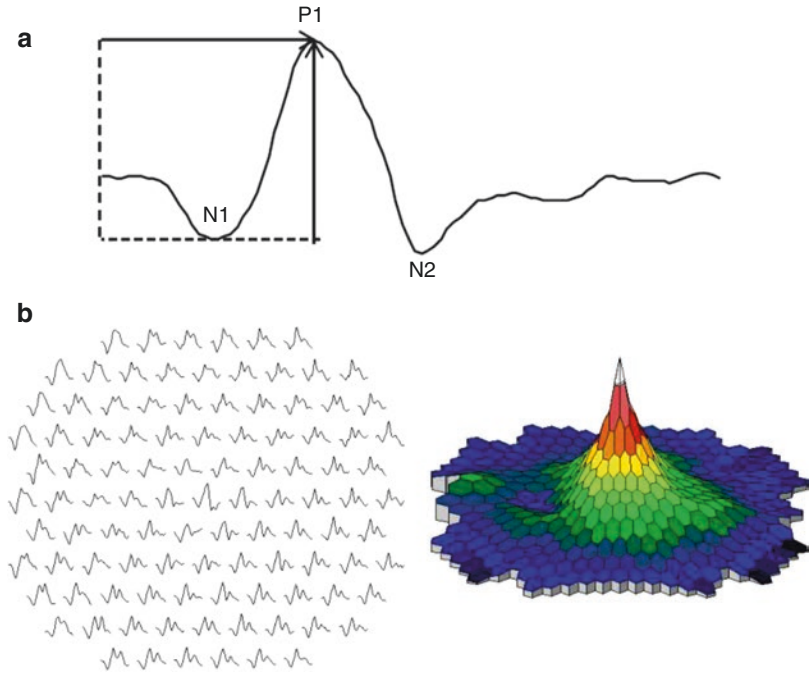


Fig. 19.9 Normal finding of multifocal ERG: (**a**) ISCEV standard of multifocal ERG, 2011 update, (**b**) 3D topographic map of trace array and amplitude of normal multifocal ERG

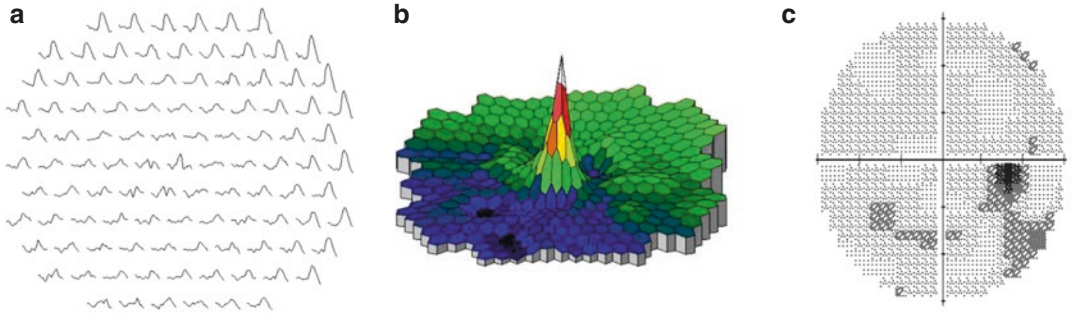


Fig. 19.10 Multifocal ERG and visual field defect in patient with acute zonal occult outer retinopathy: (**a**) trace array, (**b**) 3D topographic map of amplitude, (**c**) visual field test

Hexagonal potentials in ring shape from the center to the periphery are averaged, and the fovea is divided into four quadrants, and the average potential of each quadrant is displayed.

19.3 Pattern ERG

Pattern ERG is related to macular function which is the response of retinal ganglion cell. It is useful for early diagnosis of glaucoma and evaluation of progression. Abnormality in pattern ERG is used for discrimination of optic nerve disease or macular disease.

19.3.1 Method

Visual acuity is corrected with patient's glasses or trial lens set without pupil dilatation. Multifocal glasses should be avoided. Fluorescein angiography or fundus photo should be avoided before the test, but if already done, 30 min interval is needed. Contact lens electrode is inadequate for recording electrode due to blurred vision, and DTL electrode which is inserted to conjunctival sac or roof electrode is suitable.

The size of each rectangle in pattern is 0.8° (0.2°). The width and height of the entire stimulus should be 15° (3°) and aspect ratio should be between 4:3 and 1:1. The luminance of the white square is 80 cd/m^2 or more. Conventional CRT monitors can be widely used, but LCD monitor is needed to reduce the errors in luminance. The black and white contrast is better when closer to 100% and should be at least 80%. It inverts 4 ± 0.8 times per second (2 ± 0.4 Hz). Recording and reporting should use reversal per second (rps) rather than Hz. Both eyes should be examined at the same time. Pattern ERG should be performed for one eye at a time when visual evoked potential is scheduled to be done at the same time.

Pupil dilatation should not be done, and test is done with corrected vision. Pupil size should be recorded.

Recording electrode is located past the inside of the lower conjunctival sac, and roof electrode should not be in contact with cornea.

Reference electrode is attached to both lateral canthal areas. Ground electrode is attached to the forehead but other parts are also possible.

The central retina is tested with check pattern stimulus alternating black and white. Center point of the monitor should be watched. Eye flicker should be avoided during examination, and it is better to stop the test for a while when it is difficult to avoid eye flicker.

Recorded responses of at least 100 stimuli are averaged. Over 300 stimuli are needed to find a slight change or if there are a lot of background noises.

19.3.2 Interpretation

Distinct single positive wave (P50) and two negative waves (N35, N95) are recorded (Fig. 19.11). P50 and N95 are used for analysis because N35 is prone to error. Amplitude of P50 and N95 and implicit time are recorded and reported. Amplitude of P50 is calculated by the difference between minimum of N35 and maximum of P50. If N35 is not clearly observed, it is calculated from the average potential from the zero point to the point at which P50 starts to the maximum point of P50. Amplitude of N95 is calculated by the difference between maximum of P50 and minimum of N95. Implicit time of P50 is 45–60 ms and amplitude is generally 2.0–6.0 μV in normal person. Implicit time of N95 is 90–100 ms.

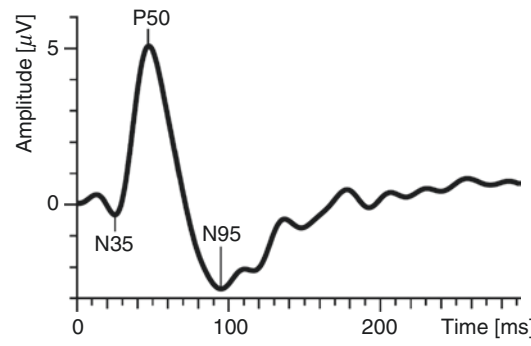


Fig. 19.11 Normal pattern ERG that shows N35, P50, and N95. (ISCEV standard, 2012 update)

19.4 Visual Evoked Potential, VEP

Visual evoked potential (VEP) is a computer averaged response of the nervous system to sensory stimuli, used for examining function of visual pathway from the sensory organs to the central nervous system. VEP is the recording of response of the central nervous system when giving the visual stimulus. ISCEV standard is revised in 2016, and the main changes in this revision are the acknowledgment that pattern stimuli can be produced using a variety of technologies (Fig. 19.12).

VEP is used for examination of the retinal pathway from retinal ganglion cell to the occipital lobe. Visual acuity level is considered in the interpretation of the results because it reflects the macular function. Pattern stimulus reflects central retinal function that it could be used for evaluating central vision.

Optic nerve diseases, optic radiation disease, evaluation of potential visual acuity with invisible fundus due to corneal opacity, cataract and vitreous opacity, unknown cause for decreased vision, and pediatric visual function test with poor cooperation could be evaluated by VEP.

It is known that the light stimulus to the retina or alternating black and white check pattern can induce visual evoked potential (Fig. 19.13). These evoked potentials appear as variable waveforms, and they affect each other by the anatomy and physiological structure or condition of visual pathway. Neurophysiological abnormalities can be assessed by determining the shape of these evoked potential waveforms and the time and amplitude of reaching the peak after stimulation.

Various kinds of visual evoked potential can be measured by visual stimulation. Pattern reversal VEP and flash VEP are the most widely used. Pattern reversal VEP is correlated to 17 area of brain and flash VEP is associated with 18 and 19 areas of brain. Pattern reversal VEP is basically used and flash VEP is performed with media opacity and visual acuity below 0.1. Pattern onset/offset VEP is added to standard test on revised ISCEV standard.

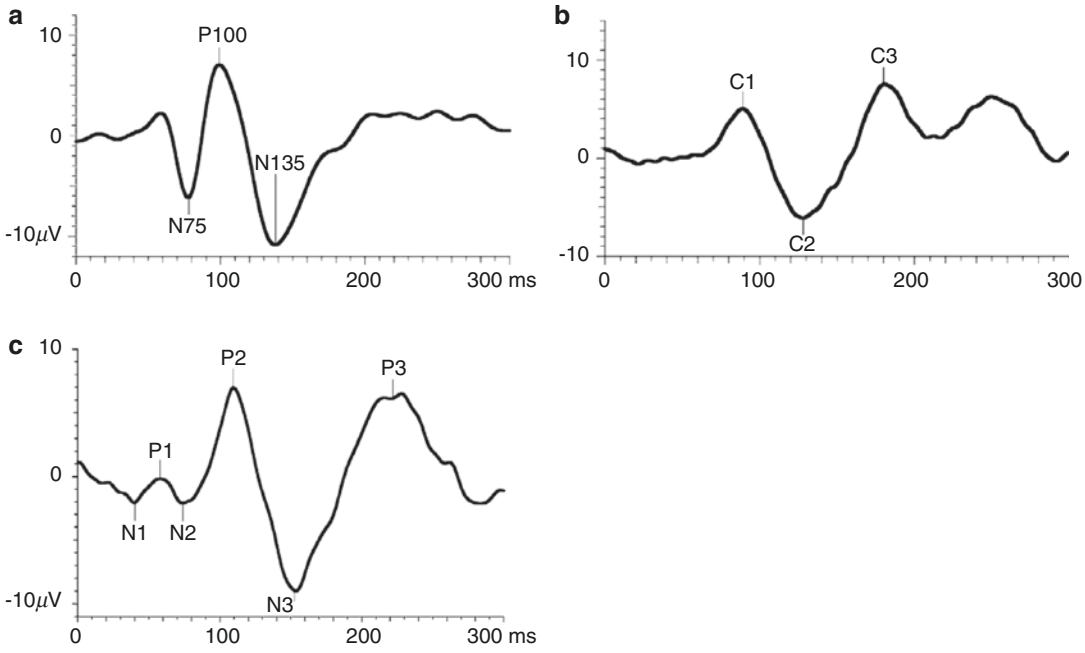


Fig. 19.12 Normal VEP: (**a**) pattern reversal VEP, (**b**) pattern onset/offset VEP, (**c**) flash VEP (ISCEV standard, 2016 update)

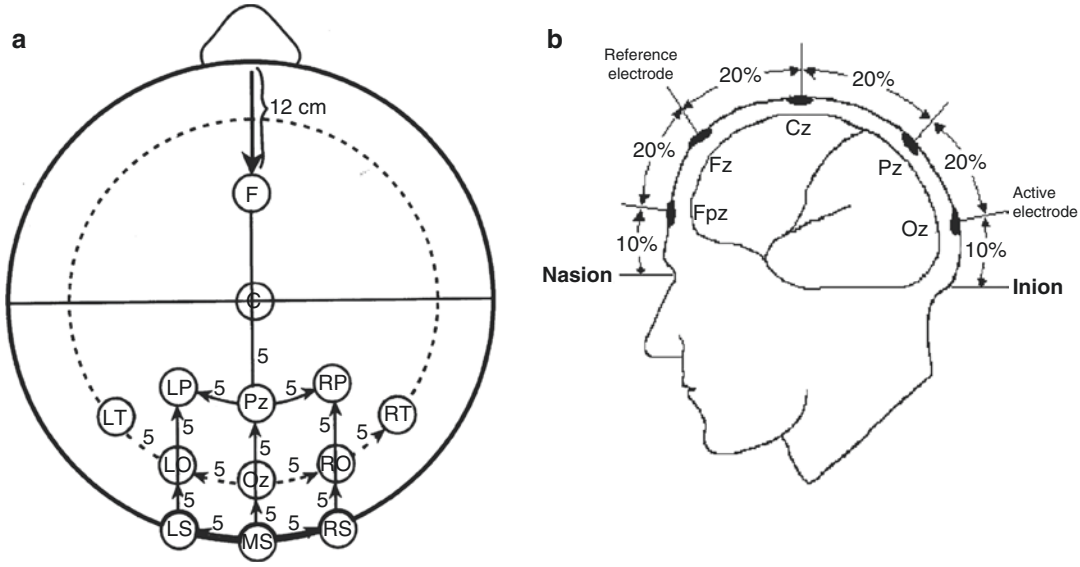


Fig. 19.13 Electrode attachment site of VEP: (**a**) F frontal, O occipital, P parietal, S suboccipital, T temporal, C vertex, L left, R right, M middle (**a**) Z means midline. (**b**) Find the electrode attachment position as a percentage of distance from the nasion to inion

19.4.1 Pattern Reversal VEP

Pattern reversal VEP can be used for visual pathway defect, especially optic nerve disease; diagnosis of demyelinated disease, retrobulbar optic neuritis, ischemic optic neuropathy, and compressive optic neuropathy; and also assessment of objective visual acuity: pediatric visual function, psychogenic visual impairment, and differentiation of malingering.

It is stimulated by alternating black and white check pattern. Average luminance should be 50 (40–60) cd/m^2. Contrast sensitivity should be at least 80%. The size of each rectangle is used more than one including 1° and 15 min; total visual field of the stimulus is minimum 15°. The alternating speed is used twice per second (1.0 Hz, ±10%). Visual angle of each pattern, alternating frequency, alternating time, average luminance, pattern contrast, and visual field size are reported.

Normally, the amplitude and implicit time of the maximum negative wave N2 (or N75) after 75 m/s after stimulation and maximum positive wave P2 (or P100) after 100 m/s after stimulation are calculated (Fig. 19.12). It is easier to detect and measure than flash VEP and waveform is more consistent. Implicit time of P100 is the most important variable since there is a small error between individuals and between eyes and examinations.

19.4.2 Pattern Onset/Offset VEP

Discrimination of malingering and patient with nystagmus can be evaluated by pattern onset/offset VEP.

Pattern and diffuse background are stimulated alternately. The condition of the pattern is the same as the pattern reversal stimulus. The luminance of diffuse background is set equal to the average luminance. The time when the pattern appears is recommended as 200 ms and diffuse background appears is recommended as 400 ms. The response is recorded when the pattern appears on diffuse background.

Individual difference is greater than pattern reversal VEP but it has less error due to poor cooperation. Three waves appear in normal (C1, C2, and C3). C1 is positive wave which is recorded near 75 ms. C2 is negative wave near

125 ms. C3 is positive wave near 150 ms (Fig. 19.12). Each amplitude is calculated by the difference between the maximum and minimum of the front wave.

19.4.3 Flash VEP

Flash VEP can be used when the pattern stimulus cannot be focused on the retina due to media opacity such as corneal opacity, cataract and vitreous opacity, poor cooperation in young children, and visual acuity below 0.1 with non-response to pattern stimulus such as macular degeneration disease, macular hypoplasia, visual development delay, cortical blindness, etc.

At least 20° of flash stimulation should be given. Light stimulus is at least 3 cd·s/m^2 in a room with dim light. Screen or full-field stimulating device can be used. The frequency of light stimulation should be 1 per second (1.0 Hz ± 10%).

It is useful in patients with media opacity. Two positive waves and two negative waves (N1, P1, N2, P2) appeared and maximal positive wave P2 appears after 95–120 m/s (Fig. 19.12).The abnormal findings are shown as delayed response, loss of waveform, and decreased amplitude, but there is a big individual difference that it is common to evaluate the difference between the right and left eye. Each laboratory should have normal range data of the measurements.

19.4.3.1 Method

Correct the refractive error and attach the electrode. Resistance of electrode should be below 5000. There are various methods depending on the attachment sites; a reference electrode is generally attached to the midline frontal (Fz) above 12 cm from the nasion, and a recording electrode is attached to the midline occipital (Oz) above 5 cm from the inion and on its left and right 2.5–5 cm (right occipital, RO; left occipital, LO). Ground electrode is attached to the forehead, parietal area (Cz), earlobe (A1 or A2), or the mastoid process (Fig. 19.13).

Visual stimulus should be given with occluding one eye. Distance between visual stimulus and the patient should be kept 100 cm.

Recording range is adjusted to 1–300 Hz and 10–100 Hz is used in general. After visual stimulation, EEG response is recorded after 150–200 averaging procedures using a computer. At least three channels (RO-MF, MO-MF, LO-MF) should be recorded and recording time is 250 m/s.

Contralateral eye is covered and recorded again.

Brightness, contrast, stimulus range, size and location, status of examiner, sex, and age can affect the result. Especially, flash VEP is very difficult to compare with a normal person because there is a big individual difference. But the difference of response between both eyes is less than 10%, and both eyes should be compared to determine abnormality.

All examinations should be done in constant luminance indoor and outdoor. As the lightning of the room becomes bright, the intensity of the stimulus decreases that P100 (P2) implicit time elongates. Lighting of the retina according to pupil size should also be considered. Test result is different depending on the degree of contrast of the lightness and darkness of the pattern. The implicit time of P100 is delayed and the amplitude is decreased with low contrast.

Based on a constant size of stimulus range, the smaller the size of the pattern of black and white check, the wider the amplitude. For P2 implicit time, there is no difference in the range of stimulation over 8°, but it elongates in a small stimulus range of 8° or less. It is more prominent in large pattern. Central 8° is projected to 17 area which is apex of the occipital lobe and outside 8–32° is projected to visual cortex. Implicit time of flash VEP P2 is 10% longer than pattern reversal VEP P100.

There is a slight difference depending on fixation, visual acuity, and pupil size. Waveform abnormalities might occur without optic nerve disease if the patient is not focused on the central point on the monitor. N75 disappears and implicit time to P100 elongates in a patient with blurred vision with inadequate correction. Therefore, pattern reversal VEP should be done after correction of visual acuity. For adult with poor cooperation, child, or during the surgery, flash

VEP could be used. Implicit time to P100 elongates with age. Males have larger amplitudes and shorter implicit times than females.

19.4.3.2 Abnormal Findings

VEP result is closely related to macula status. If the fundus examination shows abnormality of the macula, the information obtained by VEP is limited. Therefore, VEP is performed to evaluate the abnormality of the visual pathway with normal fundus finding and also used to investigate the potential for visual recovery in cases where fundus examination is not possible. Early diagnosis prior to optic nerve abnormality in multiple sclerosis, visual pathway disease, infant, or, where communication is not possible, VEP is useful for vision assessment and visual field impairment.

In cases of non-recordable, P100 (P2) delay compared to normal range, P100 (P2) difference between the right and left eye more than 10% or 9 m/s, and P100 delay 118 m/s or more in pattern reversal VEP, it can be suspected as lesions of optic nerve, optic radiation, or visual pathway posterior to optic radiation (Fig. 19.14).

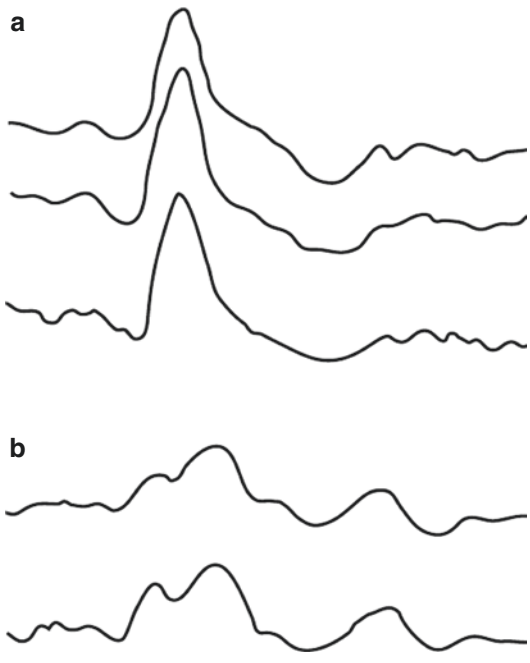


Fig. 19.14 VEP in normal and optic neuritis (multiple sclerosis) patient: (**a**) normal and (**b**) optic neuritis (multiple sclerosis) patient

19.5 Electrooculography, EOG

It is an assessment of retinal pigment epithelium (RPE) function and useful for distinguishing RPE disease with normal ERG and abnormal EOG. The most typical disease is the Best disease. But a lot of neuroretinal diseases could be shown as RPE abnormality with disease progression. Therefore, EOG abnormalities could be seen as the disease progresses.

EOG is useful for the following diseases:

Bestrophine gene abnormality: Best disease, autosomal recessive bestrophinopathy, autosomal dominant vitreoretinochoroidopathy (AD-VIRC)

Multiple evanescent white dot syndrome (MEWDS), acute zonal occult outer retinopathy (AZOOR), acute idiopathic blind spot enlargement (AIBSE) syndrome

Choroidal circulation disorder, ocular ischemic syndrome

For geographic chorioretinitis, early retinitis pigmentosa, Stargardt disease, choroideremia, chorioretinal gyrate atrophy, central retinal artery occlusion, chloroquine retinopathy, pattern dystrophy or butterfly dystrophy, cone cell dystrophy, abnormal value could be shown according to the disease progression.

As mentioned above, there is a potential difference between the anterior and posterior segment of the eyeball; it is called as a static potential. The cornea and lens do not respond to light but the potential of RPE varies according to the variation of surround brightness. It decreases in dark adaptation and increases in light adaptation. In accordance with this finding, EOG decreases in dark adaptation and increases in light adaptation. To record the normal EOG, adhesion status of RPE and photoreceptor and normal circulation of the retina and choroid are needed. If one of them is missing, EOG result can be changed. Both EOG and ERG should be performed clinically for evaluating pathophysiology of various retinal diseases, especially for evaluation of RPE function because normal ERG does not reflect the RPE activity.

19.5.1 Method

Patient should be in ordinary room lighting more than 1 h before examination, and fundus photography is prohibited during this period. Full dilation of pupil is needed. ISCEV recommends 7 mm pupil dilatation. The size of pupil is recorded and the lighting should be brighter when dilation is not enough. For example, a 5 mm pupil needs twice the brightness to get the same retinal response. Each electrode is attached to the medial and lateral canthal area. Reference electrode is attached to the forehead.

Under a room lighting of constant brightness, EOG can be measured in either method; the horizontal eye movement is performed in a rhythmic manner along two moving red lights within 30° horizontal range or looking at two flashing red lights at intervals of 6 times/min (1 time per 10 s) located at 30° apart from each other. EOG is measured for several minutes (Fig. 19.15). If amplitude obtained is stable, it is called base value. If noise is recorded, every electrode should be checked again.

Recording begins after 15 min of dark adaptation. EOG is measured once per minute. The examiner should check the patient's compliance and noise to ensure proper recording during the test. Light adaptation is done with 100 cd/m^2. If the patient complains of severe glare, the light intensity increases gradually for 20 s. EOG is recorded every 1 min for 15 min. At each recorded time point, the magnitude of the amplitude is continuously plotted on the vertical line, and the time (min) is plotted on the transverse line. Then EOG period curve is created. Some irregular amplitude can be recorded due to noise; it is roughly drawn with a smooth curve passing through the middle of each point. Experienced examiner can manually draw or can be drawn automatically by built-in program. Minimal amplitude of EOG after dark adaptation is called as dark trough; maximal amplitude of EOG after light adaptation is called as light peak (Fig. 19.16).

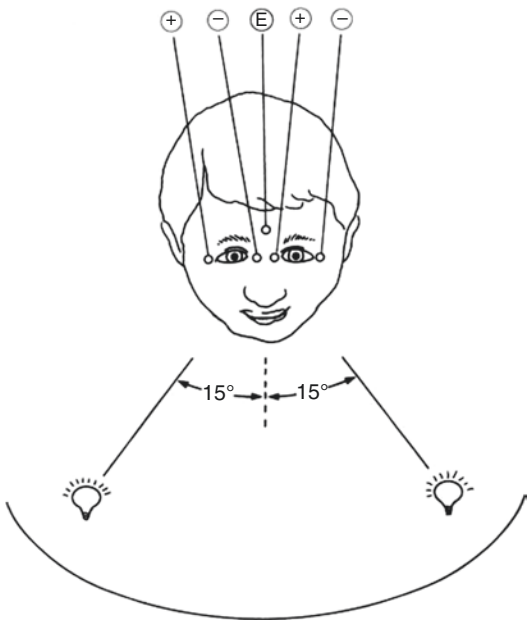


Fig. 19.15 Principle of EOG method

19.5.2 Interpretation

Normally there is a transient increase in amplitude after dark adaptation and then it decreases with time. It is lowest at around 10 min after dark adaptation and slightly increases afterwards. The ratio of light peak by dark trough is called as Arden ratio. The Arden ratio value with 2.0 or more is normal, 2.0–1.5 is subnormal, and 1.5 or less is abnormal (Fig. 19.17).

19.6 Ocular Electromyography, EMG

Ocular motor nerve palsy which causes eye movement disorder and neuromuscular junction disorder is all targeted. Ocular electromyography (EMG) is used for monitoring when injecting botulinum toxin into the external ocular muscle for strabismus treatment.

EMG is finding, amplifying, and recording of electrical activity within the muscle. However, its clinical use is limited because the results are not easily quantified. Mean rectified voltage (MRV) is the average value obtained by rectifying alternating current and converting it into direct current. It is a quantitative measure of

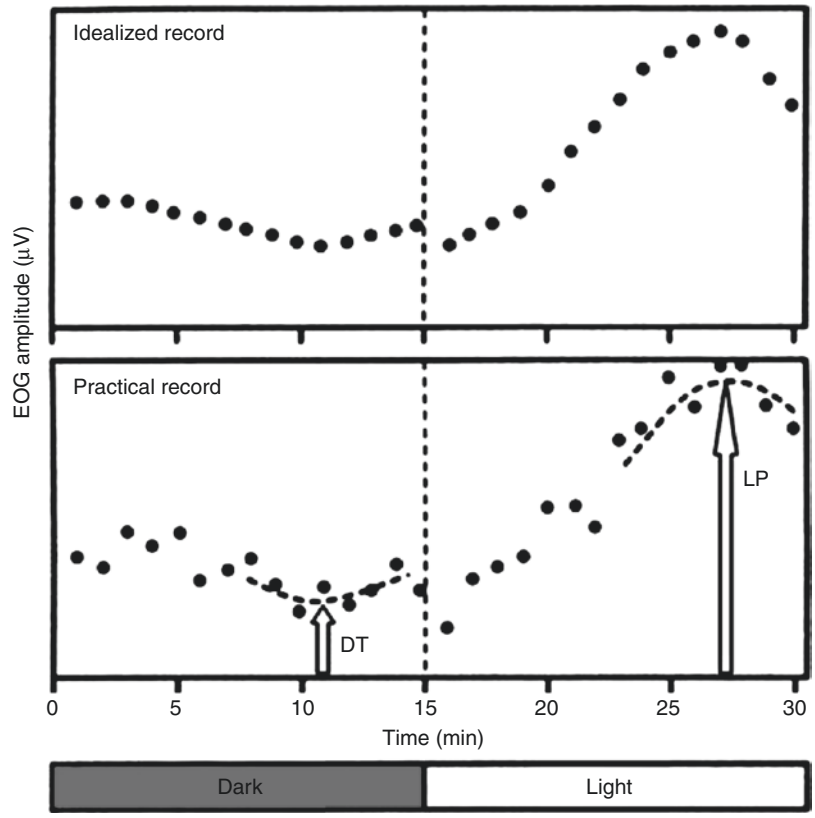


Fig. 19.16 Waveform of EOG (ISCEV standard, 2010 update)

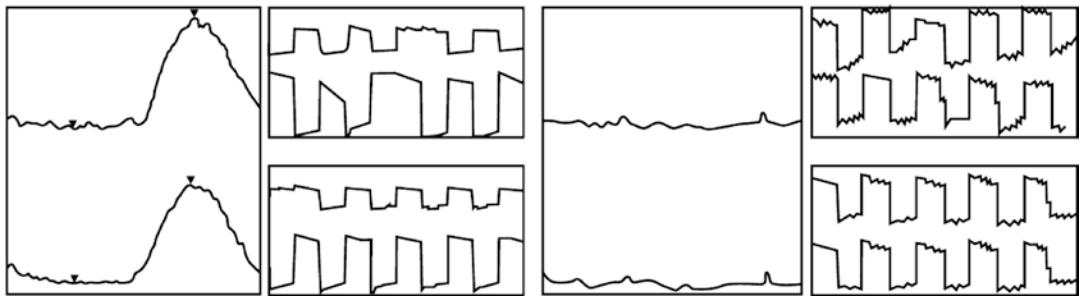


Fig. 19.17 Arden ratio of EOG. Normal (●: 2.0) and Best disease (▲: 1.3)

EMG. Root mean square (RMS) is electric current or electric value which has an AC waveform that is expressed by RMS value using the formula. It is compared to the tension of the external ocular muscle.

19.6.1 Method

The neutral electrode and the ground electrode are first contacted with the skin around the eyes. A very thin electrode is inserted through the

conjunctiva into the muscle under local anesthesia. The position of the electrode is adjusted until appropriate electrical activity appears. Normally, electrical activity is maximized when moving in the direction of muscle motion, and electrical activity is minimal when moving in the opposite direction.

19.7 Electronystagmography, ENG

Electronystagmography (ENG) is recording of eyeball movement using EOG. It is used in the diagnosis and treatment of various eye movement disorders. It is more sensitive than direct eyeball observation in patients with nystagmus and helps to distinguish the type of nystagmus by recording the movements quantitatively and calculating the velocity of eyeball movements.

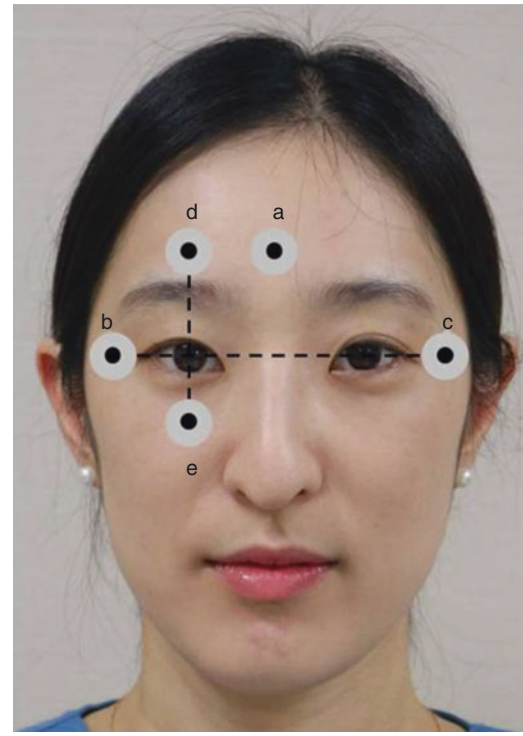
19.7.1 Method

19.7.1.1 Examination of Nystagmus

The method of attaching the electrodes may be the same as EOG, or each electrode may be attached to the skin of the lateral canthal area of both eyes. For measuring vertical movement, electrodes are attached to the upper and lower eyelids (Fig. 19.18). The degree of nystagmus is recorded in patient with nystagmus. According to patient's symptoms, saccadic movement and pursuit movement are induced using target or vestibulo-ocular reflex which is induced by rotation of patient's head, and then degree of nystagmus is recorded. Latent nystagmus is recorded with occluding one eye.

19.7.1.2 Examination of Eyeball Movement

The range of moving the target is within 20° left and right side and 30° in total. The recording



a. Reference electrode: frontal head
b,c. Horizontal movements: medial, lateral canthus
d,e. Vertical movements: upper, lower lids

Fig. 19.18 Electrode attachment site of ENG

electrode uses a silver electrode for EEG. The connecting line of both electrodes is placed passing through the pupil center horizontally or vertically close to the eyeball in primary position. Initially, the recorder is operated while moving the target at a relatively high speed of about 0.3 Hz. A small vibration of high speed is recorded almost simultaneously as the target moves. The velocity of target in pursuit movement is 0.1 Hz, 0.2 Hz, and 0.3 Hz, and the saccadic movement is around 0.3 Hz. Each movement is recorded for 30 s at a recording paper speed of about 10 mm/s. When the motor eyeball movement abnormality is suspected, the recording paper is accelerated at a speed of

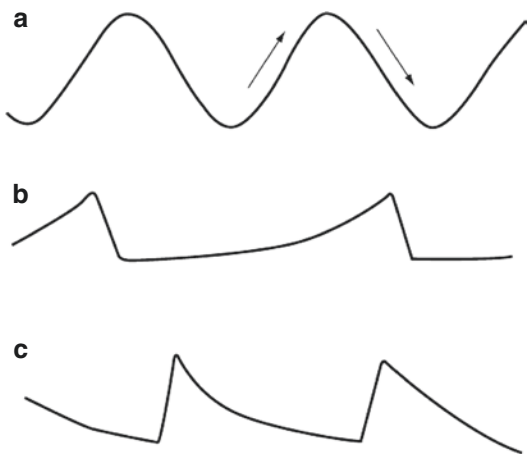


Fig. 19.19 Type of nystagmus: (**a**) pendular type, oscillations of equal velocity in each direction without the distinction between low speed and high speed; (**b**) accelerated type, the speed of eye movements increased at low speed; (**c**) decelerated type, the speed of eye movements decreased at low speed

50–100 mm/s and the target is reciprocated about 10 times.

The right motion is recorded upward and the left motion is recorded downward. It can be classified into several types depending on the type of nystagmus (Fig. 19.19).

Suggested Reading

Brown KT. The electroretinogram: its components and their origins. Vis Res. 1968;8:633–77.

Brown KT, Wiesel TN. Localization of origins of electroretinogram components by intraretinal recording in the intact cat eye. J Physiol. 1961;158:257–80.

Dawson WW, Trick GI, Ltzkow CA. Improved electrode for electroretinography. Invest Ophthalmol Vis Sci. 1979;18:988–91.

Frishman LJ. Electrogenesis of the electroretinogram. In: Ryan SJ, editor. Retina. 6th ed. St. Louis: Elsevier; 2017a. p. 224–48.

Frishman LJ. Clinical electrophysiology. In: Ryan SJ, editor. Retina. 6th ed. St. Louis: Elsevier; 2017b. p. 249–72.

Gjotterberg M. Electrodes for electroretinography: a comparison of four different types. Arch Ophthalmol. 1986;104:569–70.

Hood DC, Bach M, Brigell M, et al. ISCEV Standard for clinical multifocal electroretinography (2011 edition). Doc Ophthalmol. 2012;124:1–13.

Marmor MF, Brigell MG, McCuloch DI, et al. For the International Society for Clinical Electrophysiology of Vision. ISCEV standard for clinical electro-oculography (2010 update). Doc Ophthalmol. 2011;122:1–7.

McCulloch DL, Marmor MF, Brigell MG, et al. ISCEV standard for full-field clinical electroretinography (2015 update). Doc Ophthalmol. 2015;130:1–12.

Odom JV, Bach M, Brigell M, et al. ISCEV standard for clinical visual evoked potentials: (2016 update). Doc Ophthalmol. 2016;133:1–9.