# Testing of Visual Function: Visual Acuity, Refraction, Contrast Sensitivity


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Vision is commonly expressed as visual acuity, but to evaluate visual function not only in terms of quantity but also quality, additional measurements such as contrast sensitivity, color perception, stereopsis and visual fields should be included. In the context of lens surgery, visual acuity, contrast sensitivity, and stereopsis are of particular interest and most informative for testing practical visual function. In this chapter, we consider visual acuity and contrast sensitivity in the context of lens surgery.

## The Visual Acuity

The basis of an examination of the visual system is the determination of visual acuity. It is relatively easy to measure, reproducible within a certain range of variation, and comparable between individuals. Depending on the type of visual stimulus, the following types of visual acuity can be determined [1]:

1. Recognition visual acuity (minimum cognoscible) = visual acuity
2. Resolution visual acuity (minimum separable) = grating visual acuity
3. Localization visual acuity (minimum discriminable)
4. Point visual acuity (minimum visible)
5. Reading ability

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## *Standards of Distance Visual Acuity Determination*

In practice, the recognition visual acuity (i.e. the visual acuity), is of particular interest. It is defined as the limit of ability to discriminate points as separate objects and is determined by means of calibrated visual objects (optotypes). The following parameters have been defined for the visual acuity test according to EN ISO 8596:

- Sighting mark: Landolt rings with openings in eight directions.
- Examination distance: at least 4 m if there is no significant visual impairment.
- Test field size: diameter 2.0–5.0°.
- Test field luminance: 160–320 cd/m$^2$.
- Character contrast: luminance of the optotypes <15% of the luminance of the test field.
- Distance between optotypes: >15′ or more (depending on the visual acuity level).
- Distance of the optotypes from the edge of the test field: 0.5°.
- Termination criteria: A visual level is detected if 60% of the visual signs could be correctly named (e.g., 3 of 5 or 6 of 10 optotypes) [2].

Abbreviations such as “p” or “pp” (in the sense of “partially read”), after the achieved visual acuity level should be avoided, as they can lead to misinterpretations due to a lack of standardized application guidelines. It is also important to motivate the patient to make a statement for each optotype (=principle of Forced choice). Thus, “guessing” the optotypes should be explicitly encouraged when reaching the limit of detection acuity [3]. During visual acuity testing, care should be taken to ensure that the subject is not adversely affected by light sources or reflections. Impairment due to prior diagnostic tests, topical drop application or contact tonometric pressure measurement before determination of visual acuity should also be avoided, as this can lead to false measurements.

## *Standards of Near Visual Acuity Determination*

In addition to recognition visual acuity (distance visual acuity), reading ability is also an important assessment of visual function. In the measurement of distance visual acuity, only about 1° of intact function of the fovea is necessary, whereas for fluent reading, a central visual field of at least 4° horizontally and 2° vertically are required [4]. Therefore, reading visual acuity cannot be extrapolated from distance visual acuity alone. When testing reading visual acuity, it is preferable to use actual text, rather than series of numbers, to better reflect real world scenarios where the spacing between optotypes vary within words. In an attempt to improve interindividual comparability for reading ability, the Commission for Quality

Assurance Systems of the DOG has recommended a defined, logarithmic gradation of character sizes for reading samples. The following reading samples meet these requirements to a large extent: The Colenbrander and the MNread Chart, the OCULUS near vision sample and the RADNER reading chart. In much of the published literature, near visual acuity according to the Jäger optotypes is frequently employed. These Jäger plates are not standardized however, and therefore not optimal for the comparative determination of the near visual acuity.

In everyday practice, a reading level is usually considered to have been reached when the test reading text is read fluently. The objectivity of fluency suffers from the subjective discretion of the examiner. The objectivity can be improved by determining how many words-per-minute are read from a standardized test reading text. For the sentence optotypes of the RADNER reading charts, for example, a stopping criterion of 20 s. is chosen for the block of text to be read (this corresponds to 42 wpm, words-per-minute), considered as the lower threshold for coherent reading ability. Thus, in order to consider a text block level of visual acuity to have been attained, it must be completed in less than 20 s. The visual level is also considered to be unattained if errors are made in a sentence that render the meaning of the sentence as significantly altered or unintelligible. Again, this is a determination that can be affected by subjective interpretation on the part of the examiner [5].

## Objective Refraction Determination—Subjective Refraction Determination

The goal of refraction is to determine the optimal sphere magnitude and cylinder vector that optimise distance acuity.

### *Objective Refraction*

Objective refraction is classically determined by examination using a retinoscope or sciascope by a technique known as retinoscopy or sciascopy. With sufficiently translucent ocular media, experienced examiners can obtain an objective refraction with very good accuracy within a fraction of a minute for each eye. However, the use of this technique has declined in many parts of the developed world due to the abundance of devices that perform the same function in an automated fashion. Automated refractometry is thus performed by “autorefractometers”. These devices average refraction values by automated sciascopic methods within a defined zone of the pupil area. This zone is conventionally standardized to a diameter of 2.3 mm in

most instruments. In retinoscopy the refraction is obtained within the physiologically determined pupil diameter. The decline in the use of retinoscopy has led to the loss of additional very valuable information about light transmission within the optical media (e.g. the detection of posterior sub-capsular cataract) as well as an analog form of wavefront analysis (e.g. the presence of 'scissoring' of the retinoscopic reflex produced by coma, induced by asymmetrical corneal distortion such as in keratoconus). Cycloplegic retinoscopy is still the gold standard for objective refraction determination in children as it can be performed even in conditions of poor cooperation. Furthermore, retinoscopy remains preferable to autorefractometers when examining non-cooperative patients (e.g., dementia) and in individuals who cannot be positioned behind an autorefractometer (e.g., spinal abnormalities).

## *Subjective Refraction*

Optical irregularities of the eye can lead to variable amounts of aberration of the retinal image, and these can be significantly affected by differences in pupil size (optical zone). Spherical aberration in particular can affect the determination of sphere according to pupil analysis zone. Schober et al. measured the pupil area and found refraction differences of up to 1.4 dpt [6]. Thus, it is important to consider control of the lighting conditions present during subjective refraction, rather than only relying on standardized autorefraction.

The standard recommended procedure is to first perform an objective refraction and then to refine the determined values subjectively [7]. **Maximum distance and near vision correction should be used as the examination benchmark**.

When a patient first presents, it is advisable to determine both monocular and binocular "uncorrected visual acuity" for distance and near. This measure of uncorrected visual function is relevant for both legal reasons (e.g. driving standards) but also for the assessment of the patient before a surgical or refractive intervention. In addition, the uncorrected visual acuity allows the patient to appreciate to what extent the visual acuity can be improved by spectacle correction. This is followed by measurement of objective refraction and then, subjective refraction (where possible). It is advisable to refract each eye to the best possible spectacle corrected vision, that is, beyond 20/20 or 0.0 logMAR, where possible. In this way any changes in the distance corrected visual acuity (DCVA) can be monitored over time. For example, a patient may complain of a drop in vision and found to have a visual acuity of 20/20 or 0.00 logMAR, simply because the vision was previously 20/12 (−0.20 logMAR).

Before any surgical intervention, it is worth repeating vision and refraction measurements. In the case of a patient presenting for cataract surgery on the second eye, for example, a week after the first eye, it is recommended that the vision and refraction be documented for both the post-operative eye as well as the eye about to undergo the intervention.

From a medico-legal perspective as well as a functional standpoint, we recommend that distance visual acuity both monocularly and binocularly with and without correction be documented at each visit.

## Postoperative Visual Acuity Prognosis in Dense Media Opacities

### *Measurement of Retinal Visual Acuity by Laser Interference/ Retinometer*

If a more precise indication of postoperative visual acuity in nuclear, cortical, and secondary cataracts is required prior to cataract surgery, measurement of retinal visual acuity by retinometer (laser interference measurement) can be useful [8]. It should be noted, however, that prediction becomes less accurate when posterior shell opacity, high myopia, amblyopia, or maculopathies (diabetes and AMD-related) are present [9]. In laser interference measurement, a retinometer is used to project two 0.05 mm diameter light spots into the pupillary plane of the eye being examined. Due to the coherence of the partial beams, a figure of alternating black and red stripes is formed in the overlapping area of both beams, which can be seen by the person under examination. By changing the point spacing, the line density can also be changed and it is correlated to the achievable visual acuity (the thinner the stripes become, the higher the grating visual acuity) (Fig. 1). The stripe patterns are offered in different, randomly selected spatial orientations (horizontal, vertical, diagonal). During the measurement, increasingly closer line spacings (corresponding to higher visual acuity) are projected at different orientations until the patient is only able to provide answers at the level of the guess probability, i.e., less than 3 out of 5. The last reproducibly measured level, where 3 out of 5 orientations of the stripe patterns could be correctly named, corresponds to interference visual acuity. The measurements are largely independent of refraction and can be also be performed through small pupils. In the case of more advanced lens opacification, a dilated pupil can make retinometry easier as the light spots can be projected through different regions of the entrance pupil in order to get around denser lens opacities. It should also be noted that the values obtained are actual grating visual acuity measures, not optotype recognition acuity [1].

### *Estimation of Retinal Visual Acuity with the Purkinje Choroidal/Retinal Vessel Shadow Figure*

In cases where the opacity of the media is so dense that retinometer measurements are not possible, the use of the entoptic phenomenon, where retinal vessel

**Fig. 1** Measurement of grating visual acuity with the retinometer. Interference pattern as seen by the patient. The thinner the stripes, whose orientation are correctly detected, the higher the grating visual acuity

shadowing is produced, can be used to grossly assess retinal function. The "Purkinje vascular entoptic test" as it is known, is a test of retinal function which employs a light directed through the sclera, illuminating the fundus. This light casts shadows of retinal blood vessels onto posterior pole photoreceptors. By moving the trans-scleral illumination of the globe, the retinal vessels cast shadows on a constantly changing area of sensory cells producing a "vein map". Inspection of the vein map is best achieved in a dark room. The vein map visualization is produced by shining a small, intense light source trans-sclerally about 5 mm behind the limbus and this light source is moved at a frequency of two to four swings per second (Fig. 2a). Direct illumination of the retina through the pupil should be avoided and the other eye should be covered so that the patient is not distracted by other visual impressions. The range of visible vein figure perception increases when the light source is moved farther from the limbus. The phenomenon disappears immediately when the light is static. The patient's perception of the vein figure is subjectively described very differently, e.g., as branches of a tree or rivers in a landscape (Fig. 2b). The possibility of triggering the vein figure depends very much on the patient's cooperation and understanding. It is recommended to describe the expected image to the patient beforehand. Since it is not always possible to produce the vein figure perception even in healthy eyes, a non-recognition of the vein figure by the patient is no proof of a functional disorder. However, if triggering of the choroidal figure is possible, a postoperative visual acuity of at least 1.0 logMAR can be assumed if the central choroidal figure is complete (the central 20° part of the visual field, forms the center of the vein figure with the enclosing vascular arches). The vein figure is pathologically obliterated in cases of retinal detachments, retinal (especially arterial) vascular occlusions, and severe forms of tapetoretinal degeneration. In central scotomas (neuritis), parts of the figure are not perceived. Overall, as a simple procedure to perform, testing of the vein figure provides a good indication of central visual acuity in cases of severe media opacities and can thus be used as a prognostic factor in upcoming surgery [10].

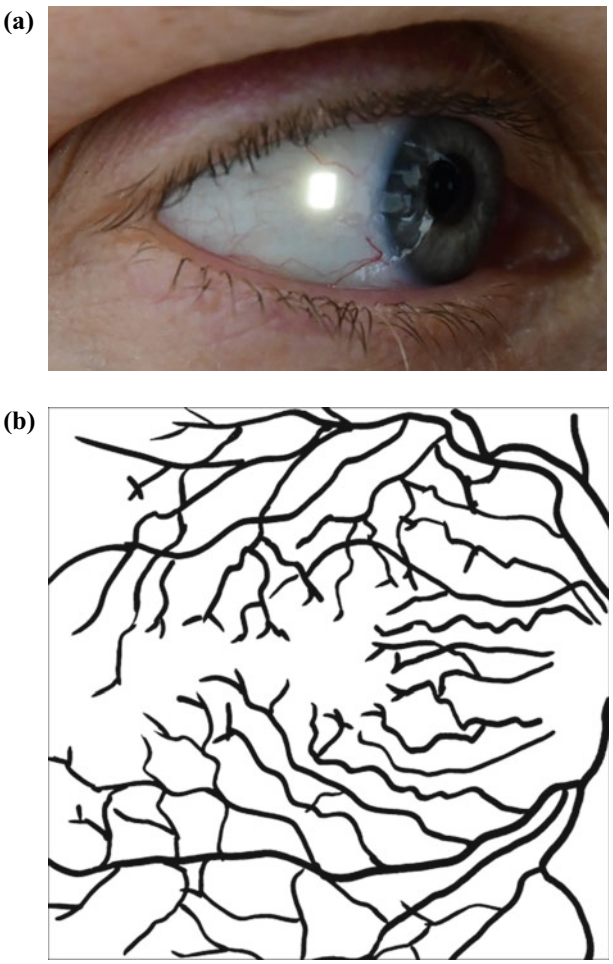


**Fig. 2** **a** Testing of the vein figure. The vascular shadow figure of the retina is best evoked by projecting an intense light source onto the sclera near the limbus in the area of the temporal palpebral fissure. The light source must then be moved slowly up and down. The eye of the person being examined is in adduction. **b** Schematic representation of the vessel shadow figure as perceived by the person under examination

## *Neuronal Functional Testing of the Retina*

If severe media opacities are present where no view of the fundus is visible and where no retinometer is available, a flash VEP (visual evoked cortical potentials) can be used to make a global assessment of the entire visual system, up to the visual cortex. However, it should be considered that in the case of pronounced media opacities, it may no longer be possible to elicit a flash VEP. Compared to the

pattern VECP, the waveforms of the flash VECP are very variable and therefore only suitable to answer rough questions about whether a signal arrives in the visual cortex at all. For the flash stimulus (with a stroboscopic flash unit), the flash area should be at least 20° of the visual field, and the flash duration should be less than 5 ms. The stimulus should be diffuse and have an intensity of 1.5 to 3 cd s/$m^2$ (standard flash of the ISCEV-ERG standard) [11].

## Contrast Vision

Good contrast vision is particularly important when driving in poor visibility conditions, i.e., in fog, rain or snow, but also for recognizing uneven surfaces, e.g., curbs and steps. Reading different fonts on colored backgrounds or on paper with poor contrast or in poor lighting also requires functional contrast vision [12]. Reduced contrast vision can occur even when visual acuity measured is still good. Causes of a loss in contrast sensitivity can be an opacity of the optical media, such as corneal edema or incipient cataract, or as a consequence of higher order aberrations due to irregularities on the cornea or lens. Normal aging processes can also lead to a decrease in contrast sensitivity. Since contrast is high when visual acuity is determined by visual sign projectors or on optotype charts, contrast sensitivity should be tested separately. The Pelli–Robson test charts or the MARS charts can be used to measure low contrast acuity. Both boards work with large letters that do not change in size but are printed on the boards with increasingly weaker contrast. These charts can be used to test contrast vision under daylight conditions in a readily reproducible form. It is essential however, that standardized illumination (60–120 cd/$m^2$ or 189 to 377 lx) is maintained for testing. Contrast vision is measured in logCS (the mentioned panels allow testing between 0 and 2.0 logCS). As borderline contrast vision, 1.5 logCS is given in the literature for elderly persons over 60 years of age (instruction manual of the MARS panels). Values lower than 1.5 are considered to have moderate contrast sensitivity limitation and values lower than 0.5 are considered to have massive contrast sensitivity limitation [3].

Contrast sensitivity can also be measured using sine-wave gratings where the luminance of the grating is varied from 0.5% contrast to 90% contrast. The contrast sensitivity is the lowest contrast level that can be detected by the patient. Contrast sensitivity charts present 4–5 rows of 8–10 contrast level gratings, with each row a different spatial frequency of the sinusoidal pattern (i.e. different thickness of the grey stripes, similar to the retinometer gratings). By measuring responses at different spatial frequencies, a contrast sensitivity curve is plotted to show the lowest contrast level a patient can detect for each spatial frequency from low (thick gratings) to high (thin gratings). The spatial frequencies used are usually 1.5, 3, 6, 12, and 18 cycles

per degree. An example of this is the CSV-1000 (VectorVision, Greenville, OH), which has been used in the majority of FDA clinical trials for laser refractive surgery and is a fast and efficient test for measuring contrast sensitivity [13].

In lens surgery, it is useful to routinely test contrast vision before surgery as a baseline measurement that can be used to monitor the progression and extent of a cataract. Because it is a more sensitive test than visual acuity, contrast sensitivity may also diagnose visually significant cataract earlier. This is particularly important for the implantation of multifocal lenses, as these can lead to a lower contrast sensitivity, particularly when performing clear lens exchange. Measuring the contrast sensitivity again after surgery can be used as a compelling demonstration of the improvement in quality of vision gained from lens surgery. Postoperatively, contrast sensitivity tests can be used to assess whether a patient might benefit from a YAG treatment for posterior capsule opacification (PCO), and again in demonstrating an improvement following the YAG.

**Note**

Before any surgical procedure, it is important to perform an objective refraction as a baseline and for surgical planning. Afterwards the distance visual acuity should be determined with the best subjective refraction and then the near visual acuity, if necessary, with an accommodation compensation. An additional determination of the contrast visual acuity is especially interesting before implantation of special lenses.

## Objective Measurement of Quality of Vision

Quality of vision can also be assessed using devices that measure higher order aberrations and/or point spread function. Aberrometers are in widespread use in refractive surgery and help in the diagnosis of patients complaining from reduced quality of vision. Spherical aberration and coma are the dominant aberrations linked to patient symptoms. Modern high resolution aberrometers, such as the Osiris (CSO, Florence, Italy), are even able to measure the aberrations within a multifocal IOL. An example of an Osiris scan for an eye implanted with a diffractive multifocal IOL is shown in Fig. 3, where the rings are clearly visible on the scan and correlated with the image drawn by the patient describing their vision with that eye.

Devices measuring optical scatter as a point spread function are also available and can provide an objective measurement to complement the subjective clinical interpretation of cataract progression. In many cases where a lens can appear yellow, the point spread function can still be within normal limits, indicating that a corneal procedure may be the preferred option for a patient with early presbyopia.

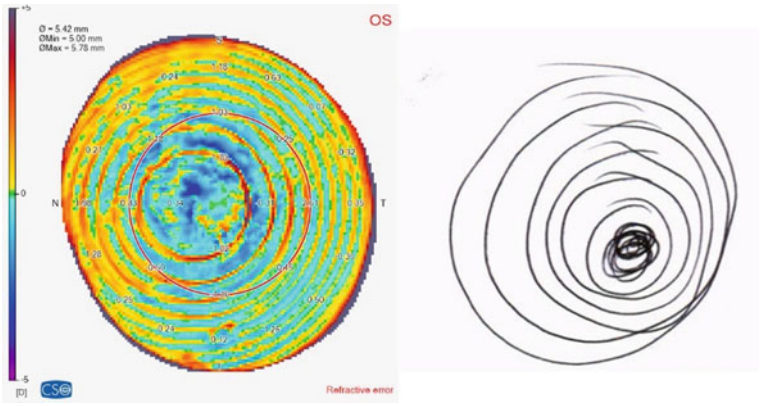


**Fig. 3** Osiris refractive error map for an eye implanted with a Symfony multifocal IOL (J&J, New Brunswick, NJ) showing the aberrations due to the diffractive lens design. In this patient, these induced concentric rings around lights (e.g. traffic lights) as drawn by the patient

The HD Analyser (Keeler, Windsor, UK) and iTrace (Tracey Technologies, Houston, TX) are two examples. The HD Analyser provides the optical scatter index (OSI), which grades the point spread function with an OSI of 2 or below within normal limits.

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