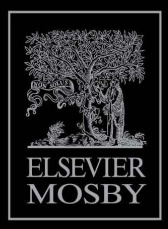
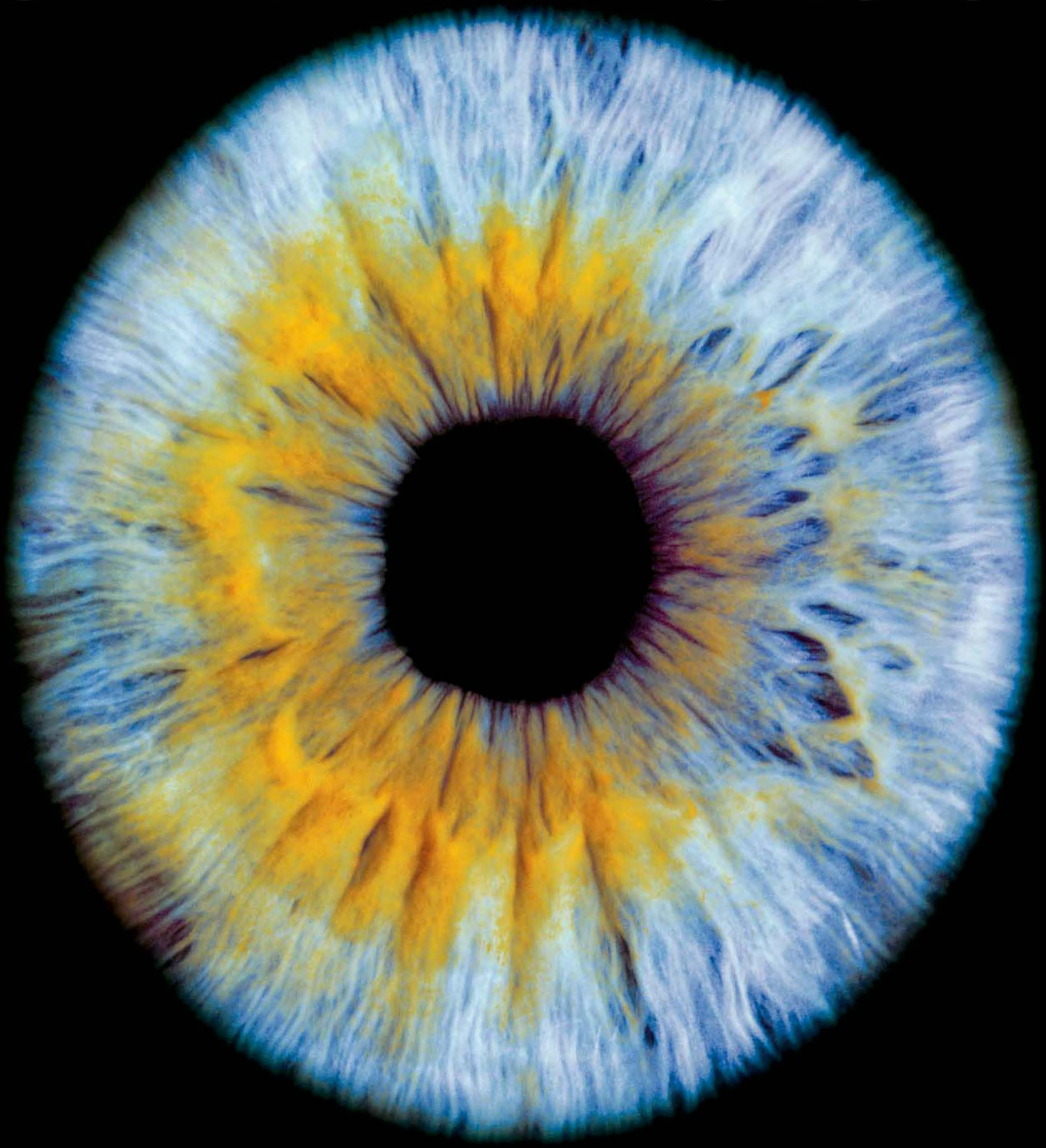


THIRD EDITION

ATLAS OF CLINICAL OPHTHALMOLOGY



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1 Ocular Examination

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PSYCHOPHYSICAL TESTS OF VISUAL FUNCTION

Vision arises from the detection and subsequent processing of light stimuli from the external environment and the integration of several different sets of information. Visual acuity, colour vision and visual fields are routinely assessed in clinical practice. The visual system also detects other modalities such as luminance or motion but these are not normally investigated in routine clinical examination. Clinicians need to understand exactly what such tests measure, how they should be used and their limitations.

VISUAL ACUITY

The measurement of visual acuity is the first essential part of any ocular examination and, although the examination technique is simple, the process being assessed is complex and requires the interaction of many factors, both physiological and psychological. Assessment of visual acuity requires the eye to detect the object and resolve it into its component parts. This information is then transmitted to the cerebral cortex where it is matched against existing memory shapes. The patient must then be able to communicate recognition of the object to the examiner. Physiologically, visual acuity measures the capability of the visual system to resolve a target; this is dependent on three main factors: the background illumination, the contrast of the target to the background and the angle that the target subtends at the nodal point of the eye.

In theory the eye has a maximal resolution of 1 minute of arc at the nodal point. In practice, young people normally have a better acuity than this at 20/15 (6/5) which corresponds to the spacing of individual cones in the foveola. Although visual acuity is primarily a function of cones the degree of visual processing in the retina must be considered and, in particular, the receptive fields of the retinal ganglion cells. In the foveola there is a 1 : 1 relationship of cones to ganglion cells but this increases rapidly more peripherally. There is an increasing loss of visual acuity with age so that in old age 20/30 (6/9) or even 20/40 (6/12) may be considered normal.

Although distance acuity is normally measured clinically near vision is in some ways more important in the daily life of the patient. Near vision is tested by reading test print of standardized sizes with the appropriate spectacle correction and good illumination. Factors of accommodation and magnification are important in the assessment of near vision and the correlation between distance acuity and near acuity is not always good. Patients with 20/60 (6/18) distance vision can often manage to read print of J3(N5) size, provided their macular function is normal. There appears to be a large redundancy of nerve fibres in the visual pathways: probably only approximately 15 per cent of the optic nerve fibres are actually required to be able to read 20/30 (6/9).

Table 1.1 shows the pathological and physiological factors that can limit visual acuity. This process can be influenced by physiological and pathological factors anywhere along this pathway.

Background illumination alters the level of retinal adaptation. Low levels of light stimulate the rod system; the receptor density and level of retinal integration of this system are less than that of the cones and consequently acuity is also low. At high levels of illumination the cone system is stimulated and acuity is maximal. To obtain the best visual acuity illumination should be in the optimal photopic range. Because of the effect of reduced retinal illumination from lens opacities in patients with cataract may be seeing in the mesopic to low photopic range where the acuity is proportional to background illumination. In these patients, an increase in the ambient lighting will give them better vision provided that light scattering by the cataract does not counter this.

Table 1.1 Factors that limit visual acuity

Steps in visual perception	Physiological factors	Pathological factors	Physiological limitations
Image formation on the retina	Refractive error	Media opacities	Optical aberrations
Image detection by photoreceptors	Cone receptor function (retinal adaptation)	Cone receptor loss or dysfunction	Cone receptor spacing and integration
Initial data processing and transmission	Optic nerve axonal content	Damaged to anterior visual pathway	
Higher visual processing		Dysfunction of visual cortex, secondary cortical areas	

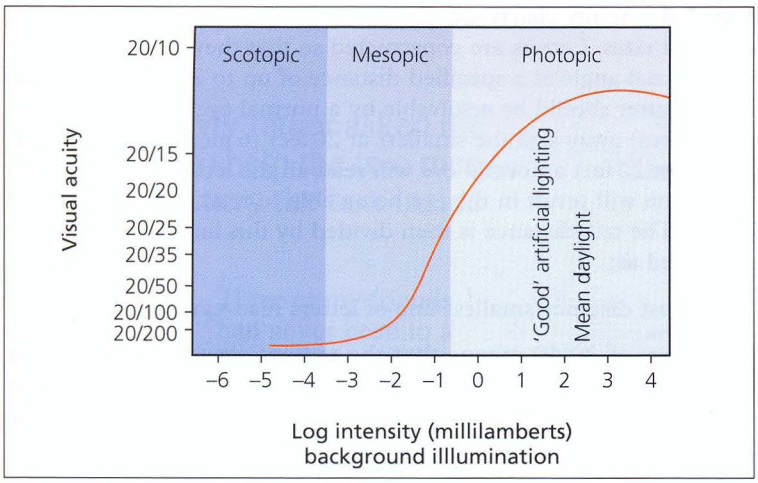

Fig. 1.1 As high-resolution central vision depends on cone receptors any reduction in cone function will greatly compromise acuity. This graph shows visual acuity plotted against background illumination. The best acuity in the scotopic (rod-sensitive) region of the curve is 20/200 (6/60), whereas under photopic (cone-sensitive) conditions acuity can increase to approximately 20/15 (6/5). The curve flattens once optimal conditions are reached and then reduces owing to the effect of dazzle.

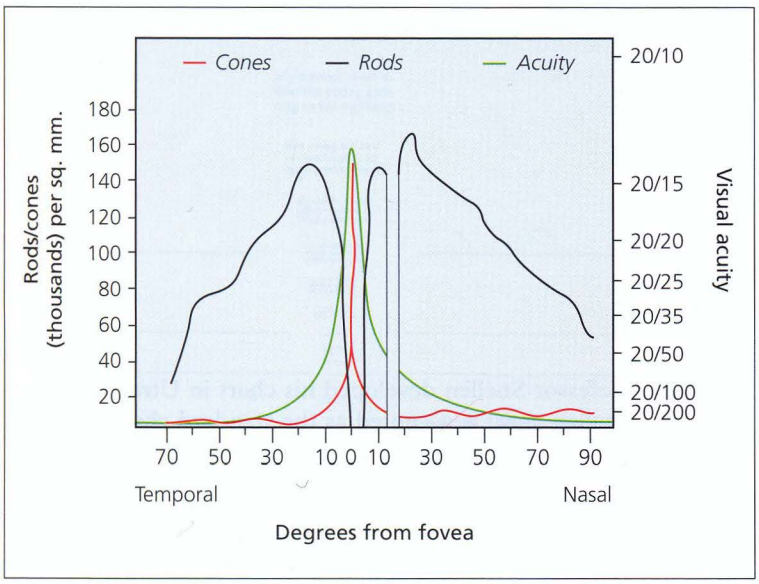

Fig. 1.2 Visual acuity and cone and rod density plotted against degrees from the foveal centre. There are no blue cones at the fovea.

MEASUREMENT OF VISUAL ACUITY

Visual acuity is usually measured at a distance of 6 metres (20 feet) to eliminate the contribution from accommodation. It should be performed on each eye in turn without and with full refractive correction. Acuity is usually measured at high contrast. The visual angle refers to the angle subtended by an object at the nodal point of the eye; it depends on the size and distance of the object from the eye. The normal limit of resolution is 1 minute of arc but some individuals see better than this possibly due to a finer cone mosaic, better image processing in the retina or cortex, or fewer optical aberrations.

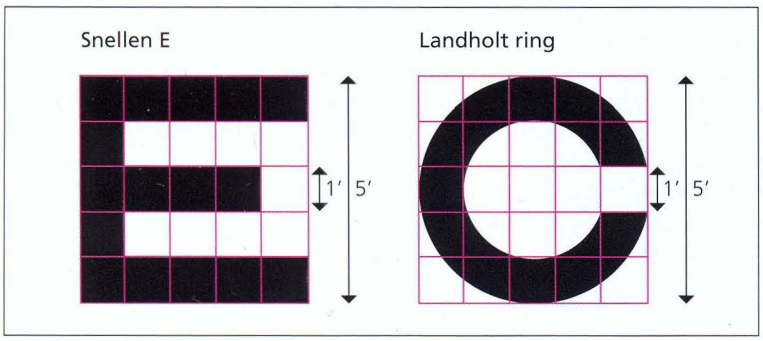

Fig. 1.3 Each individual component of a letter or shape must be resolved to be identified. A letter 'E' viewed at the limit of resolution (20/20, 6/6) subtends 5 min of arc, each individual component subtending 1 min. The same principle is used in the construction of the Landholt rings.

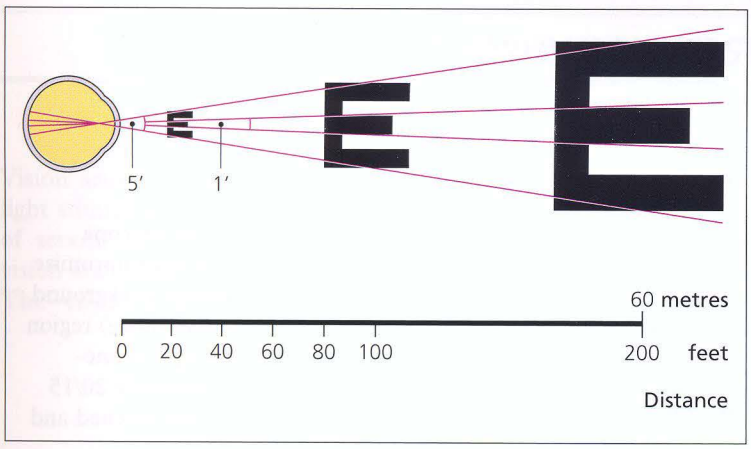

Fig. 1.4 Acuity charts are constructed with rows of letters of different sizes. Letters are constructed so that they subtend the same visual angle at a specified distance of up to 200 feet. Thus the largest letter should be resolvable by a normal eye from 200 feet (60 metres) away and the smallest at 20 feet (6 metres). If the chart is read at 20 feet a normal eye will read all the letters. Any loss of resolution will result in the eye being able to read only larger letters. The test distance is then divided by this line and is expressed as:

test distance/smallest line of letters read = visual acuity

An acuity of 20/40 means that the patient sees at 20 feet what a normal eye would see at 40 feet. It can also be measured in metres (6/12), as a decimal (0.5), or as the angle subtended by the smallest gap of the letter (2 min of arc).

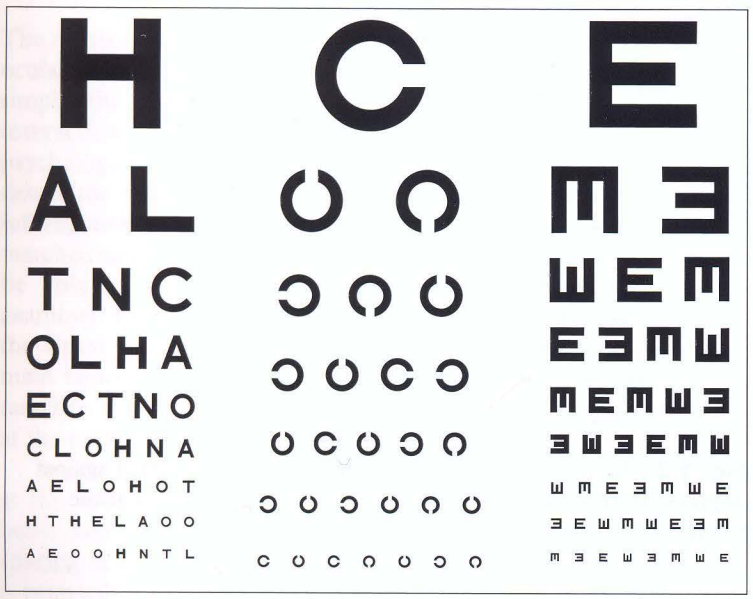

Fig. 1.5 Professor Snellen developed his chart in Utrecht in 1863. The Snellen chart is accepted as the standard chart for clinical practice but it has some problems. Some letters are more legible than others; for example, 'L' is easier to read than 'E'. Patients must also be literate. Modifications to avoid this include Landholt rings where the patient must identify the orientation of a gap or illiterate charts where a cutout letter 'E' is matched with the same letter in different orientations.

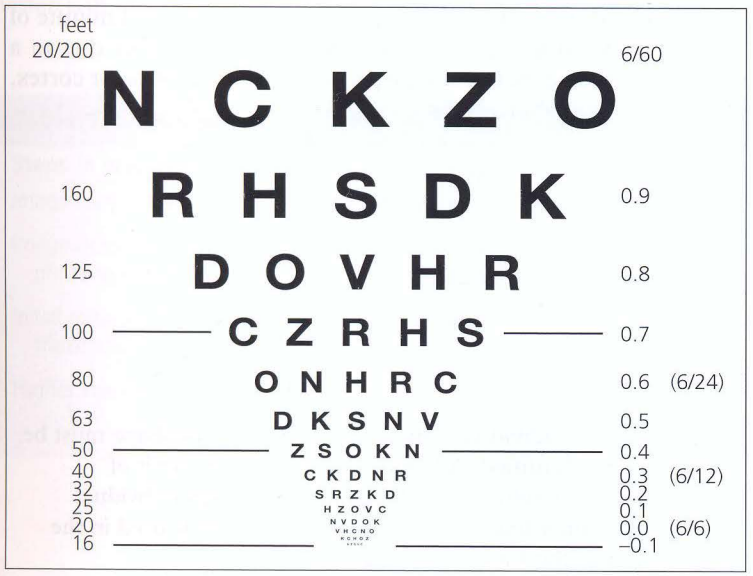

Fig. 1.6 Snellen charts also have the defect of different numbers of letters on each line causing crowding phenomena and nonproportional spacing between letters and lines. Furthermore, the measured range does not extend far enough into low visual acuity ranges. The Bailey–Lovie, Early Treatment Diabetic Retinopathy Study (ETDRS) or LogMAR (log of minimum angle of resolution) chart overcomes these problems. It gives a progressive linear assessment of acuity and has become the standard for clinical research. Each row has five letters with a doubling of the visual angle every three lines. It is read at 4 m and covers Snellen equivalents from 20/200 to 20/10. Each letter read is scored as -0.02 and each row as -0.1 (5 × -0.02). Visual acuity is given as the log value of the last complete row read plus -0.02 for each letter read on the row beneath. An acuity of 1.0 equates to 20/200, 0.3 to 20/40, and 0.0 to 20/20. This contrasts with Snellen charts in that the lower the value for visual acuity, the better the vision.

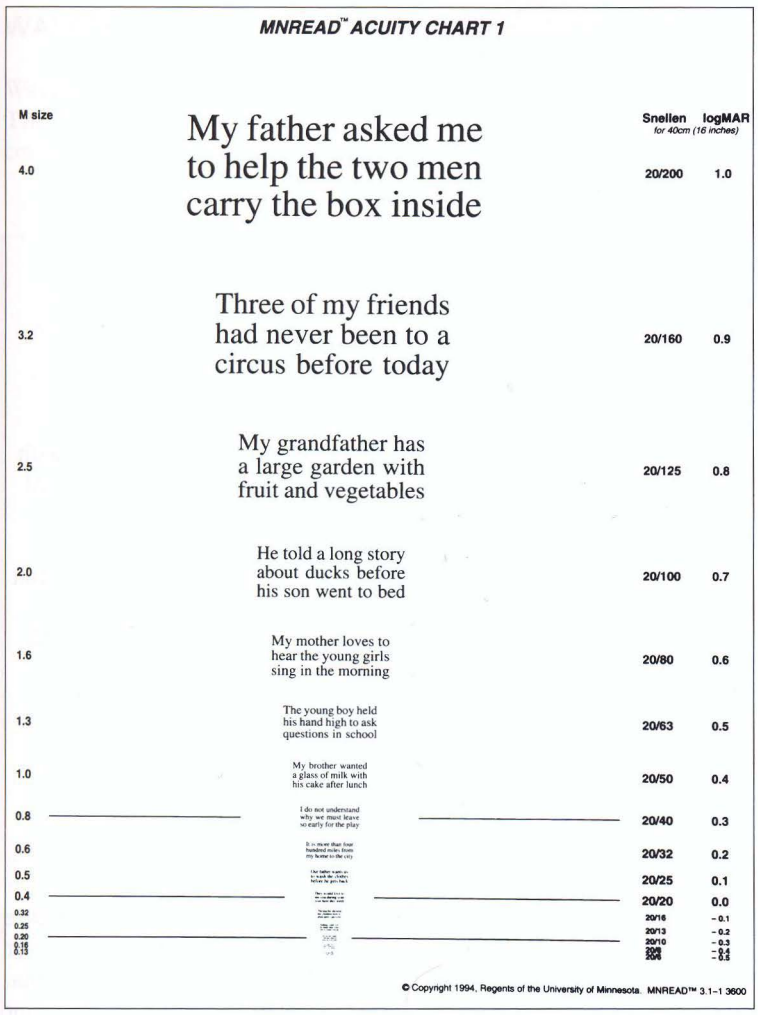

Fig. 1.7 Traditionally near vision testing is done using the appropriate reading correction with a chart of different font sizes. This has, however, no physiological basis and a more scientific method is to use a reduced LogMAR chart such as the MN Read card at a standardized distance and illumination. The text in this chart conforms to LogMAR principles; in addition each paragraph is standardized for length of words, sentences and grammatical complexity. It also allows for reading speed to be measured. Patients need to read at 80 words a minute or better to have functional near vision at that size of print.
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TESTING ACUITY IN CHILDREN

Visual acuity assessment in children presents particular problems. Good results can be achieved only with time and patience and by selecting the right test for the age of the child. These include qualitative tests such as the child turning to fixate a face or light, suppression of optokinetic nystagmus following rotation or objecting to occlusion of one eye. While semiquantitative measurements are available, for instance picking up 'hundreds and thousands' sweets or following small balls quantitative tests are most informative. For infants forced-choice preferential looking or visual evoked potentials (VEPs) can be used; both give different results. Older verbal children can use picture cards (Cardiff cards, Kay's pictures) and from the age of three may manage matching letter tests (e.g. the Sheridan–Gardiner test; see Ch. 18). Caution is necessary when using Snellen charts with single letters because of the phenomenon of 'crowding' – being able to see single letters more easily than rows of letters – which can overestimate true acuity.

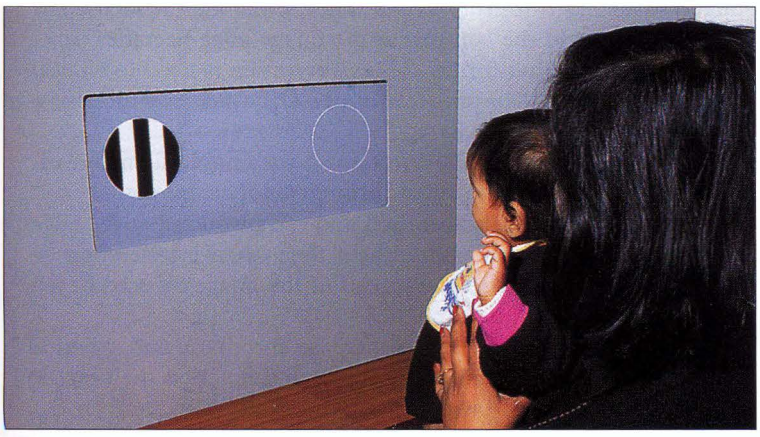


Fig. 1.8 With preferential viewing techniques the child is shown two cards: one has a grating, the other has the same uniform overall luminance. If the child can distinguish the grating, he or she looks at this 'preferentially' – presumably because it is more interesting.
By courtesy of Professor A Fielder.

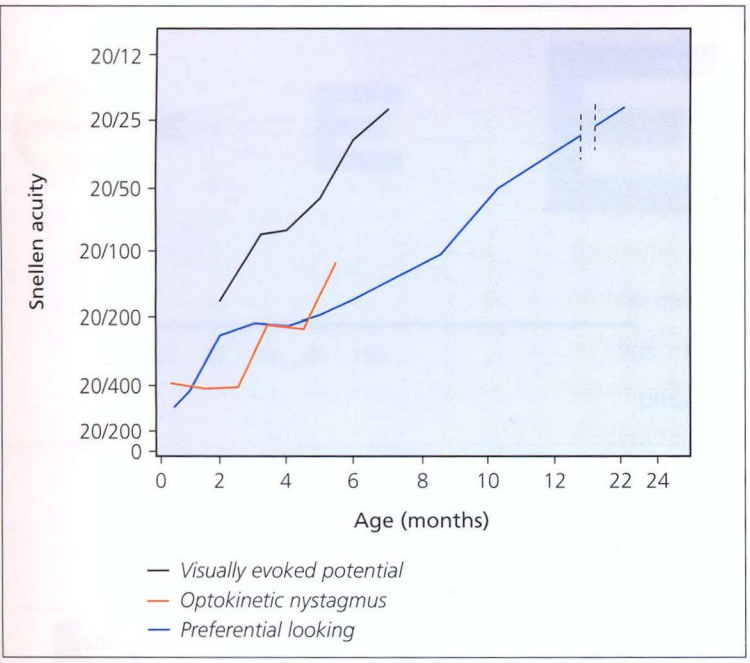


Fig. 1.9 What is known of the development of visual acuity with age depends to some extent on which method of testing was used in studies as VEPs, optokinetic reflexes or preferential looking techniques all give different results. The latter is the most commonly used technique; it shows that infants do not reach adult levels of acuity until 2–3 years of age.
By courtesy of the Editor, Survey of Ophthalmology *1981; 25: 325–332.*

PHYSIOLOGICAL LIMITATION OF ACUITY

The physiological limits of visual acuity are essentially set by the sources of error in the system uncorrectable by standard refraction. Light rays passing through the eye are degraded by inbuilt optical aberrations, thereby increasing the blur at the margins of the images. This loss in edge contrast reduces the resolving power of the visual system. Apart from refractive error (sphere and cylinder), the main optical factors are higher-order aberrations, chromatic aberration and diffraction. Glare disability is produced from forward light-scatter from the ocular media and opacities. It casts a veiling luminance over the macula, reducing image contrast. A good clinical example is posterior subcapsular cataract where acuity is relatively well preserved but the patient has a disabling glare in bright light.

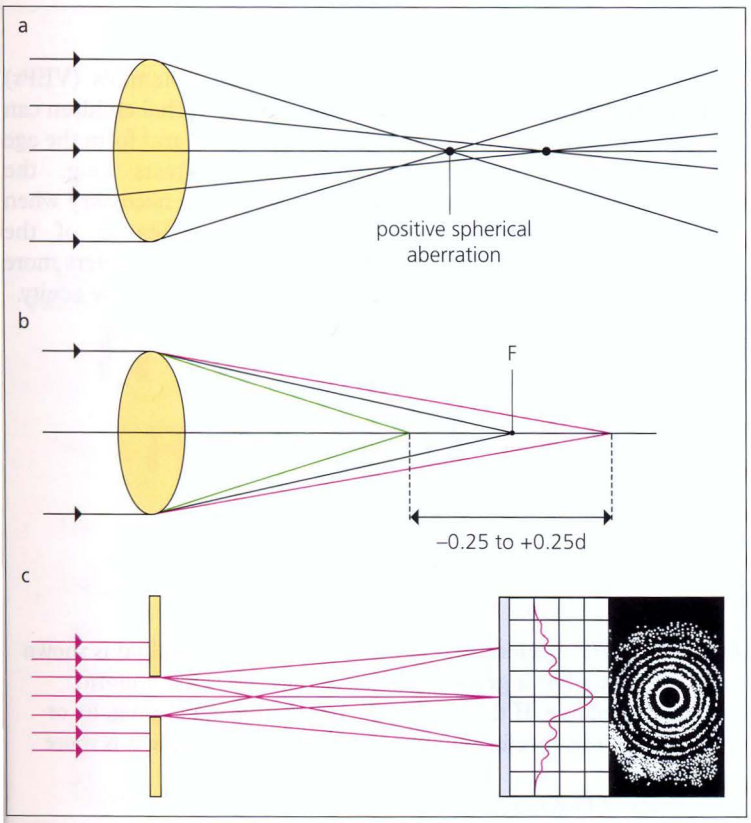


Fig. 1.10 (Top) Spherical aberration. The refractive surfaces of the eye have more effective power at the periphery than at the central paraxial zones. This causes the edge of an image to be blurred by the resulting 'line spread'. Spherical aberration increases with pupillary dilatation. The eye normally has a positive spherical aberration (see Ch. 11).

Chromatic aberration. The refraction of light varies according to its wavelength. Short wavelengths (blue) are refracted more than longer wavelengths (red), polychromatic white light is focused as a coloured blur, and the contrast at the image edge becomes degraded by coloured fringes. (This aberration is used to clinical advantage in the duochrome test to prevent overaccommodation in myopes.)

Diffraction. This becomes important with pupil diameters of less than 2 mm. Light projected through an aperture passes through the centre but is absorbed and retransmitted at the edges. The wavefronts of retransmitted light then cause interference patterns that increase the line spread of the image focused beyond the pupil.

As larger pupillary apertures increase chromatic and spherical aberration and smaller diameters increase diffraction the best compromise is achieved with a pupil diameter of 2.4 mm.

WAVEFRONT ANALYSIS

Wavefront analysis plots the total optical aberration of the eye. The low-order aberrations of sphere and cylinder can be corrected by simple optics; higher-order aberrations cannot be corrected by routine refraction. These used to be referred to as 'irregular astigmatism' and, in the case of irregular corneal astigmatism, can be corrected only by wearing a contact lens. Wavefront analysis allows detailed analysis of these aberrations; it has become important in understanding patient dissatisfaction following refractive surgery and, by correcting aberrations, offers the possibility of supranormal vision. This has yet to be achieved.

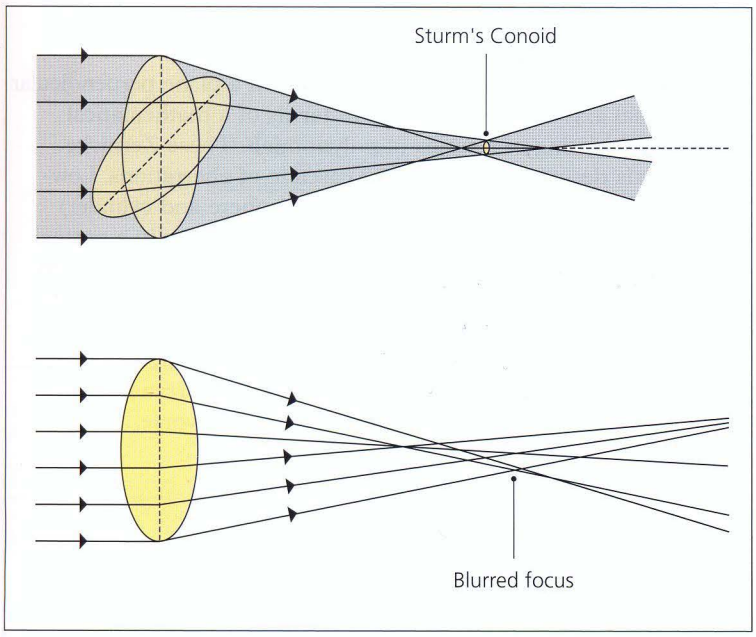


Fig. 1.11 With regular astigmatism, light is brought to focus at two points. Sturm's conoid is the circle of least confusion that can be brought to focus by a sphero–cylinder combination. With the imperfect optics of the eye light is bought to focus in an irregular manner. This caused by higher-order aberrations which can be demonstrated by wavefront analysis and described mathematically by Zernicke polynomial curve fitting equations.

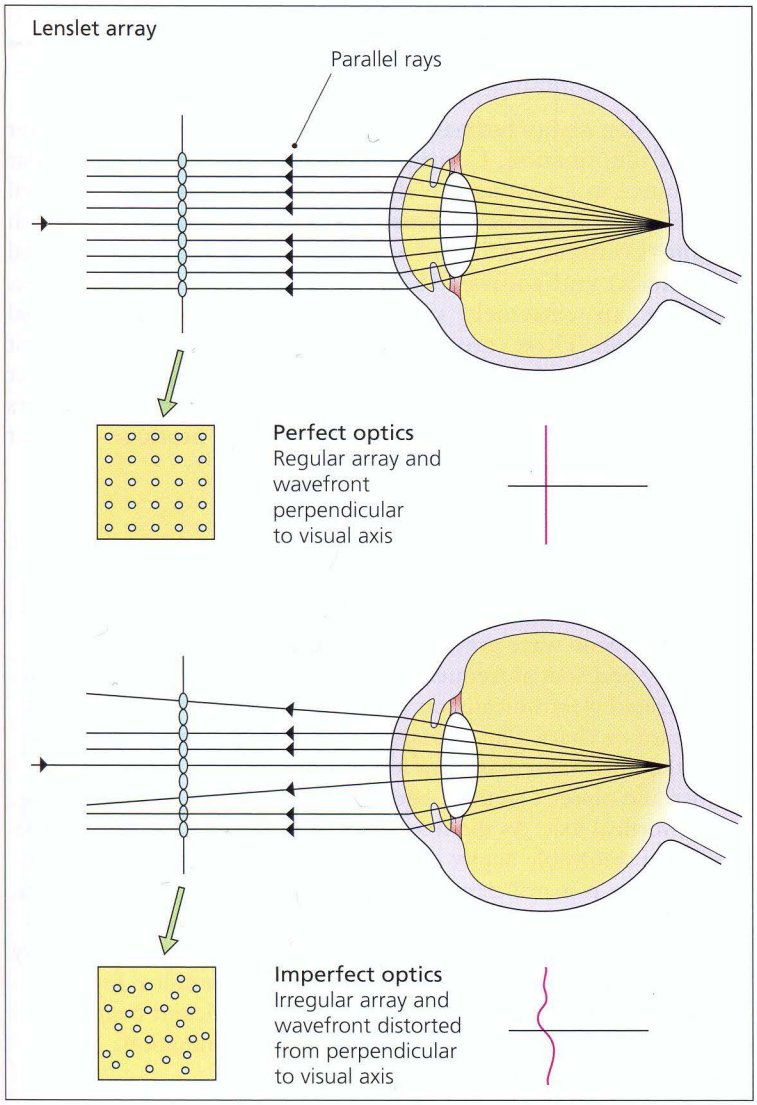


Fig. 1.12 In a perfect optical system rays of light exiting the eye from a spot projected on the fovea should exit the eye parallel to the visual axis with a wavefront perpendicular to the visual axis.

If these exiting rays are imaged through an array of lenslets their displacement from parallel to the visual axis is a measure of the optical errors in the visual pathway. This can be done with a Shack–Hartman aberrometer, a technique that has long been used in astrophysics. Light coming to focus in front of the plane is 'advanced' and that behind the plane is 'retarded'. In the eye most aberration is produced in the cornea.

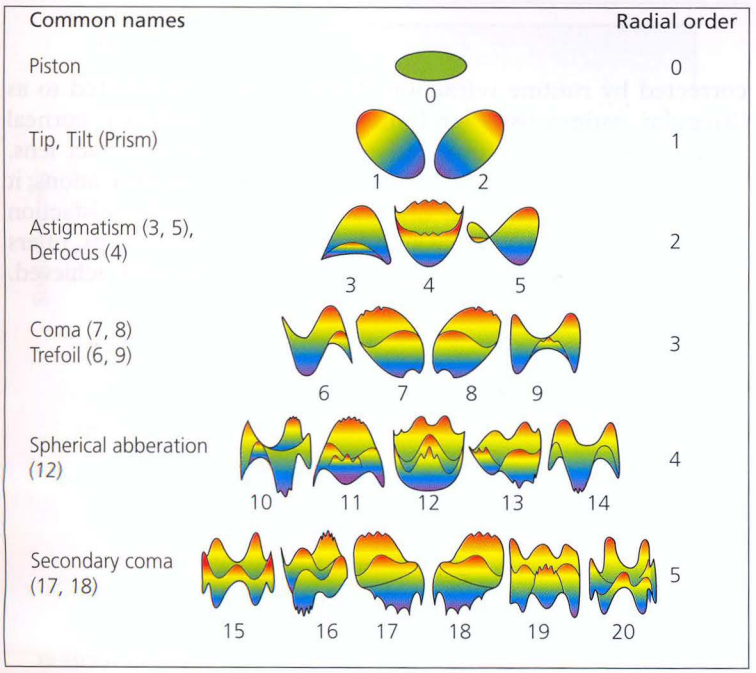


Fig. 1.13 The wavefront deformation from a plane perpendicular to the visual axis can be expressed in terms of a mathematical equation consisting of a series of polynomials. These Zernicke polynomials describe an increasing cascade of aberrations. Low-order aberrations (first and second order: sphere and cylinder) account for more than 90 per cent of refractive error in a normal eye. Third order is coma and fourth order is spherical aberration. Spherical aberration is the clinically most important after sphere and cylinder. Higher orders account for less and less of the aberration. The system becomes extremely complicated as some aberrations can cancel out others; treating one aberration in the absence of all can therefore actually make vision worse.

CONTRAST SENSITIVITY

The eye can detect objects by responding to the differing levels of luminance between a target and its background. This is defined in terms of the maximum and minimum luminance at the detected edge.

$$\text{Contrast} = \frac{\text{Target luminance - background luminance}}{\text{Target luminance + background luminance}}$$

Standard visual acuity tests measure acuity under high contrast conditions but do not tell us anything about visual performance under different circumstances such as driving at night or reading in poor light which are often more appropriate to daily life and cause clinical symptoms. It is thus possible for patients to retain good Snellen acuity but have reduced contrast sensitivity at lower levels of illumination. Contrast sensitivity testing is of particular importance in assessing the effect of refractive surgery on visual performance. It can be measured at either a fixed target size with varying contrast or over a range of target sizes (spatial frequencies) and contrast to derive a contrast sensitivity curve, which is an extremely useful way to assess overall visual performance. There are a number of different ways to test contrast sensitivity; they fall into two groups – either differentiating bars, stripes and gratings or, alternatively, letters against a background. Letter tests usually produce a better performance than gratings.

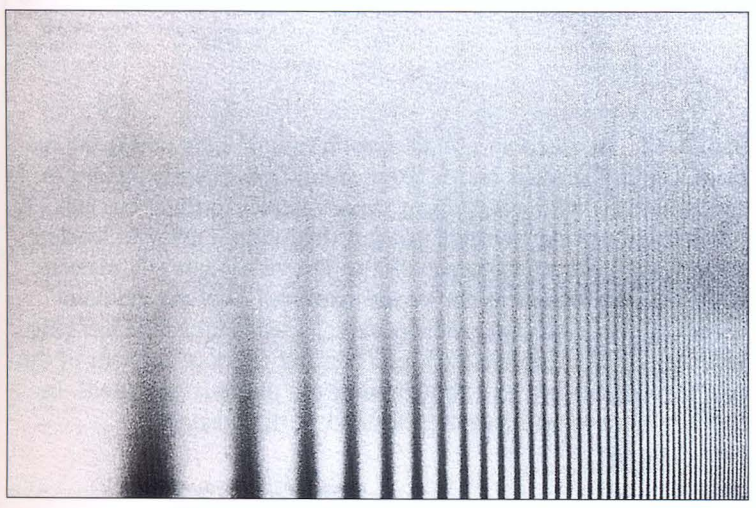


Fig. 1.14 Sine wave gratings can be used to assess contrast sensitivity and spatial frequency simultaneously. The patterns can be generated electronically on a television screen or graphically on a test card or chart. The spatial frequency of the stripes increases along the horizontal axis from left to right (that is, the stripes get thinner and closer together) and the contrast decreases on moving up the vertical axis. As the frequency of the stripes increases to the minimum resolvable acuity (30–40 cycles per second or 1–0.5 min of arc), there is insufficient contrast to distinguish the stripes from the background. As a result the highest resolvable frequencies can be seen only at high contrast (this equates to standard visual acuity tests). Beyond this point the grating appears as uniform greyness. As the spatial frequency decreases there is insufficient contrast to distinguish the stripes from the background illumination.
By courtesy of Mr J W Howe.

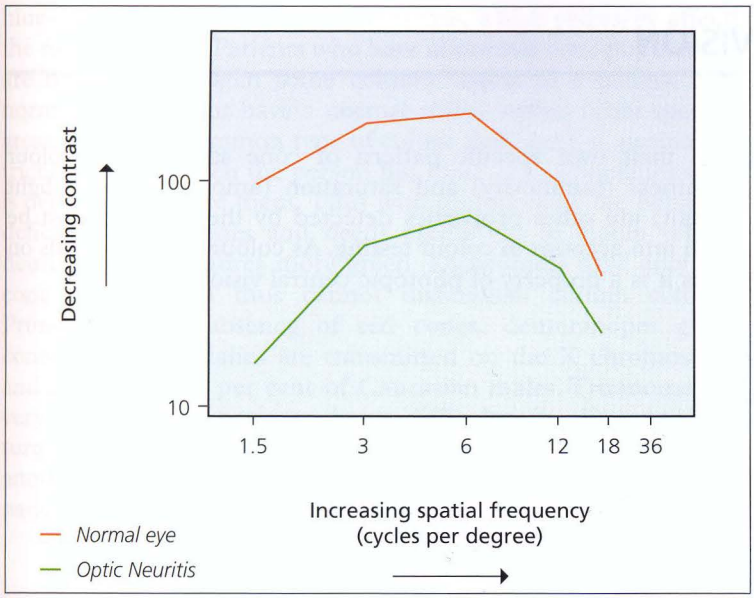


Fig. 1.15 If grating visibility is plotted on a graph, the axes being contrast and spatial frequency, a bell-shaped curve known as a contrast sensitivity curve is formed. At the apex of the curve the subject reaches their highest level of sensitivity at low contrast levels and changes in contrast of 1 per cent or better can be detected. The graph shows the curves of a normal eye compared to the fellow eye with optic neuritis. Although the affected eye has good acuity it will have poorer performance in low-contrast conditions such as poor lighting.

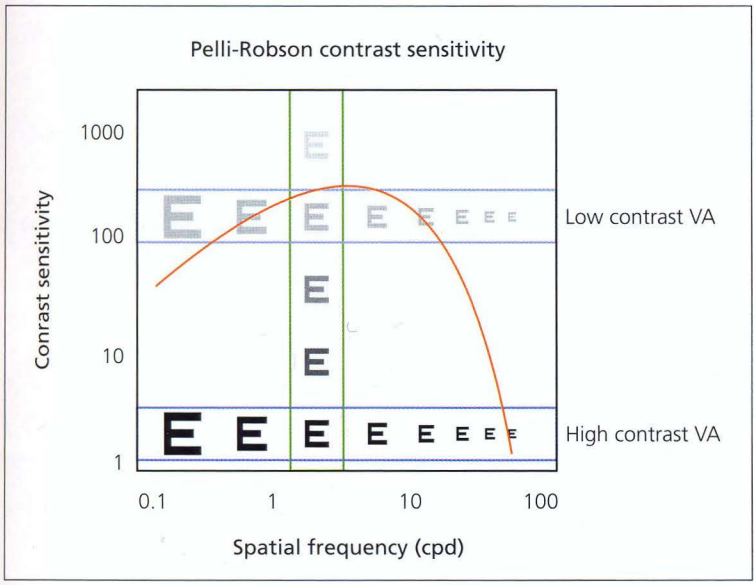


Fig. 1.16 This shows how the different measurements of visual acuity and contrast acuity interrelate. High- and low-contrast visual acuity charts measure a change in spatial frequency at a fixed contrast (horizontal) and the Pelli–Robson chart measures contrast sensitivity at a fixed spatial frequency (vertical).

Fig. 1.17 The Pelli–Robson chart is a commonly used method of measuring contrast sensitivity at a set spatial frequency of 6 six cycles per degree. This corresponds both to the spatial frequencies most important in daily life and to the maximum contrast sensitivity of the eye. The chart is viewed at 1 metre under standardized illumination.

COLOUR VISION

The perception of colour arises from the different cone receptors that are maximally sensitive at three separate wavelengths: red (protan), green (deuteran) and blue (tritan). Light of different wavelengths stimulates each of the cone populations to a different degree so that colours within the visible spectrum arise from their own specific pattern of cone stimulation. Colour brightness (luminosity) and saturation (amount of white light present) are other properties detected by the eye that must be taken into account in colour testing. As colour vision depends on cones it is a property of photopic central vision.

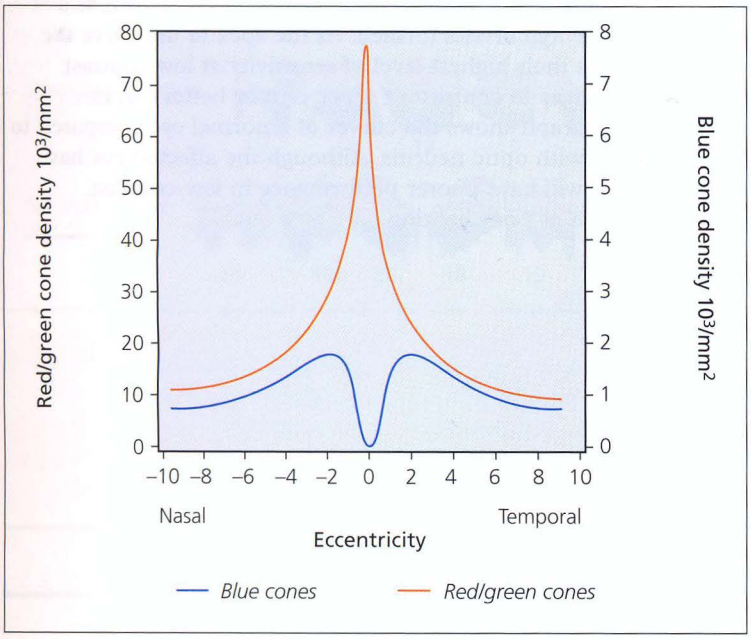


Fig. 1.18 Colour perception is maximal in the centre of the retina but extends out to 25–30° of the visual field. Beyond this, red–green perception disappears and then, in the periphery, all colour perception is absent. There are no blue cones in the fovea and they are less numerous than red–green cones elsewhere in the macula.

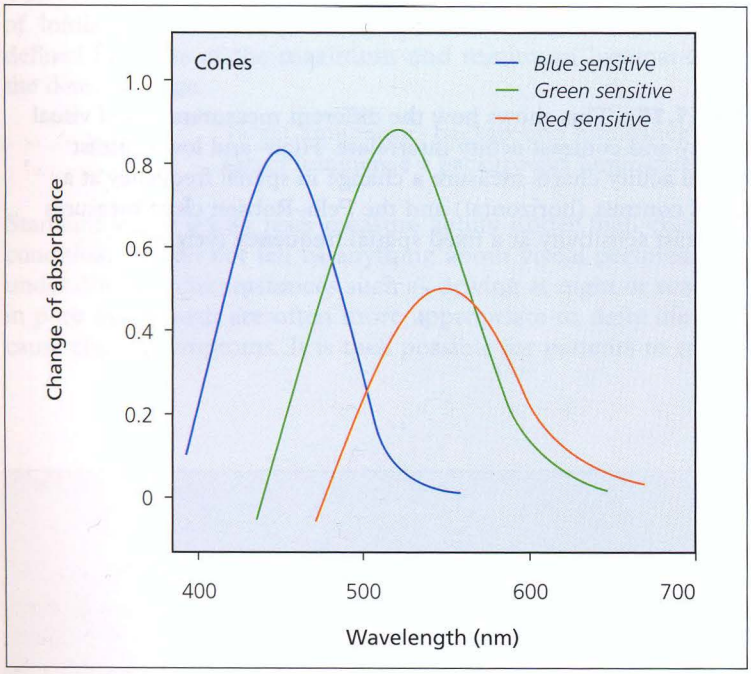


Fig. 1.19 Investigation of the spectral sensitivity curves of the human retina shows peaks at about 440 nm (blue), 540 nm (green) and 570 nm (red). This diagram illustrates the way in which the ranges of wavelength sensitivities of cones overlap; the curves have a gentle slope on the short wavelength side and a rapid fall on the side of long wavelength, that is, towards red.
Adapted from Pyman GA, Sanders L, Goldberg B. Principles and Practice of Ophthalmology. *©1979 Elsevier.*

ABNORMAL COLOUR VISION

Abnormal colour vision can either be congenital or acquired; acquired causes include macular and optic nerve damage. Kollner's rule states that optic nerve disease tends to affect the red–green axis whereas macular damage affects the blue–yellow axis. There are many exceptions to this rule, such as glaucoma and autosomal dominant optic atrophy, which affect the

blue–yellow axis; and Stargardt's disease, which primarily affects the red–green axis. Patients who have abnormal cone populations are not able to match some colours visible to a patient with normal anatomy but have a normal ability within other spectral areas. The most common type of colour deficiency is anomalous trichromacy in which the person has three cone populations but is deficient in one of them. Thus with protanomaly the person is deficient in red cones and needs excess red to match yellow; deuteranomaly requires more green. Dichromats have only two cone systems and thus cannot distinguish certain colours. Protanopes have absence of red cones, deuteranopes green cones. These anomalies are transmitted on the X chromosome and affect about 7 per cent of Caucasian males. Tritanomaly is very rare. These patients have difficulty in distinguishing turquoise blues and greens or yellows and pinks from one another. Achromatopsia is the complete absence of cones. These patients can distinguish colour only in terms of brightness; they have photophobia and poor vision. All patients with congenital colour defects have normal fundi.

Several clinical tests exist for the assessment of colour vision. These include pseudoisochromatic test plates, hue-matching tests and anomaloscopes; the former are the quickest and easiest to use. The most common is the Ishihara test for red–green defects; other types are the Hardy–Ritcher–Rand (HRR) series or the City University System which have the important advantage of testing the blue–yellow axis as well as red–green. If pseudochromatic plates are to be used properly in testing cone function they must be viewed at 75 cm in controlled white light and luminance conditions with appropriate refractive correction. Hue-matching tests, such as the Farnsworth–Munsell test, are more accurate but more time consuming. Testing colour contrast sensitivity with computerized systems is a sensitive, reliable and valid research tool.

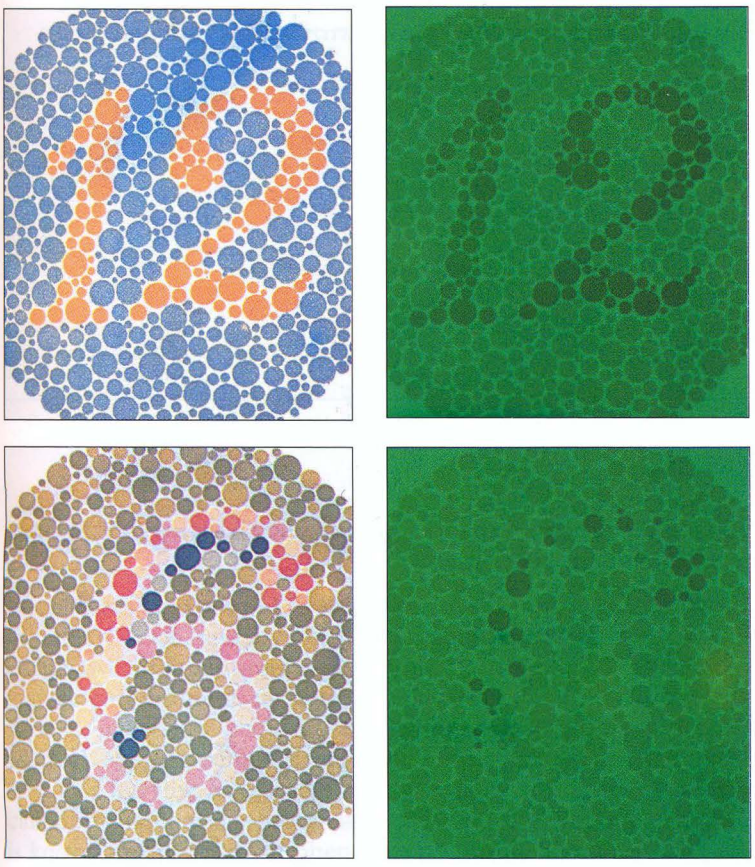


Fig. 1.20 Ishihara plates were originally designed for assessing congenital red–green confusion but are often used clinically to assess colour loss secondary to optic nerve damage. The test consists of plates with a matrix of dots arranged to make either a number or a line that can be traced out. The dots making up the numbers are visible to people with normal red–green colour vision, but are confused with adjacent colours by those who are red–green deficient. The coloured dots are designed to be isochromatic so that the dots making up the letters cannot be perceived by contrast difference alone. A test plate containing the number 12 composed of high-contrast dots is shown at the start to ensure that the subject has sufficient visual acuity to read the numbers. The test plate (a,b) and a trial plate (c,d) are illustrated, with and without a green filter. With the green filter, the test number almost disappears, but the trial plate number is still easily visible as the plate can be perceived by contrast rather than colour discrimination.

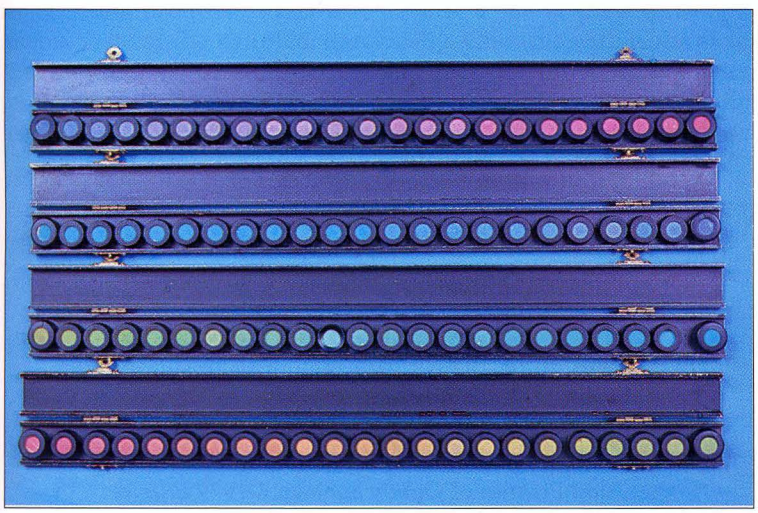


Fig. 1.21 Despite its name, the Farnsworth–Munsell 100 hue test actually consists of 84 coloured tiles arranged in four separate trays. In the test the difference between the tiles is graded so that there is one unit of 'just noticeable difference' between them. Each of the four trays covers a different range of the colour spectrum. Trays of tiles are taken one at a time and jumbled. The patient then views these under a standard white light and rearranges the tiles in chromatic order between the two reference tiles placed at each end of the tray. The misalignment of the tiles from their correct position in the chromatic series is then scored and marked on a standard chart; the greater the displacement, the higher the score. The test is considerably faster when using computerized reading and plotting.

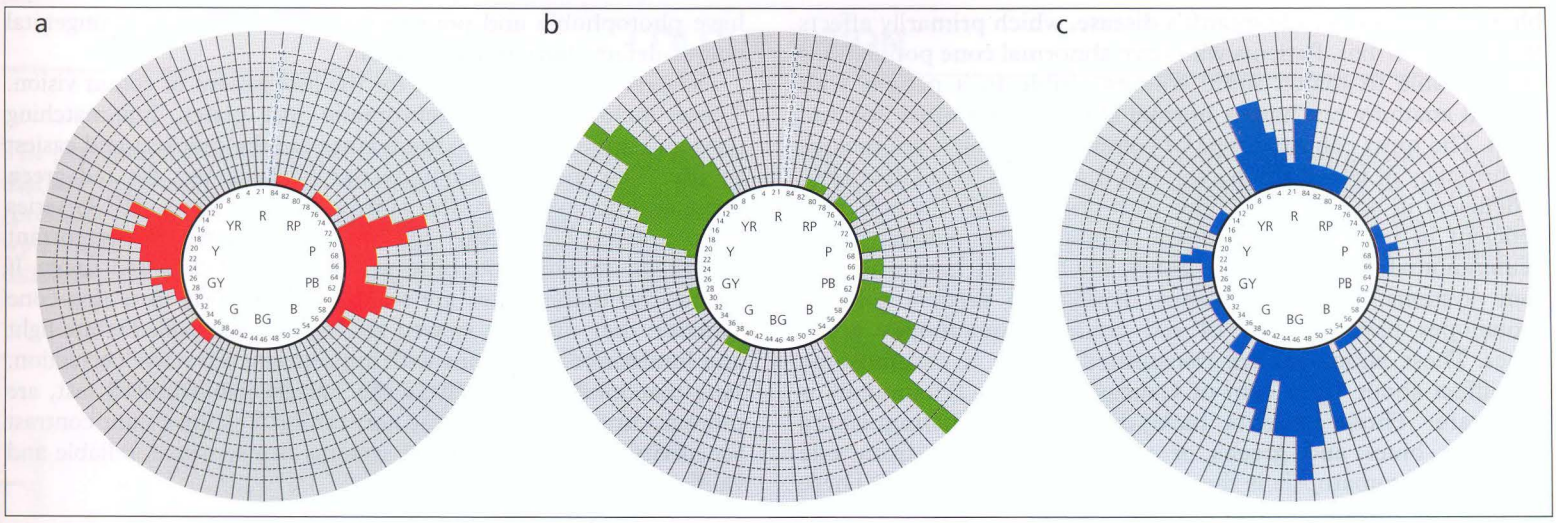


Fig. 1.22 In a normal person only one or two tiles would be misplaced, and the score sheet would appear as a small circle. In the different colour anomalies, however, the chart becomes distorted along a particular axis. The axis of distortion is typical for a particular colour deficiency; examples of the axis for protanomaly (a), deuteranomaly (b), and tritanomaly (c) are shown. Patients with nonspecific acquired colour defects usually make errors in all parts of the wheel.

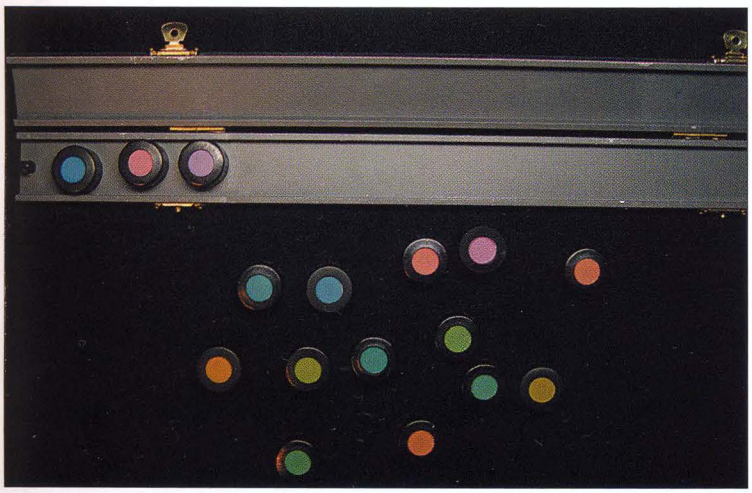


Fig. 1.23 A newer variant of the test, the D-15, uses 15 tiles and is easier and quicker to use.
By courtesy of Mr C.J. Hunt.

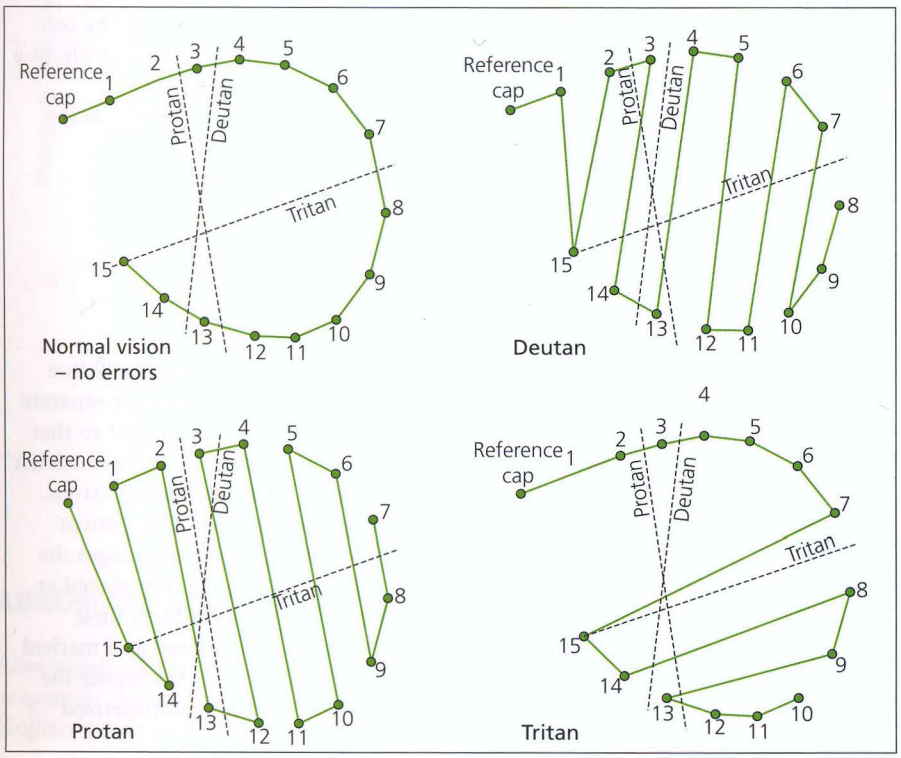


Fig. 1.24 This shows the normal result. Patients with congenital colour defects have difficulty in matching tiles along a particular axis.
Adapted from Pyman GA, Sanders L, Goldberg B. Principles and Practice of Ophthalmology. *©1979 Elsevier.*

VISUAL FIELD TESTS

The visual field is the area in space perceived by the eye classically described by Traquair as 'an island of vision in a sea of darkness'. The sensitivity (or threshold) for stimulus detection varies throughout the visual field and, in the absence of pathology, depends largely on the number and function of the ganglion cell receptive fields at any given point. Lines (isopters) connect points where a target of the same size and brightness is first perceived on kinetic perimetry, that is, points of equal retinal sensitivity. As with acuity and colour vision a person's visual field is altered by background illumination as this affects retinal adaptation and receptor function.

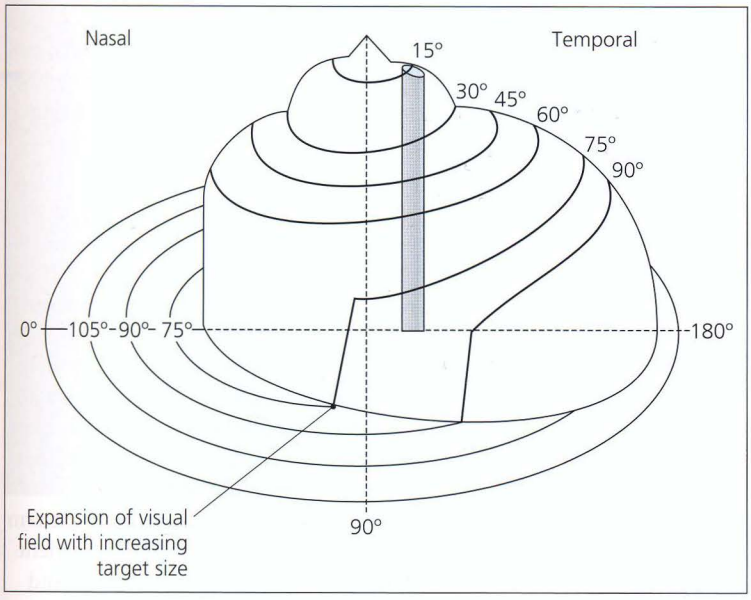


Fig. 1.25 The plot of the visual field isopters can be represented in a three-dimensional form called Traquair's Island, in which the isopters appear as contour lines on the island. The height of any point on the island is proportional to the sensitivity of stimulus detection at that point and thus is inversely proportional to the threshold. The topography of the island is not static but varies with retinal adaptation. Under mesopic conditions, the gradient of sensitivity away from the central areas is much more gentle than under photopic conditions, where the peripheral retina is desensitized and foveal function is more acute. For this reason, it is important that comparisons of the visual field are made under standardized conditions of retinal adaptation.

MEASURING VISUAL FIELDS

Visual fields are assessed to localize lesions in the visual pathway, document their severity and measure progression with time. Qualitative or quantitative techniques can be used. Perimetry may be either kinetic or static, the latter manual or automated. Kinetic perimetry requires a moving target to be detected whereas static perimetry requires perception of a stationary target of varying brightness. Occasionally, a stationary target cannot be perceived whereas an equivalent moving one can; this is known as the Riddoch phenomenon. While kinetic fields have the advantage of producing a readily interpreted 'map' of isopters static fields produce numerical data at a set of predetermined points that can be handled statistically. Changes within the field can be followed more precisely and this has proven to be very useful in the management of glaucoma. Computer-assisted static perimetry, complex testing strategies and data analysis, such as comparison with age-matched controls and the calculation of reliability indices makes it easier to store and analyse sequential data in order to detect disease progression. A major advantage of computer automated over manual kinetic perimetry is that it is less operator dependent. Disadvantages relate to its complexity, a considerable patient learning curve, patient fatigue and normal fluctuations in this field over time.

The results of visual field testing depend on the stimulus used (size, colour, brightness) and the background illumination. It is therefore important to be aware of these values when comparing different field tests. Other factors that can affect test results include patient fixation and concentration, test duration, refractive errors (for the central field only), media opacity (e.g. cataract), miosis and objects accidentally obstructing the field (e.g. rim of glasses, upper lid).

Fig. 1.26 The simplest way to test the visual field is a confrontation technique. The examiner sits opposite the patient at a distance of approximately 1 m. The patient and examiner cover opposite eyes with their palms so that the uncovered eyes have mutually congruent fields. The examiner then introduces a test target into the field (fingers, hand, red bottle cap) until the target is perceived by the patient (kinetic perimetry). The patient's and examiner's fields should be congruent, so the presence of a defect is noted by the absent patient response when the object is visible in the examiner's field. A red target is especially useful for detecting early neurological defects in the central 30° of the field. This is because the retrobulbar pathways are particularly sensitive to red, being concerned mainly with macular vision. If the patient is asked to compare the quality of colour between quadrants (static perimetry) very early defects, such as a bitemporal hemianopia, can be detected subjectively. With practice, a confrontation field can be obtained from almost any patient and produces helpful localizing information.

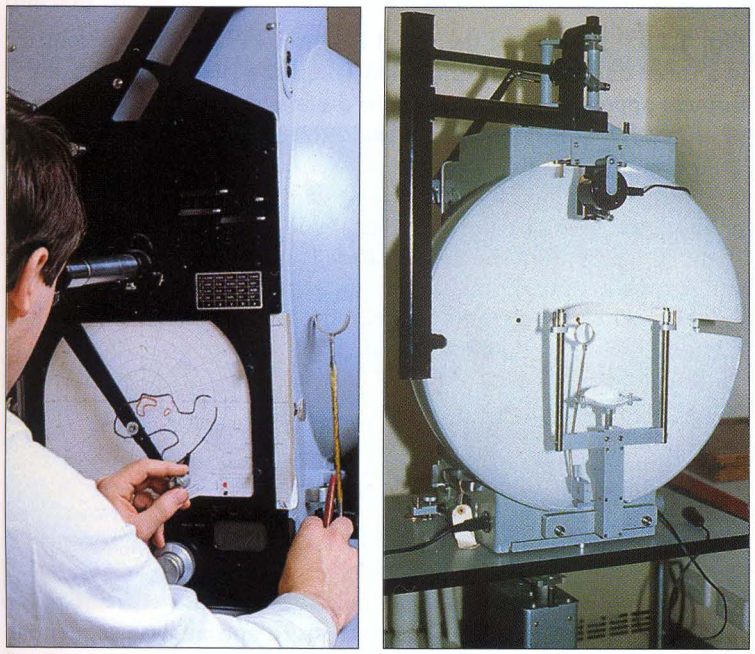


Fig. 1.27 The Goldmann perimeter is usually used for kinetic perimetry but can be adapted for some basic static perimetry. It consists of a hemispherical bowl that is uniformly illuminated and on to which target lights of varying size and brightness are projected. Target size, brightness, colour, background illumination and fixation are all controlled. The patient sits at the machine with the eye to be tested fixed on the centre of the hemisphere. Fixation is checked by an observation telescope mounted at the central fixation point. The target lights are then introduced by the projector into the visual field of the patient while a pantograph arm moves across a standard recording chart at the rear. As the patient signals perception of the target the examiner marks the chart and eventually plots the isopter to the particular target. The test is usually undertaken at several isopters of target size and brightness, thus producing a kinetic field that demonstrates the area and density of field loss. A static assessment can be made by flashing the target light within the appropriate isopter. Goldmann fields have the disadvantage of being somewhat examiner dependent but they do assess the full field area making them useful for assessment of neurological deficits.

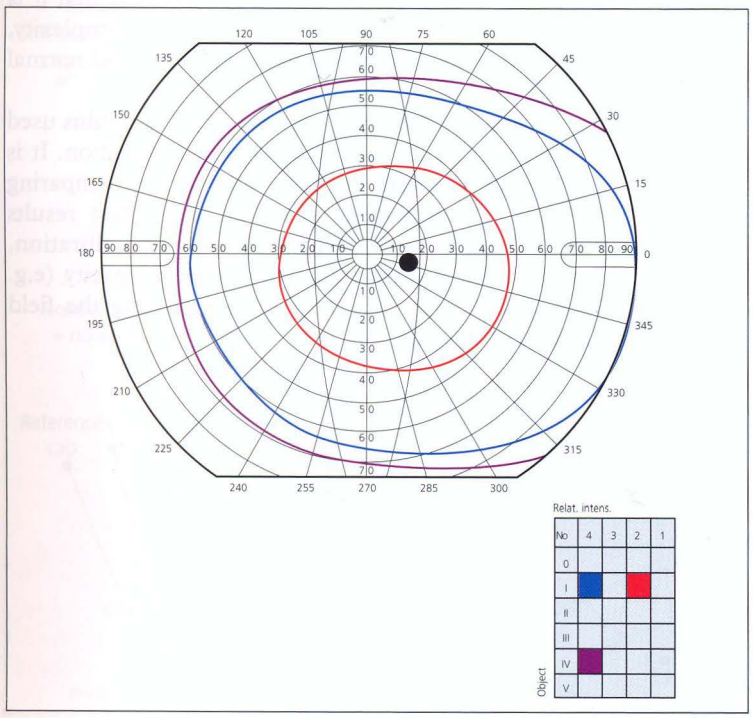


Fig. 1.28 A typical visual field as plotted on a Goldmann perimeter. The visual field, which is marked off in degrees from the fovea, is not circular but displaced laterally and downwards. The upper and medial limits are approximately 60°, the temporal 100° and the inferior 75°. In the temporal field the exit of the optic nerve is marked by the blind spot, 5.5° in height and 5° wide, the centre being about 15° from the centre of foveal fixation. The prominence of the brow and the nose may cause artefacts in the nasal and superior visual field that the examiner must be aware of and able to correct.

Fig. 1.29 The most commonly used computer-assisted static perimeter is the Humphrey analyser, shown here. Static targets of fixed size but variable intensity are presented randomly at different retinal coordinates within a bowl perimeter of constant photopic background illumination (21.5 asb). These coordinates have been selected for their discriminatory potential in glaucoma. Fixation is automatically monitored and displayed on a television screen to the side. Throughout the procedure the software program checks and rechecks that fixation is maintained and scores how well the patient fixates. To test for false-positive results the stimulus is withheld when the machine audibly indicates stimulus presentation. False-negative findings are assessed by re-examining a number of tested areas with a suprathreshold stimulus. The duration of the test depends on the number of repetitions at each point and the speed of the patient's response. To perform well the patient needs to be familiar with the test – a learning curve is often demonstrated. The Octopus machine is another computer-assisted static perimeter using a mesopic background illumination (4 asb).

Static field analysers measure the threshold intensity for stimulus detection at each point. The human eye needs about a 10 per cent increase in brightness to discern a stimulus against background luminance. The intensity of luminance of the target is measured in apostilbs and converted to a logarithmic scale (decibels). 1 log unit of retinal sensitivity is 10 dB, with a range from 0 to 40 dB. To measure threshold the Humphrey analyser increases the target luminance in 4-dB steps until detection and then decreases it by 2 dB to define the threshold. Values are given in decibels of attenuation and correspond to retinal sensitivity. Thus, the higher the value, the greater the attenuation of the stimulus and the more sensitive the retina. Full threshold testing is time consuming and difficult for some patients so a variety of faster test strategies exists. The most widely used is the SITA program (Swedish Interactive Thresholding Algorithm). Suprathreshold programs can be used for screening. These detect variation from the age-matched norm and do not calculate absolute values at each point.

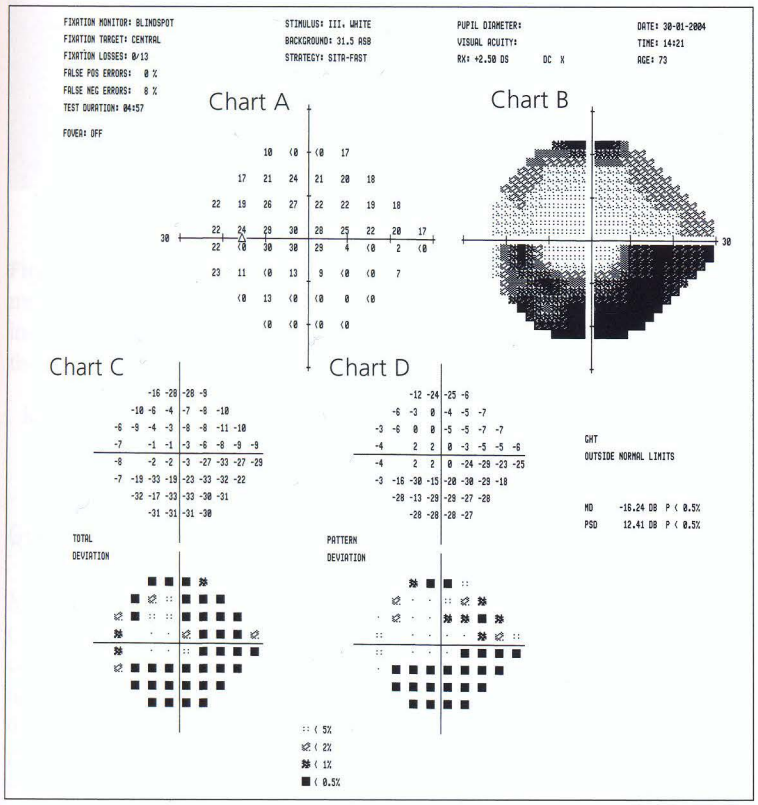
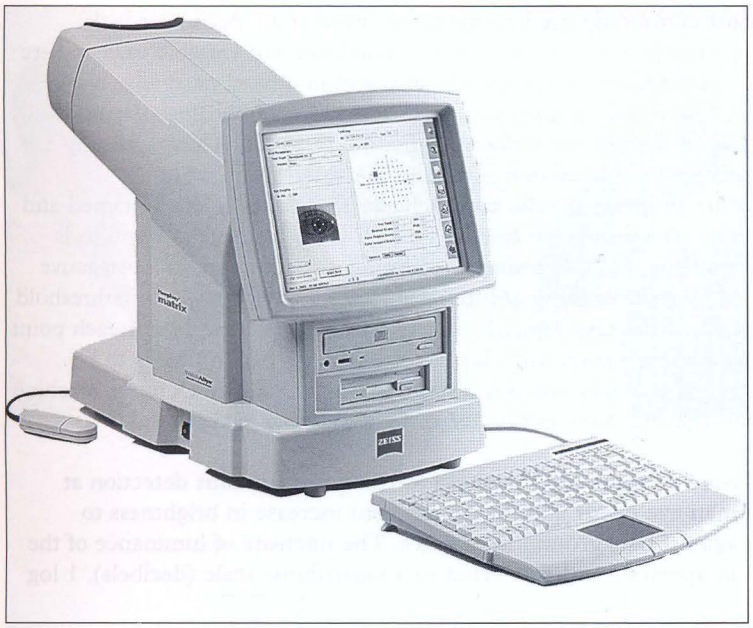


Fig. 1.30 Computer printout from a Humphrey visual field analyser showing the location and sensitivity of the 54 tested retinal loci in the 24-2 program. Chart A represents the actual retinal threshold at each locus in decibels. Chart B shows this as a grey scale for rapid interpretation. Chart C shows the total deviation. This is the difference at each point from an age-matched control; the lower chart converts this to a statistical probability. Chart D adjusts this to compensate for any generalized depression across the field (e.g. from cataract or miosis), thereby defining focal loss more clearly. Average numerical 'global indices' for these deviations are also given as mean deviation (MD) and pattern standard deviation (PSD). In addition, reliability indices are given on the printout. These are fixation losses, false positives (trigger-happy patient) and false negatives (inattentive patient). This is assessed by measuring the threshold twice at ten predetermined points.



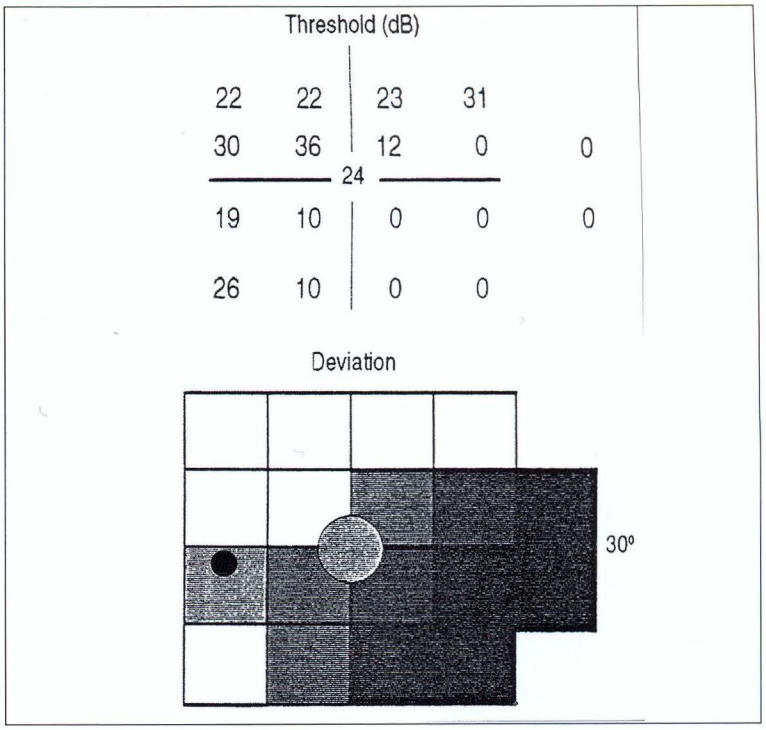


Fig. 1.31 Glaucoma has been shown preferentially to affect the large-diameter optic nerve axons (magnocellular pathway). Several new tests are designed to exploit this and have considerable clinical potential. Frequency doubling perimetry projects a low frequency (1 cpd) sine wave grating into a sector of the retina. The grating is moved at high temporal frequency until the patient gets the sensation that the frequency of the grating has doubled (i.e. there are twice as many bands); this is the endpoint. The test is rapid and sensitive, can be done in room light, and patients prefer it to conventional perimetry. Another new test is SWAP (shortwave automated perimetry) which uses a blue target on a yellow background. This test is very sensitive in detecting glaucoma defects but is affected by cataract.

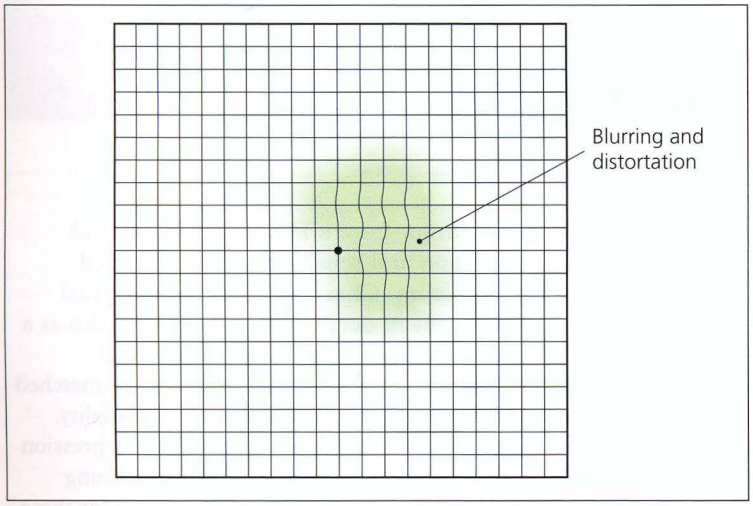


Fig. 1.32 The Amsler grid is a field test that assesses the central 10° of vision qualitatively. It is an effective and rapid method for detecting macular abnormalities that cause blurring or distortion. The test is monocular. The patient holds the grid 25–30 cm away, fixing on the central dot and draws around the area of abnormality. Sequential grids are very useful to follow changes.

OCULAR EXAMINATION

SPECULAR MICROSCOPY

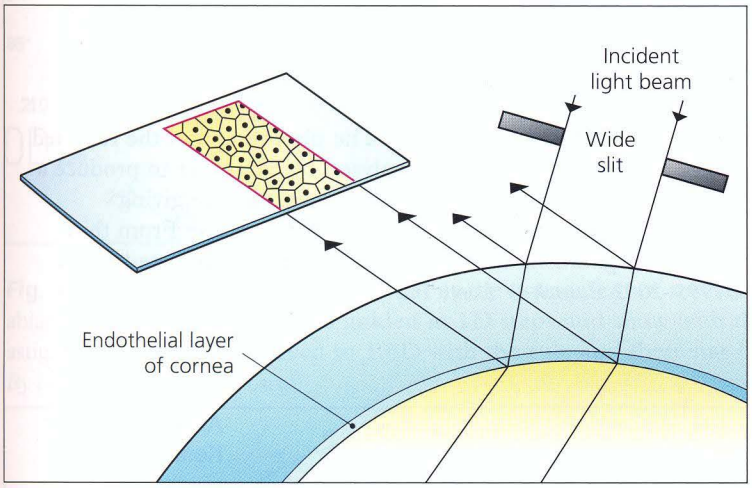
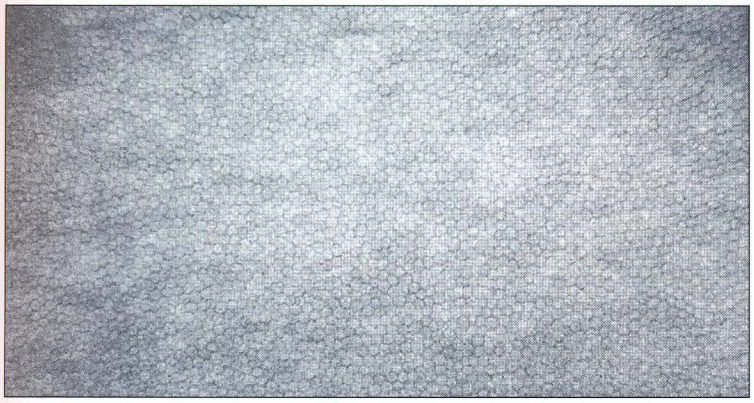


Fig. 1.33 When a beam of light traverses a heterogeneous optical medium most of the light is transmitted, but at each optical interface a proportion of light is reflected.



Fig, 1.34 Specular reflection is used as the basis of specular microscopy to view or image the corneal endothelium and other intraocular surfaces such as the surface of an intraocular lens, in this case showing foreign body giant cells on the IOL.

CORNEAL TOPOGRAPHY AND KERATOMETRY

Measurement of corneal curvature is essential for the fitting of contact lenses, assessment of the eye for refractive surgery, correction of excessive astigmatism and the correct calculation of intraocular lens power. It is also useful for monitoring corneal diseases such as keratoconus. Measurement is based on the principle that the anterior surface of the cornea acts as a convex mirror reflecting a small portion of incident light to form the first Purkinje image, which is visualized to form a map of isopteric power. It is important to realize that corneal topography simplifies corneal refraction as it assumes that refraction takes place at a single interface with a single refractive index. In reality, the anterior corneal surface has a curvature of +49D, the posterior surface of -6D, with variations in the refractive index across the corneal tissue layers. These factors become extremely important after laser refractive corneal surgery which changes all three parameters. This is the reason why standard biometry for intraocular lens calculation is unpredictable after laser surgery.

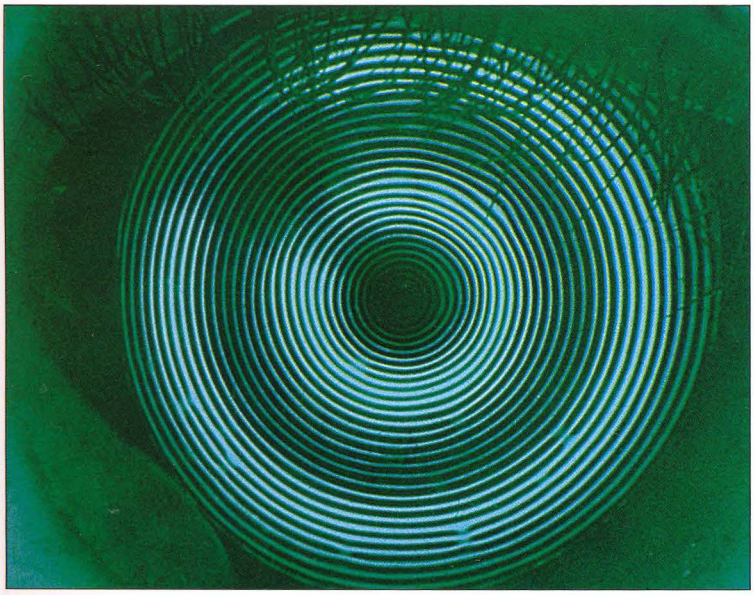


Fig. 1.35 Corneal topography. The photograph of the reflected image and its distortions are analysed by computer to produce a topographical map of the anterior corneal surface giving quantitative information on the corneal curvature. From this, corneal astigmatism and its meridians can be calculated.
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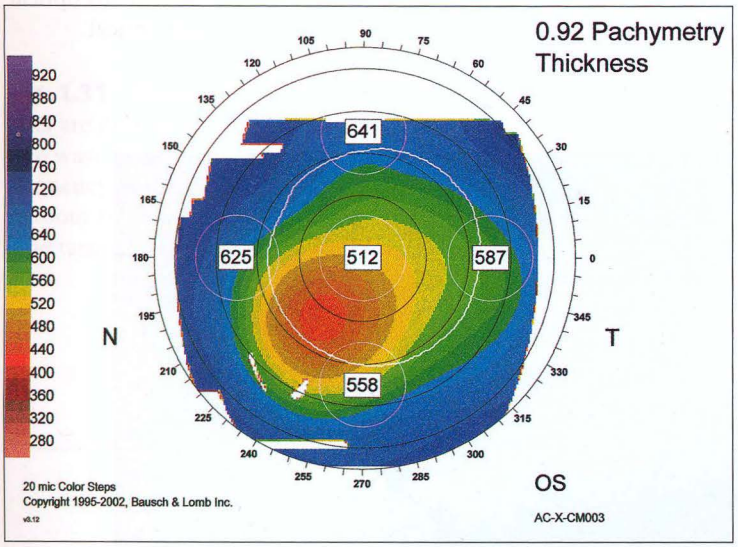

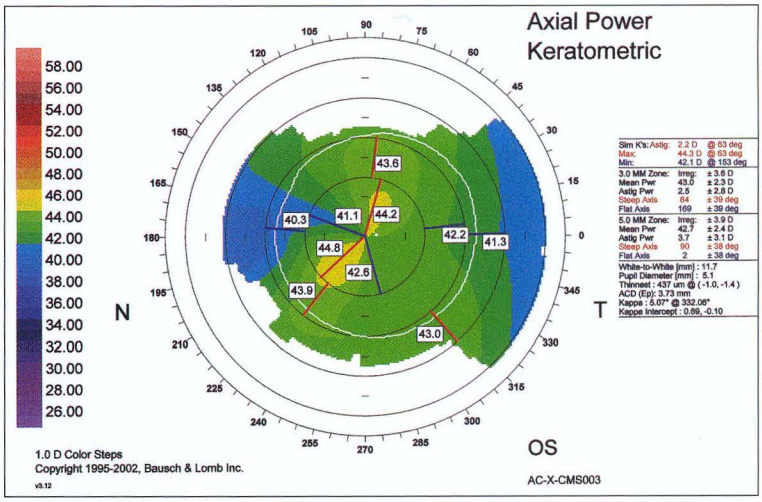

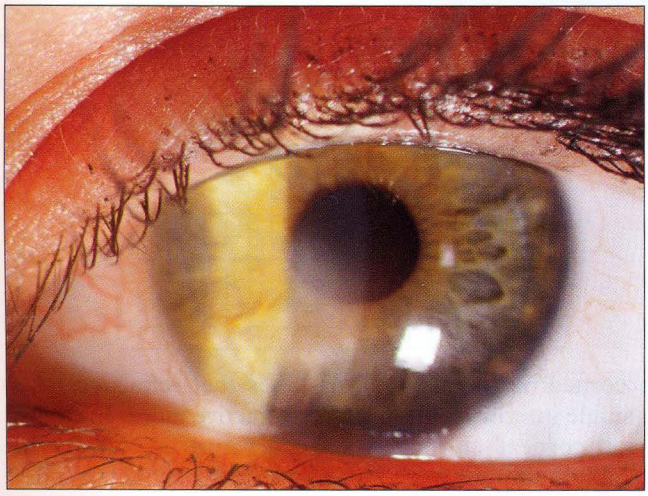

Fig. 1.36 Topographic printouts are colour coded. By convention steep areas are coloured red and flat areas blue although the actual dioptric values for each colour are not standardised between instruments. Most normal corneas remain within the yellow-green spectrum of the scale. Common patterns seen include a bow tie pattern in astigmatism and a central steep island in keratoconus (see Chapter 6). This eye has an old scar inferio-nasally. The pachymetry map shows this area is thinned. Topography shows this area is slightly ectatic with a steeper curvature causing irregular astigmatism.
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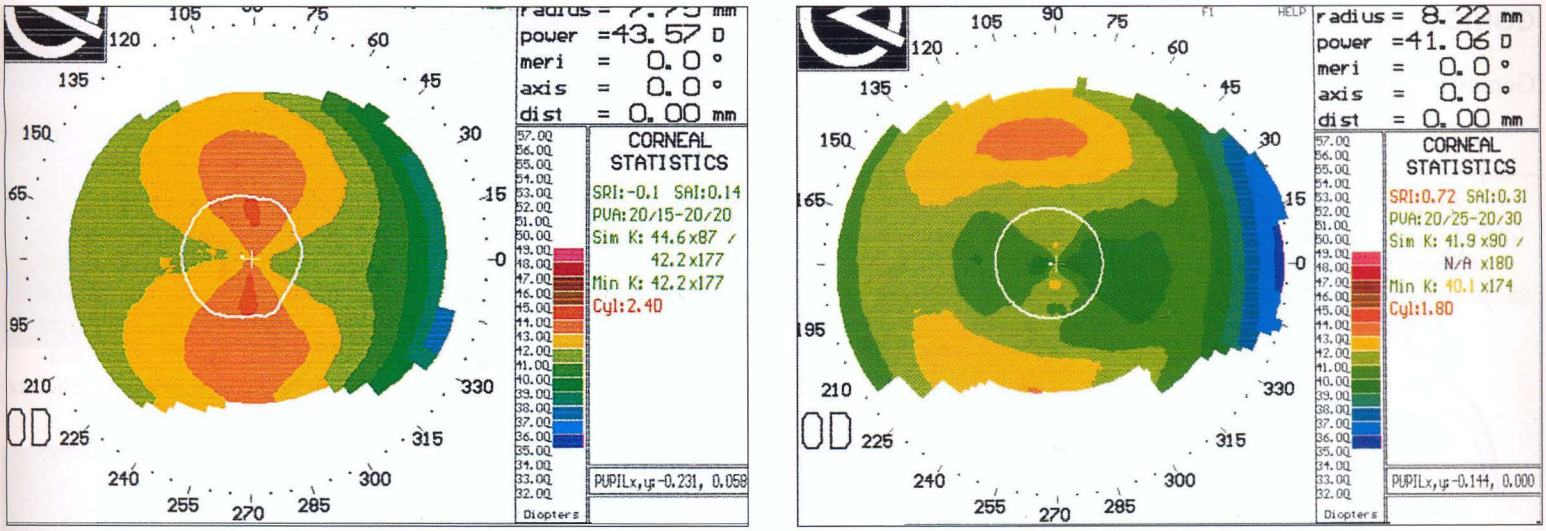
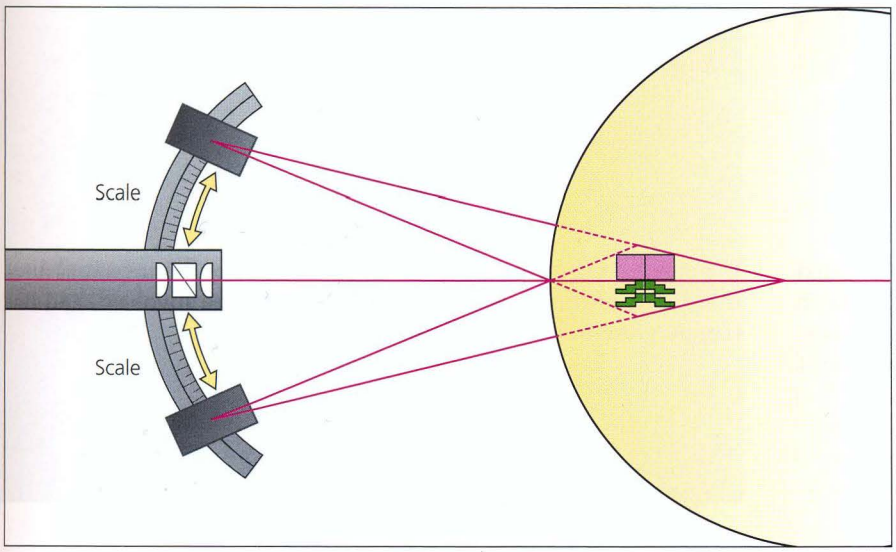


Fig. 1.37 This technology is essential in the assessment of refractive corneal surgery. These charts show a cornea before excimer laser ablation (left). The isopters are graded in 1D steps and show with the rule astigmatism of 2.4D. After photoablation (right), the astigmatism has been reduced to 1.8D with the rule and there has been a reduction of myopia of 2.5D.
By courtesy of Mr D O'Brart.



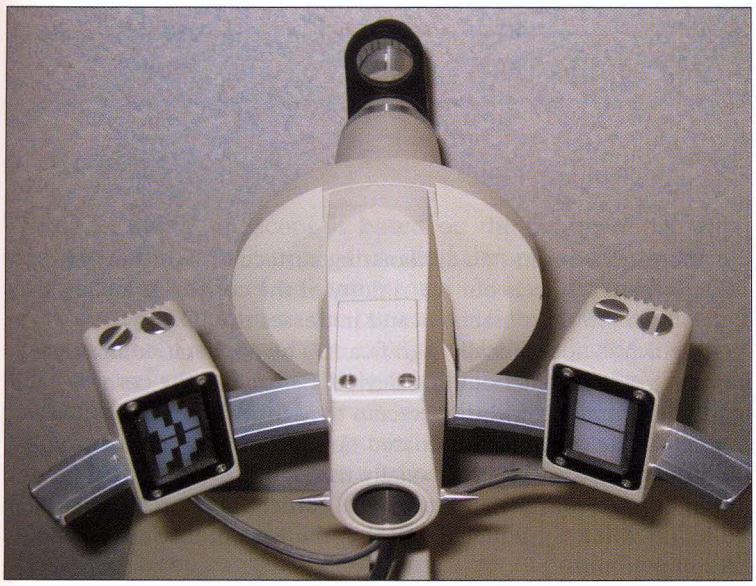


Fig. 1.38 Corneal curvature is routinely measured before cataract surgery to calculate intraocular lens power. Although this information can be obtained from detailed topography only the curvature of the central 3 mm of cornea is important for this and this can be obtained from a simplified topographic technique or by manual keratometry. The spherical power in the axis of the two regular meridians can easily be measured using a basic keratometer of which there are two types (Schiotz and Helmholtz). The former uses an object of varying size and the latter an image of varying size.

The Schiotz keratometer is essentially a microscope with a fixed working distance so that when the cornea is in focus the apparatus is a fixed distance from it. There are two illuminated objectives, green and red; these are mounted on a curved track to keep them equidistant from the cornea on either side of the central eyepiece. To prevent any relative movement of the images when viewing the cornea the instrument incorporates a doubling device so that both images move together. When the images (mires) of the two coloured objectives are seen on the cornea in apposition the endpoint has been reached and the corneal curvature can be read directly from a scale on the arms supporting the objectives. Alignment of the horizontal bars in the mires allows the axis of astigmatism to be increased and the corneal curvature in the other meridian to be measured by rotating the objectives through 90° around the axis of the telescope.

GONIOSCOPY

Gonioscopy is the visualization of the angle of the anterior chamber.

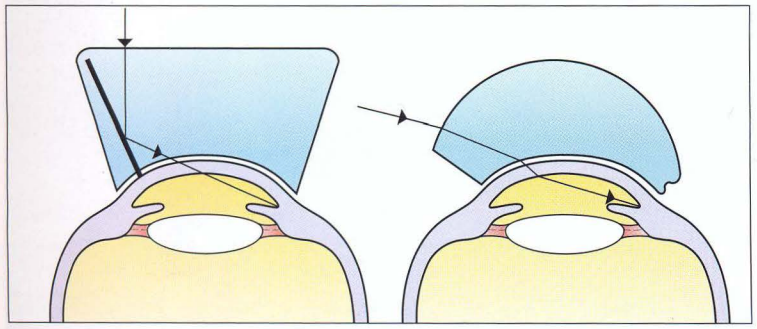


Fig. 1.39 The optics of indirect and direct gonioscopy are illustrated. Direct gonioscopes (e.g. Barkan) provide an erect view of the eye and are used for surgical goniotomy for buphthalmos. Indirect gonioscopy (e.g. with a Goldmann or Zeiss lens) produces a mirror image of the opposite angle and is used with a slit lamp for diagnostic purposes or laser goniotomy. It can be combined with corneal depression (indentation gonioscopy) to assess whether the angle can be opened by the displaced aqueous. Such indentation gonioscopy is invaluable in assessing primary angle-closure glaucoma.

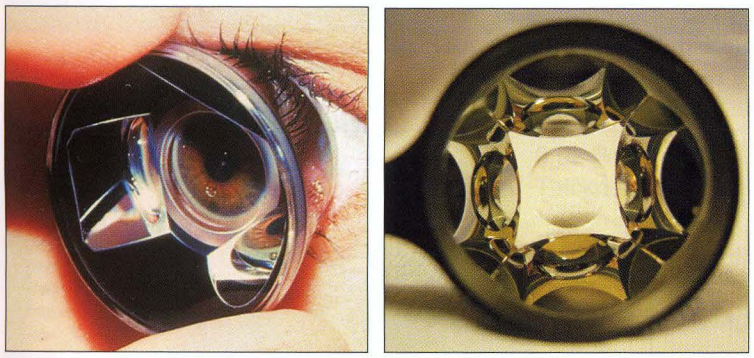


Fig. 1.40 The Goldmann indirect gonioscopy lens is a solid perspex contact lens within which is mounted a small steep mirror. The lens requires a coupling medium for use, such as saline or hypromellose, as its curvature is steeper than that of the cornea. The full circumference of the angle can be inspected by rotating the contact lens on the surface of the eye. Lenses such as the Zeiss 4 mirror goniolens have a shallower radius of curvature and hence do not require fluid between the lens and the cornea; however, this makes corneal wrinkling more likely. The additional mirrors eliminate the need to rotate the lens; such lenses will also easily indent the cornea for indentation gonioscopy.
Left image by courtesy of Mr B Dong.

TONOMETRY

Intraocular pressure (IOP) is measured by tonometry. Most instruments use applanation (e.g. Goldmann, air puff), which works on the principle that a force required to flatten a given area of corneal apex will be proportional to the IOP that maintains the corneal curve. Indentation tonometry (e.g. Schiotz) measures the depth of deformation rather than the area involved, and has largely gone out of clinical use.

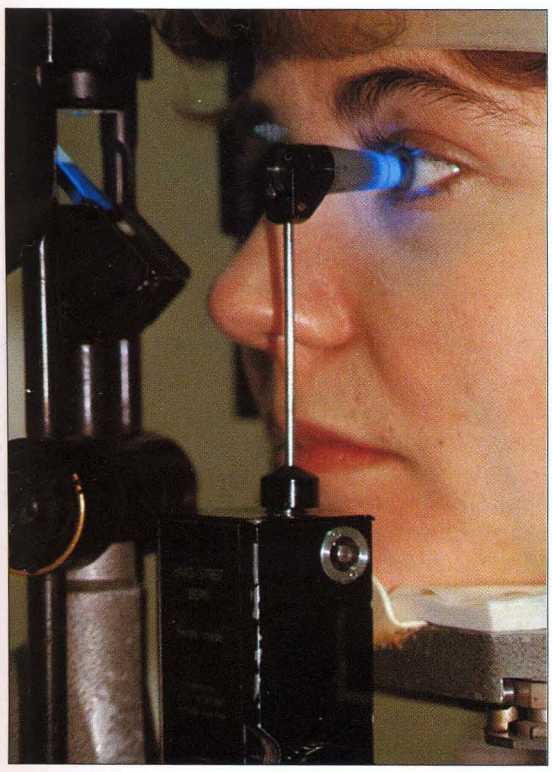


Fig. 1.41 The Goldmann tonometer has an applanating surface of 3.06 mm^2, at which the effect of surface tension cancels out the rigidity of the cornea. It indents the eye less than 0.2 mm, displaces 0.5 ml of aqueous and increases the IOP by approximately 3 per cent which is not clinically significant. The applanation head has a clear centre that incorporates a prismatic doubling device. Before use the corneal epithelium is anaesthetized and stained with fluorescein to identify the tear meniscus around the applanating head. The prism is illuminated obliquely by the slit lamp with the cobalt blue filter and the cornea is viewed coaxially through the applanation head which is then gently brought to rest on the surface of the cornea. The force applanating the cornea is increased by revolving a graduated wheel at the base of the instrument, calibrated in millimetres of mercury.

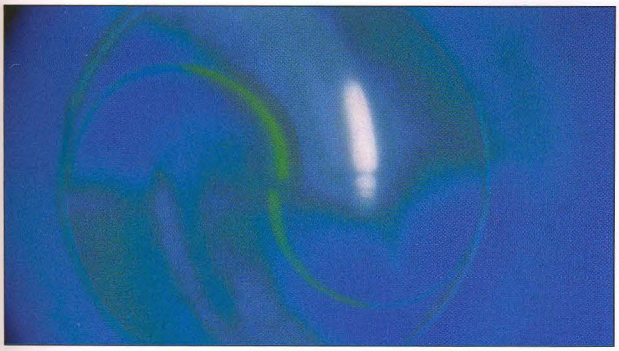


Fig. 1.42 This shows the endpoint at which the IOP is measured. The split image of the tear film meniscus can be seen around the tonometer head, outlined by the semicircular fluorescein rings with the edges just overlapping. If the pressure on the tonometer head is too low, the resulting applanation area is small and the split rings do not overlap; if it is too high, they overlap by more than the thickness of the meniscus.

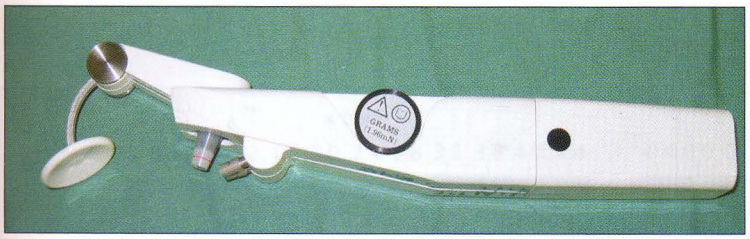


Fig. 1.43 The Perkins tonometer is a hand-held variant that employs a Goldmann prism. The body rests on the patient's forehead and the fluorescein rings are viewed through a convex lens aligned with the prism head. It is often used for assessing IOP in anaesthetized children or patients who cannot sit at a slit lamp.

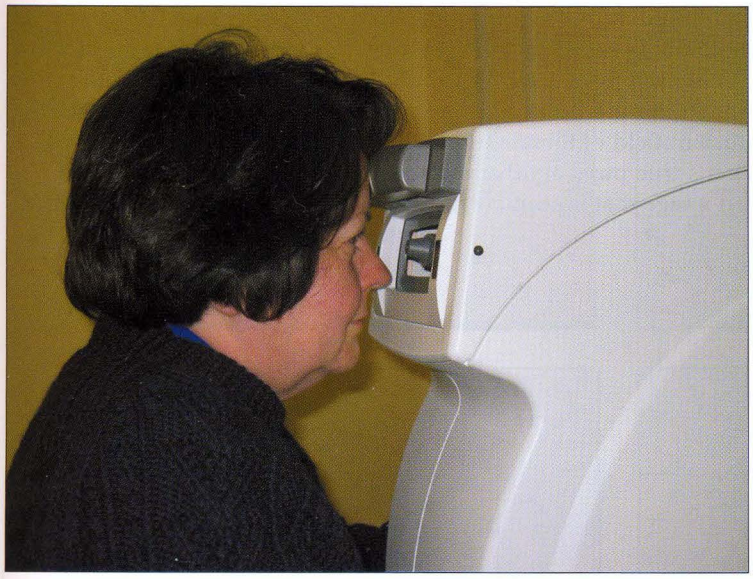


Fig. 1.44 Noncontact applanation tonometers use a puff of air to deform the cornea and measure the time taken to produce a set amount of corneal flattening. This time is proportional to the IOP. The reliability of this type of tonometer is reduced in higher pressure ranges but it has the advantage of no contact with the eye, thus preventing any risk of cross-infection and obviating the need for topical anaesthesia making it ideal as a screening device in optometric practice.

IMAGING THE GLOBE AND ORBIT

OPHTHALMOSCOPY

The direct ophthalmoscope is based on the principle that rays emanating from the retina of an emmetropic subject will be focused on the retina of an emmetropic observer. It consists of a light source directed on to the patient's retina by a small angled mirror that has a transparent area to allow light reflected from the retina to be viewed. The image is erect and real. With an emmetropic subject and observer, it has a magnification of ×15, which arises from the 60D power of the patient's eye (45D cornea + 15D lens) behaving as a loupe (60/4). The field of view is quite small at approximately 6½°. A set of lenses positioned in front of the examiner's eye allows refractive errors of either patient or examiner to be corrected and has a range of powers from +30 to -30D. The lenses also allow the ophthalmoscope to be focused to view some anterior features such as media opacities. Filters can also be rotated in the path of the returning light rays, of which the green or 'red-free' filter is particularly useful for examining the retinal nerve fibre layer and small vessels. Indirect ophthalmoscopy has the advantage of a brighter light source, long working distance, stereopsis and a wide field of view, as well as allowing a dynamic assessment of vitreoretinal pathology. Its disadvantages are that the image is inverted and more skill is needed in its use. A wide variety of aspheric contact lenses is available for retinal examination and laser treatment; these have superseded the more traditional three-mirror fundus lens.

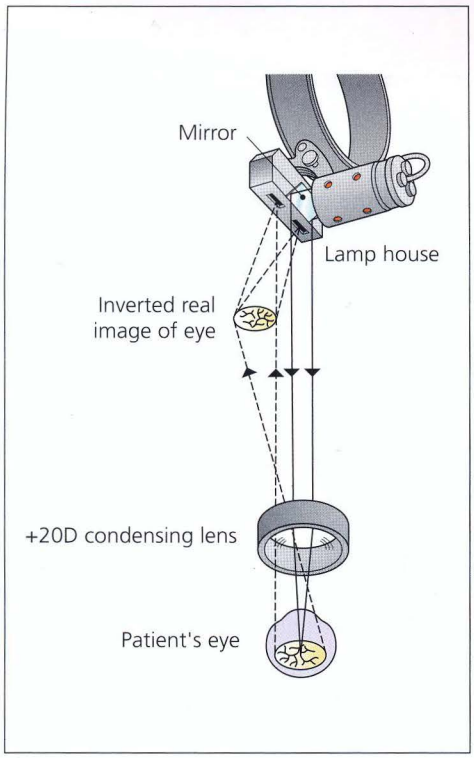
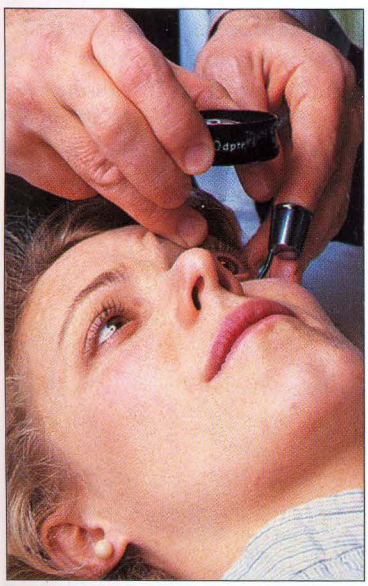


Fig. 1.45 The indirect ophthalmoscope uses a condensing lens to gather the light reflected from the subject's retina, forming a real inverted image of the retina between the examiner and the subject. Light is derived from a source on the examiner's headpiece that is directed into the patient's eye by an adjacent adjustable mirror. As the light source is further away from the patient's eye than with the direct ophthalmoscope, the patient's pupils must be dilated to allow a sufficient field of illumination. The image that is formed is viewed through an eyepiece on the examiner's headpiece; this narrows the examiner's true pupillary distance and allows binocular viewing and stereopsis. The examiner is standing behind the patient so that the inverted image that is seen corresponds to the normal erect appearance.



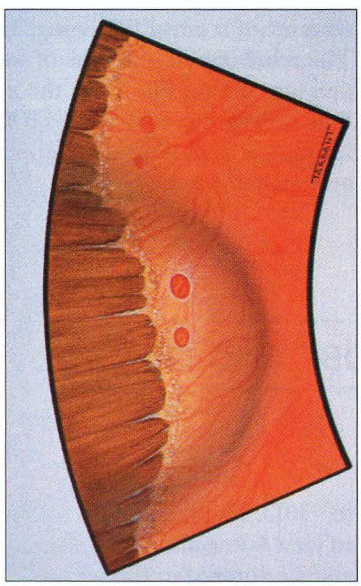


Fig. 1.46 Further detail, especially at the retinal periphery, can be seen by using an indentor to push peripheral retinal areas into the instrument's field of view. Movement of the indentor induces dynamic forces and helps to highlight pathology such as shallow retinal separations or tears.

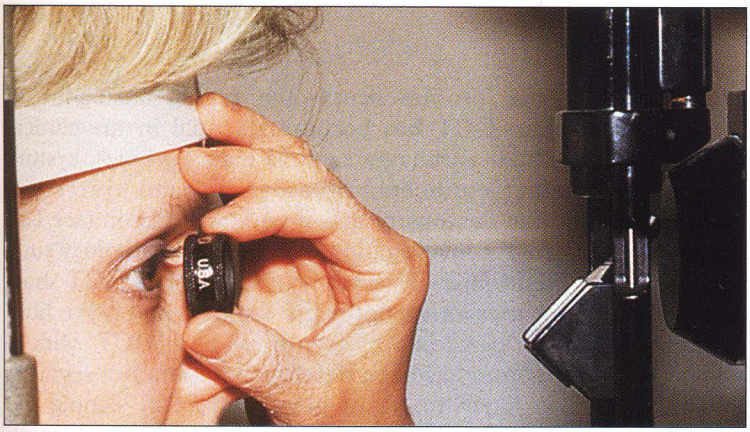


Fig. 1. 47 Slit lamp stereoscopic biomicroscopy using an aspheric lens and the same principle as indirect ophthalmoscopy has become the technique of choice for standard clinical fundus examination as it has the advantages of bright illumination, stereopsis and high magnification. A wide variety of lenses are available which have differences in magnification and field of view.

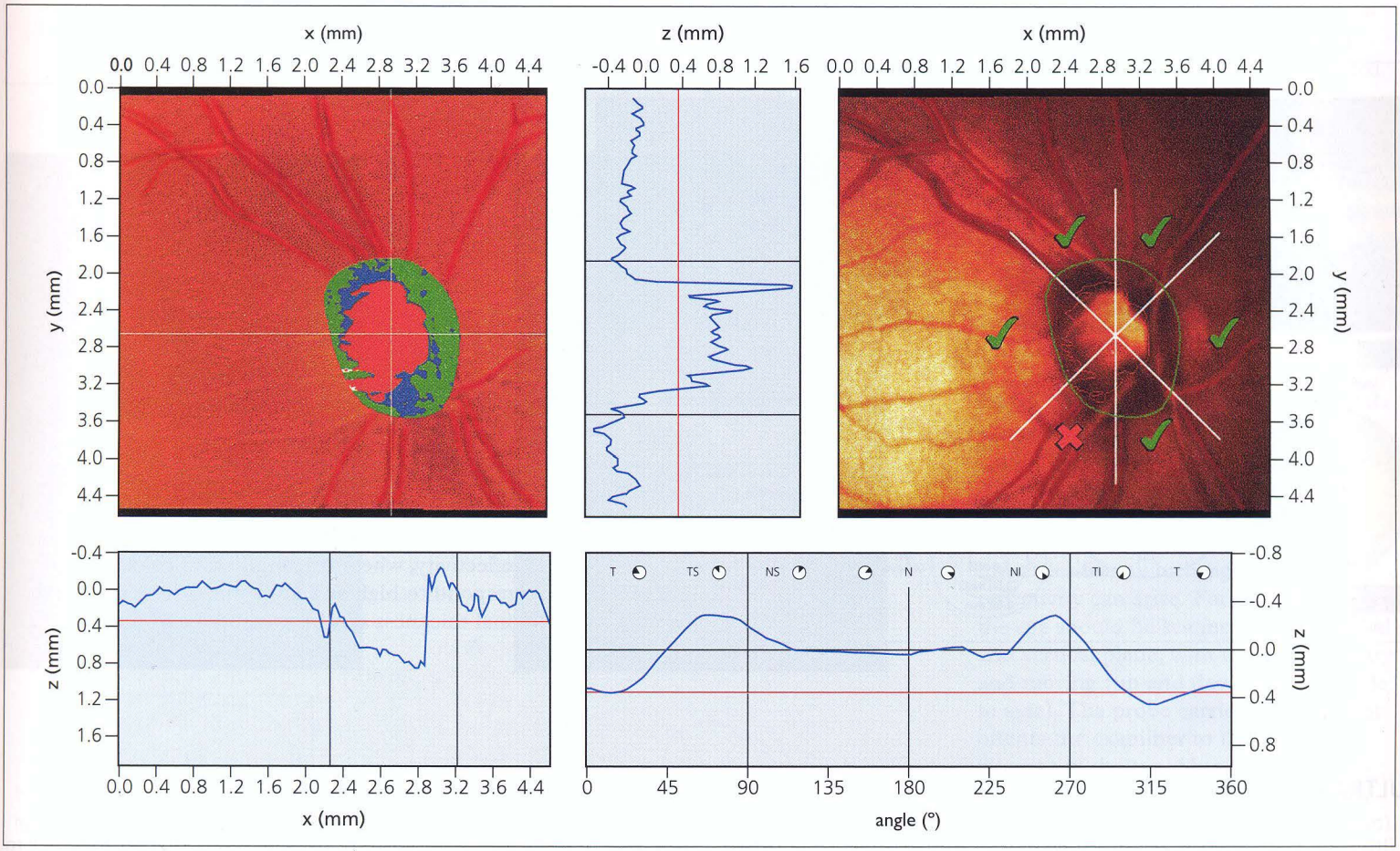


Fig. 1.48 The scanning laser ophthalmoscope (SLO) uses narrow, collimated, low-power He–Ne laser light to illuminate the retinal surface or optic nerve head. These systems have the advantage of producing real-time fundal images that can be analysed and stored digitally. In a basic system a broad beam of low-intensity light is reflected from the fundus and detected and processed to give an image of the illuminated area. More sophisticated systems use point-by-point raster scanning over a region of interest and, in confocal scanning laser tomography, imaging can be conducted in different optical planes to allow subsequent three-dimensional analysis of a structure. Introducing filters and confocal diaphragms in the path of the laser allows the nature of resulting image data to be controlled very precisely so that unwanted reflections or scattered light can be removed to give clear pictures in conditions otherwise considered challenging for conventional photography and to allow imaging through undilated pupils. For example, introducing an ellipsometer allows the amount of reflected polarized light from the eye to be measured; different filters allow fluorescein, indocyanine green (ICG) or autofluoresence to be imaged. SLOs have wide applications in clinical research and may well come into clinical practice to monitor optic disc changes in glaucoma (see Ch. 7).