Refrakční vady a korekce

16.1 základní termíny

Nekorigovaná a korigovaná zraková ostrost

Minimum separabile- dán vzdáleností čípků 2,5um, zvětšuje se do periferie
Je dán velikostí 1 minuty, což odpovídá asi 0,004mm na sítnici

Refraction: Emmetropia and Ametropia

Refraction is defined as the ratio of the refractive power of the lens and cornea (the refractive media) to the axial length of the globe. Emmetropia is distinguished from ametropia.

Emetropie (Figs. 16. **2**, 16.**6a**)

Resolution of the eye (minimum threshold resolution)

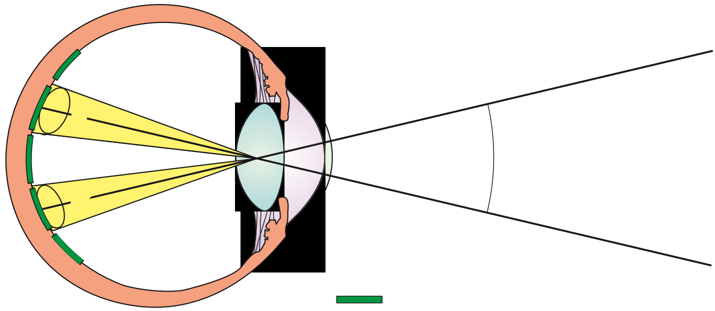


Fig. 16.**1** Two points (O_1 and O_2) can only be perceived as distinct if at least one unstimulated cone (z) lies between two stimulated cones (x and y) on the retina. Due to optical aberrations and diffraction, a punctiform object is reproduced as a circle (k). This results in a maximum resolution of the eye of 0.5–1 minutes of arc or 0.5/60–1/60 of a degree. The drawing is not to scale.

Focal point in emmetropia and ametropia

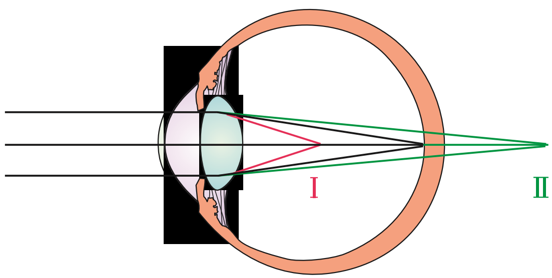


Fig. 16.**2** Parallel rays of light entering the eye from an optically infinite distance meet at a focal point on the retina in emmetropia (black lines). In hyperopia, this focal point (II) lies posterior to the retina (green lines). In myopia (I), it lies anterior to the retina (red lines).

Ametropia (refrakční vada). Může být axiální a refrakční

6.1 Basic Knowledge

Tab. 16.**1** Important refractive indices (**n**) of the various tissues of the eye

Eye tissue	Refractive index n
Cornea	1.376
Aqueous humor	1.336
Lens at the poles	1.385
Lens at the core	1.406
Vitreous body	1.336

From Krause K. *Methoden der Refraktionsbestimmung*. Münster, Germany: Biermann, 1985.

Very few people have refraction of exactly 0.0 diopters. Approximately 55% of persons between the ages of 20 and 30 have refraction between + 1 and – 1 diopters.

Emmetropia is not necessarily identical to good visual acuity. The eye may have other disorders that reduce visual acuity, such as atrophy of the optic nerve or amblyopia.

The refractive power of an optical lens system is specified in *diopters*, which are the international units of measure. Refractive power is calculated according to the laws of geometric optics. According to **Snell's law**, the refraction of the incident light ray is determined by the angle of incidence and difference in the refractive indices **n** of the two media (Table 16.**1**).

The maximum **total refractive power of an emmetropic eye** is 63 diopters with an axial length of the globe measuring 23.5 mm. The cornea accounts for 43 diopters and the lens for 10–20 diopters, depending on accommodation. However, the refractive power of the eye is not simply the sum of these two values. The optic media that surround the eye's lens system and the distance between the lens and cornea render the total system more complex.

The refractive power D (specified in diopters) of an optical system is the reciprocal of the focal length of a lens f (specified in meters). This yields the equation: $D = 1/f$.

Example. Where a lens focuses parallel incident light rays 0.5 m *behind* the lens, the refractive power is 1/0.5 m = + 2 diopters. This is a converging lens. Where the virtual focal point is *in front of* the lens, the refractive power is 1/– 0.5 m = – 2 diopters. This is a diverging lens (Fig. 16.**3**).

Accommodation

The refractive power of the eye described in the previous section is not a constant value. The eye's refractive power must alter to allow visualization of both near and distant objects with sharp contours. This accommodation is made possible by the *elasticity of the lens*.

Refraction of light rays traveling through converging and diverging lenses

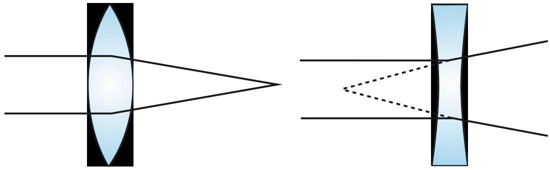


Fig. 16.**3** **a** The converging lens (biconvex) concentrates incident light rays at a focal point behind the lens. **b** A diverging lens (biconcave) ensures that the light rays do not meet at all. The light rays appear to originate at a virtual focal point in front of the lens.

Accommodation mechanisms. Accommodation involves the lens, zonule fibers, and ciliary muscle.

Lens. The soluble proteins of the lens are surrounded by a thin elastic capsule. The curvature of the posterior capsule of the lens is greater than its anterior curvature, with a posterior radius of 6.0 mm as opposed to an anterior radius of 10.0 mm. The *intrinsic elasticity of the lens capsule* tends to make the lens assume a spherical shape. However, in the unaccommodated state this is prevented by the pull of the zonule fibers. The elasticity of the inner tissue of the lens progressively decreases with age due to deposits of insoluble proteins.

Zonule fibers. The radiating zonule fibers insert into the equator of the lens and connect it to the ciliary body. They hold the lens securely in position and transmit the pull of the ciliary muscle to the lens.

Ciliary muscle. *Contraction of the ring-shaped ciliary muscle* decreases the tension in the zonule fibers. The lens can then approach the spherical shape (with a radius of curvature of 5.3 mm) that its physical configuration and chemical composition would otherwise dictate. This change in the curvature of the lens is especially pronounced in its anterior surface. The deformation *increases the refractive power*; the focus of the eye shifts to the near field (Fig. 16.**4**), and close objects take on sharp contours. As *the ciliary muscle relaxes*, the tension on the lens increases and the lens flattens. The resulting *decrease in refractive power* shifts the focus of the eye into the distance (Fig. 16.**4**), and distant objects take on sharp contours.

The ciliary muscle is innervated by the short ciliary nerves, postganglionic parasympathetic fibers of the oculomotor nerve. Parasympatholytics such as atropine, scopolamine, and cyclopentolate inhibit the function of the ciliary muscle and therefore prevent accommodation. Referred to as *cycloplegics*, these medications also cause *mydriasis* by inhibiting the sphincter pupillae. *Parasympathomimetics* such as pilocarpine cause the ciliary muscle and sphincter pupillae to contract, producing *miosis*.

Morphologic changes in accommodation

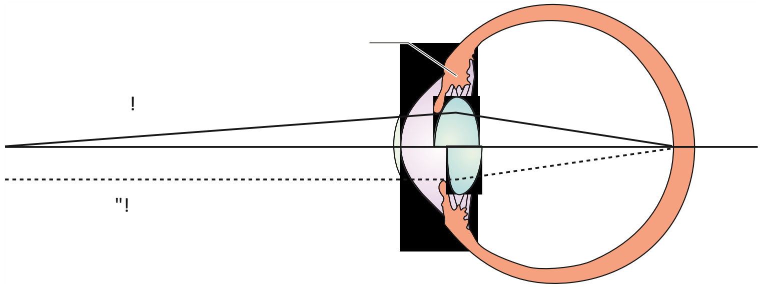


Fig. 16.**4** *Top half:* In accommodation, the lens becomes increasingly globular. The curvature of the anterior surface in particular increases. The ciliary muscle is shifted slightly anteriorly, and the anterior chamber becomes shallower. Objects in the near field (continuous line) are represented on the retina with sharp contours.
Bottom half: With the ciliary body relaxed, parallel incident light rays (dotted line) are focused on the retina. Distant objects are represented on the retina with sharp contours.

When the ciliary muscle is *at rest*, the zonule fibers are under tension and the eye focuses on distant objects.

Accommodation is regulated by a *control loop*. The control variable is the sharpness of the retinal image. The system presumably uses the color dispersion of the retinal image to determine the direction in which accommodation should be corrected.

Range of accommodation. This specifies the *maximum increase in refractive power that is possible* by accommodation in diopters (Fig. 16.**5**). In mathematical terms, the range of accommodation is obtained by subtracting near-point refractive power from far-point refractive power. The **near point** is shortest distance that allows focused vision; the **far point** describes the farthest point that is still discernible in focus. The near and far points define the range of accommodation; its specific location in space is a function of the refractive power of the eye.

Example. In one patient, the near point lies at 0.1 m and the far point at 1 m.
This patient's range of accommodation is then 10 diopters – 1 diopter = 9 diopters.

In an emmetropic eye, the far point is at optical infinity. However, accommodation can also bring near-field objects into focus (Fig. 16.**6b**). The elasticity of the lens decreases with increasing age, and the range of accommodation decreases accordingly (Fig. 16.**5**). **Presbyopia** (physiologic loss of accommo-

Range of accommodation in diopters as a function of age

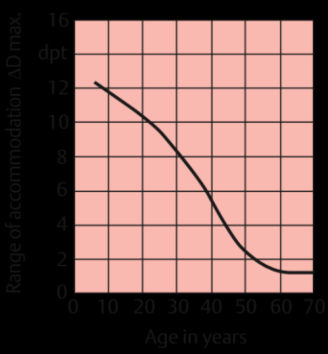


Fig. 16.5 When the range of accommodation falls below 3 diopters, a previous emmetropic patient will require eyeglasses for reading (adapted from Goersch 1987).

Refraction in the emmetropic eye

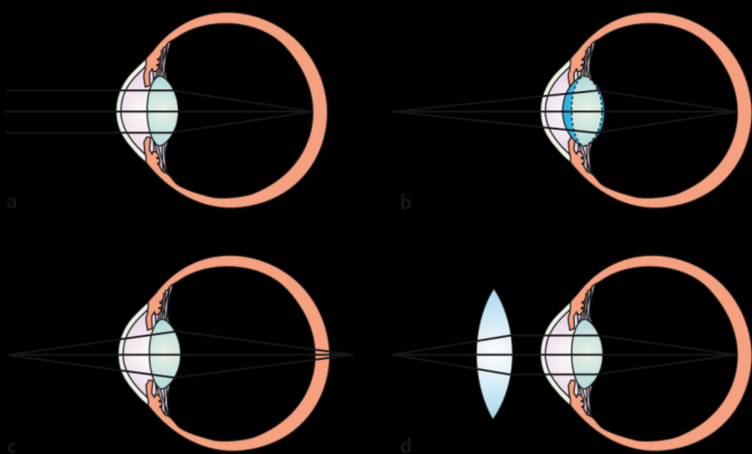


Fig. 16.6 **a** Parallel light rays entering the eye from optical infinity are focused on the retina in an *unaccommodated eye*.
b Accommodation focuses the light rays from a close object on the retina, and the object is visualized with sharp contours.
c When accommodation is insufficient, as in advanced age, close objects appear blurred.
d A converging lens is required to correct insufficient accommodation for near vision in advancing age.

16.2 Examination Methods

dation in advancing age) begins when the *range of accommodation falls below 3 diopters*. The gradual loss of accommodation causes the near point to recede; the patient's arms become "too short for reading." Depending on age and limitation of accommodation, presbyopia can be compensated for with converging lenses of 0.5–3 diopters (see Fig. 16.**6c**, **d**).

Adaptation to Differences in Light Intensity

Like a camera, the eye's aperture and lens system also automatically adapts to differences in light intensity to avoid "overexposure." This adjustment is effected by two mechanisms.

1. **The iris acts as an aperture to control the amount of light entering the eye**. This regulation takes about 1 second and can change the light intensity on the retina over a range of about a power of ten.
2. **The sensitivity of the retina changes** to adapt to differences in light intensity. The sensitivity of the retina to light is a function of the *concentration of photopigment in the photoreceptors* and of the *neuronal activity of the retinal cells*. The change in neuronal activity is a rapid process that takes only a few milliseconds and can alter the light sensitivity of the retina over a range of three powers of ten. The change in the concentration of photopigment takes several minutes but can cover a wide range of retinal light sensitivity, as much as eight powers of ten.

16.2 Examination Methods

Visual acuity. See Chapter 1.

Refraction Testing

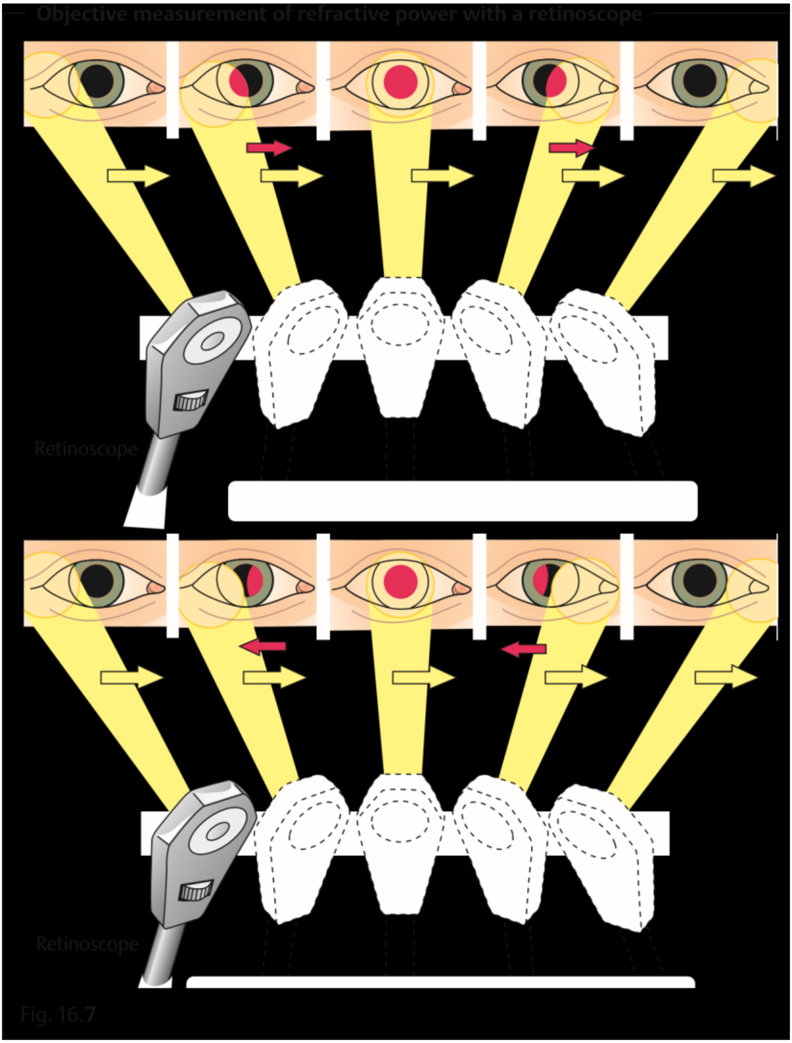
Refraction testing means measuring the *additional* refractive power required to produce a sharp image on the retina. Subjective and objective methods are used. Subjective methods require information from the patient.

Subjective refraction testing. This consists of successively placing various combinations of lenses before the patient's eye until the maximum visual acuity is reached (see Correction of Refractive Errors).

Objectiverefractiontesting. Objective testing is unavoidable when the patient is unable to provide subjective information (for example with infants) or when this information is unreliable. This method also greatly accelerates subjective refractive testing.

Retinoscopy (shadow testing). The retina is illuminated through the pupil. The examiner observes the optical phenomena in the patient's pupil while moving the light source (Fig. 16.**7**).

Refractometry. The measuring principle is based on ophthalmoscopic observation of a test image projected onto the patient's retina. The distance between the test figure and the eye is changed until the image appears in focus on the retina. Refraction can then be calculated from the measured



values. An alternative to changing of the distance is to place various lenses in the path of the light beam.

Automated refractometry. The method measures refraction automatically with the aid of light-sensitive detectors and a computer until a focused image appears on the retina. These systems operate with infrared light.

Any objective measurements of refraction should be verified by subjective testing whenever possible.

Testing the Potential Resolving Power of the Retina in the Presence of Opacified Ocular Media

Special examination methods are indicated in the presence of opacification of the ocular media of the eye (such as a cataract) to determine the potential visual acuity of the retina. This permits the ophthalmologist to estimate whether optimizing the refractive media with techniques such as cataract surgery or corneal transplantation would achieve the desired improvement.

Laser interference visual acuity testing. Lasers are used to project interference strips of varying widths onto the retina. The patient must specify the direction in which these increasing narrower strips are aligned. This examination can no longer be performed where there is severe opacification of the optic media such as in a mature cataract. The preliminary examination then consists of **evaluating the pattern of the transilluminated retinal vasculature**.

Fig. 16.**7** With the retinoscope, the examiner moves a light source (a beam of yellow light) across the pupil (dark spot) at a distance of about 50 cm from the patient. This produces a light reflex (red spot) in the patient's eye. It is important to note how this light reflex (red spot) behaves as the light source in the retinoscope is moved. There are two possibilities. **a Concurrent movement.** The light reflex in the pupil (red spot) moves in the same direction (red arrows) as the light source of the retinoscope (yellow arrows). This means that the far point of the eye is *behind* the light source. **b Countermovement.** The light reflex in the pupil moves in the *opposite* direction (red arrows) to the light source of the retinoscope (yellow arrows). This means that the far point of the eye lies *between* the eye and the light source. The examiner places appropriate lenses in front of the patient's eyes (plus lenses for concurrent movement and minus lenses for countermovement) until no further movement of the light reflex is observed. The movement of the retinoscope will

then only elicit a brief flicker (**neutral point**). This method is used to determine the proper lens to correct the refractive error.

16.3 Refractive Anomalies (Table 16.2)

Myopia (Shortsightedness)

> ***Definition:*** A discrepancy between the refractive power and axial length of the eye such that parallel incident light rays converge at a *focal point anterior to the retina* (Fig. 16.**8a**).

Epidemiology. Approximately 25% of persons between the ages of 20 and 30 have refraction less than – 1 diopters.

Etiology. The etiology of myopia is not clear. Familial patterns of increased incidence suggest the influence of genetic factors.

Pathophysiology. Whereas parallel incident light rays converge at a focal point on the retina in emmetropic eyes, they converge at a focal point *anterior to* the retina in myopic eyes (Fig. 16.**8a**). This means that *no sharply defined images* appear on the retina when the patient *gazes into the distance* (Fig. 16.**8a**). The myopic eye can only produce *sharply defined images* of *close objects* from which the light rays diverge until they enter the eye (Fig. 16.**8b**). The far point moves closer; in myopia of –1 diopter it lies at a distance of 1 m.

> In myopia, the far point (distance from the eye = A) can be calculated using the formula: A (m) = 1/D, where D is myopia in diopters.

Possible causes include an *excessively long globe* with normal refractive power (**axial myopia**; Fig. 16.**8c**) and, less frequently, *excessive refractive power* in a normal-length globe (**refractive myopia**; Fig. 16.**8d**).

> A difference in globe length of 1 mm with respect to a normal eye corresponds to a difference of about 3 diopters in refractive power.

Special forms of refractive myopia.

- Myopic sclerosis of the nucleus of the lens (*cataract*) in advanced age (see p. 177). This causes a secondary focal point to develop, which can lead to monocular diplopia (double vision).
- Keratoconus (increase in the refractive power of the cornea).
- Spherophakia (spherically shaped lens).

Forms. These include:

- **Simple myopia** (school-age myopia): Onset is at the age of 10–12 years. Usually the myopia does not progress after the age of 20. Refraction rarely exceeds 6 diopters. However, a *benign progressive myopia* also exists, which stabilizes only after the age of 30.

Pathologic myopia. This disorder is largely hereditary and progresses continuously, independently of external influences.

Tab. 16.**2** Overview of the major refractive anomalies

Refractive anomaly	Focal point of parallel incident light rays	uses	ion	Possible complications	Optical correction
Myopia (nearsightedness)	Anterior to the retina	Eyeball too long (axial myopia). Excessive refractive power (refractive myopia)	Very good near vision. Poor distance vision	Increased risk of retinal detachment.	Diverging lenses (minus or concave lenses)
Hyperopia (far-sightedness)	Posterior to the retina	Eyeball too short (axial hyperopia). Insufficient refractive power (refractive hyperopia)	Poor near vision. Accommodation usually permits normal distance vision (in young patients and in slight to moderate hyperopia)	Disposition to acute angle closure glaucoma (shallow anterior chamber). Caution is advised with diagnostic and therapeutic mydriasis. Esotropia	Converging lenses (plus or convex lenses)

Astigmatism	Lack of a focal point	Anomalies in the curvature of the normally spheri-cal surfaces of the refractive media (cornea and lens)	Patients see everything dis-torted	Risk of refractive amblyopia	Cylindrical lenses; eyeglass correction is only possible where astigmatism is regular

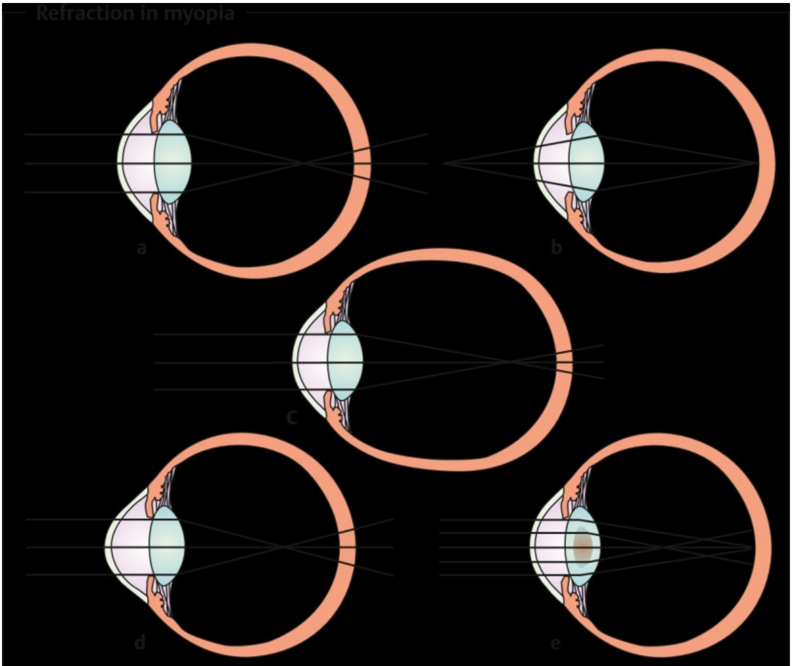


Fig. 16.8 **a** The focal point of parallel light rays entering the eye lies anterior to the retina. **b** Only close objects from which the light rays diverge until they enter the eye are focused on the retina and appear sharply defined. The far point is a finite distance from the eye. **c** Axial myopia: normal refractive power in an excessively long globe. **d** Refractive myopia: excessive refractive power in a normal-length globe. **e** Nuclear cataract with a secondary focal point (the patient sees double).

Symptomsanddiagnosticconsiderations. The diagnosis is made on the basis of a typical clinical picture and refraction testing. Myopic patients have very good near vision. When gazing into the distance, they squint in an attempt to improve their uncorrected visual acuity by further narrowing the optic aperture of the pupil. The term “myopia” comes from this squinting; the Greek word “myein” means to squint or close the eyes. *Older* myopic patients can read without corrective lenses by holding the reading material at about the distance of the far point.

The typical **morphologic changes** occurring in myopia are referred to as **myopia syndrome**. Progressive myopia in particular is characterized by *thinning of the sclera*. The *elongation of the globe* causes a *shift in the axes of the eye*. This often simulates esotropia. The *anterior chamber* is deep. *Atrophy of the ciliary muscle* is present as it is hardly used. The volume of the vitreous body is too small for the large eye, and it may collapse prematurely. This results in *vitreous opacifications* that the patient perceives as floaters.

Morphologic fundus changes in myopia, such as maculopathy and Fuchs spot, are discussed in Chapter 12.

The **risk of retinal detachment** is increased in myopia. However, it *does not* increase in proportion to the severity of the myopia.

> Because of the increased risk of retinal detachment, patients with myopia should be examined particularly thoroughly for prodromal signs of retinal detachment, such as equatorial degeneration or retinal tears. Therefore, examination of the fundus with the pupil dilated is indicated both when the first pair of eyeglasses is prescribed and at regular intervals thereafter.

Glaucoma is more difficult to diagnose in patients with myopia. Measurements of intraocular pressure obtained with a Schiøtz tonometer will be lower than normal due to the decreased rigidity of the sclera.

> Applanation tonometry yields the most accurate values in patients with myopia because the rigidity of the sclera only slightly influences results.

The **optic cup** is also difficult to evaluate in patients with myopia because the optic nerve enters the eye obliquely. This also makes glaucoma more difficult to diagnose.

Treatment. The excessive refractive power of the refractive media must be reduced. This is achieved through the use of **diverging lenses** (minus or concave lenses; Fig. 16.**9a**). These lenses cause parallel incident light rays to diverge behind the lens. The divergent rays converge at a virtual focal point in front of the lens. The refractive power (D) is negative (hence the term “minus lens”) and is equal to 1/f, where f is the focal length in meters. Previously, *biconcave* or *planoconcave* lens blanks were used in the manufacture of corrective lenses. However, these entailed a number of optical disadvantages. Today lenses are manufactured in a *positive meniscus shape* to reduce lens aberrations.

Correction with contact lenses (Fig. 16.**9b**) offers optical advantages. The reduction in the size of the image is less than with eyeglass correction. Aberrations are also reduced. These advantages are clinically relevant with myopia exceeding 3 diopters.

> The closer the “minus lens” is to the eye, the weaker its refractive power must be to achieve the desired optic effect.

Minus lenses to be used to correct myopia should be no stronger than absolutely necessary. Although accommodation could compensate for an overcorrection, patients usually do not tolerate this well. Accommodative asthenopia (rapid ocular fatigue) results from the excessive stress caused by chronic contraction of the atrophic ciliary muscle.

Correction of myopia

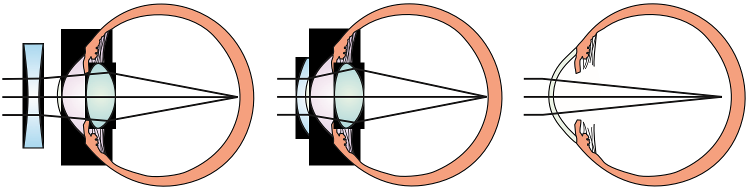


Fig. 16.**9** **a** Correction with diverging lenses (minus lenses).**b** Correction with a contact lens.**c** Correction by removing the lens to reduce the refractive power of the eye.

Myopic patients have "lazy" accommodation due to atrophy of the ciliary muscle. A very slight undercorrection is often better tolerated than a perfectly sharp image with minimal overcorrection.

In certain special cases, **removal of the crystalline lens** (Fig. 16.**9c**) can be performed to reduce the refractive power of the myopic eye. However, this operation is associated with a high risk of retinal detachment and is rarely performed. There is also the possibility of implanting an **anterior chamber intraocular lens** (diverging lens) anterior to the natural lens to reduce refractive power. See Chapter 5 for additional surgical options.

Popular health books describe exercises that can allegedly treat refractive errors such as nearsightedness without eyeglasses or contact lenses. Such exercises cannot influence the sharpness of the retinal image; they can only seemingly improve uncorrected visual acuity by training the patient to make better use of additional visual information. However, after puberty no late sequelae of chronically uncorrected vision are to be expected.

Hyperopia (Farsightedness)

Definition: In hyperopia, there is a discrepancy between the refractive power and axial length of the eye such that parallel incident light rays converge at a *focal point posterior to the retina* (Fig. 16.**10a**).

Epidemiology. Approximately 20% of persons between the ages of 20 and 30 have refraction exceeding + 1 diopters. Most newborns exhibit slight hyperopia (*newborn hyperopia*). This decreases during the first few years of life. In advanced age, refraction tends to shift toward the myopic side due to sclerosing of the nucleus of the lens.

Refraction in hyperopia

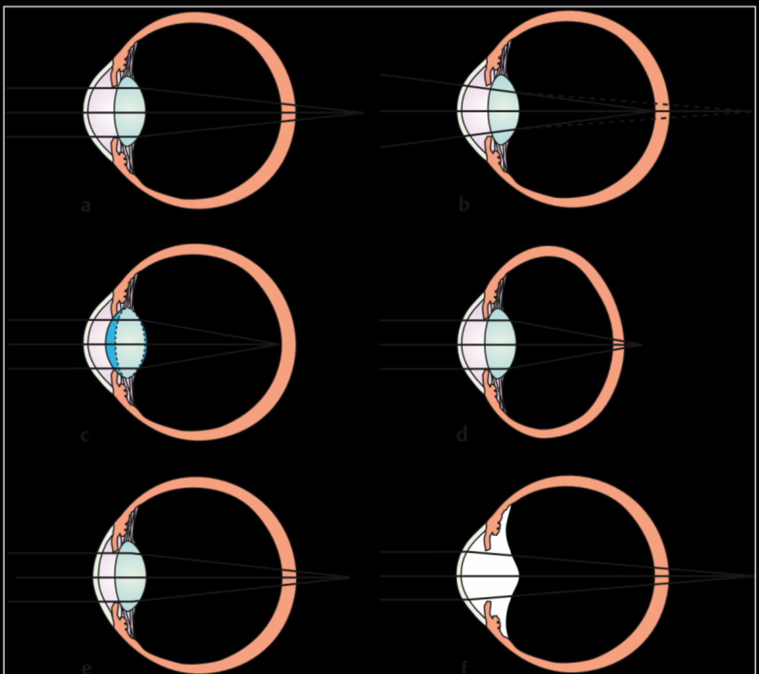


Fig. 16.**10** **a** The focal point of parallel light rays entering the eye lies posterior to the retina. **b** Divergent light rays are focused on the retina. The virtual far point lies posterior to the eye (dashed line). **c** To bring the focal point onto the retina, a farsighted person has to accommodate even when gazing into the distance. **d** Axial hyperopia. The refractive power is normal, but the globe is too short (more common). **e** Refractive hyperopia. The globe has a normal length, but the refractive power is insufficient (less common). **f** A special form of refractive hyperopia is aphakia (absence of the lens).

Etiology. The mechanisms that coordinate the development of the eyeball so as to produce optic media of a given refractive power are not yet fully understood.

Pathophysiology. In farsighted patients, the virtual *far point* of the eye lies *posterior to the retina* (Fig. 16.**10b**). Only convergent incident light rays can be focused on the retina (Fig. 16.**10b**). This is due either to an *excessively short globe* with normal refractive power (**axial hyperopia**; Fig. 16.**10d**) or, less frequently, to *insufficient refractive power* in a normal-length globe (**refractive hyperopia**; Fig. 16.**10e**). Axial hyperopia is usually congenital and is characterized by a shallow anterior chamber with a thick sclera and well developed ciliary muscle.

> Hyperopic eyes are predisposed to acute angle closure glaucoma because of their shallow anterior chamber. This can be provoked by diagnostic and therapeutic mydriasis.

Special forms of refractive hyperopia.
- Absence of the lens (aphakia) due to dislocation
- Postoperative aphakia following cataract surgery without placement of an intraocular lens (see Fig. 16.**10**)

To bring the focal point onto the retina, a farsighted person *must accommodate even when gazing into the distance* (Fig. 16.**10c**). *Close objects remain blurred* because the eye is unable to accommodate any further in near vision. As accommodation is linked to convergence, this process can result in *esotropia* (accommodative esotropia or accommodative convergent strabismus).

Symptoms. In young patients, accommodation can compensate for slight to moderate hyperopia. However, this leads to chronic overuse of the ciliary muscle. Reading in particular can cause **asthenopic symptoms** such as eye pain or headache, burning sensation in the eyes, blepharoconjunctivitis, blurred vision, and rapid fatigue. **Esotropia** can also occur, as was mentioned above. As accommodation decreases with advancing age, near vision becomes increasingly difficult. For this reason, hyperopic persons tend to become presbyopic early.

Diagnostic considerations. Ophthalmoscopic examination of the fundus may reveal a slightly blurred **optic disc** that may be **elevated** (hyperopic pseudoneuritis). However, this is not associated with any functional impairment such as visual field defects, loss of visual acuity, or color vision defects. The retina is too large for the small eye, which leads to **tortuous retinal vascular structures**. Transitions to abnormal forms of axial shortening, such as in microphthalmos, are not well defined.

The ciliary muscle is chronically under tension in slight or moderate hyperopia to compensate for the hyperopia. This overuse of the ciliary muscle leads to a condition of residual accommodation in which the muscle is unable to relax even after the hyperopia has been corrected with plus lenses. This residual or **latent hyperopia** may be overlooked if refraction testing is performed without first completely paralyzing the ciliary body with cycloplegic agents such as cyclopentolate or atropine. The full extent of hyperopia includes both this residual hyperopia and clinically manifest hyperopia.

> In the presence of asthenopic symptoms of uncertain origin, refraction testing under cycloplegia is indicated to rule out latent hyperopia.

Treatment. The insufficient refractive power must be augmented with **converging lenses** (plus or convex lenses; Fig. 16.**11a**). A watch-and-wait approach is indicated with asymptomatic young patients with slight hyperopia. Spherical plus lenses converge parallel incident light rays at a focal point behind the lens. The refractive power (D) in plus lenses is positive. It is equal to 1/f, where f is the focal length in meters. Previously, *biconvex* or *planoconvex* lens blanks were used in the manufacture of corrective lenses. However, these entailed a number of optical disadvantages. The optical aberrations of the *positive meniscus* lenses used today are comparatively slight.

The clinician should determine the *total degree of hyperopia present* (see Diagnostic considerations) prior to prescribing corrective lenses. The second step is to prescribe the **strongest plus lens** that the patient can tolerate without compromising visual acuity. Care should be taken to avoid overcorrection. This will compensate for the manifest component of the hyperopia. If the patient wears these corrective lenses permanently, then with time it will also become possible to correct the latent component (see Diagnostic considerations). This is because the permanent tension in the ciliary body is no longer necessary.

Prior to any correction of hyperopia, refraction testing should be performed after administering cycloplegics to the patient. The correction is then made with the strongest plus lens that the patient can subjectively tolerate without compromising visual acuity.

In contrast, refraction testing to **correct aphakia** *does not require cycloplegia*. Here, too, *plus lenses* are required to correct the hyperopia. The closer the plus lens is to the retina, the stronger its refractive power must be to converge incident light at a point on the retina. For this reason, a cataract lens (Fig. 16.**11b**) has a refractive power of about 12 diopters, a contact lens (Fig. 16.**11c**) about 14 diopters, an anterior-chamber intraocular lens about 20 diopters (Fig. 16.**11d**), and a posterior-chamber lens about 23 diopters (Fig. 16.**11e**). See chapter 5 for additional surgical options.

Astigmatism

Definition: Astigmatism is derived from the Greek word stigma (point) and literally means lack of a focal point. The disorder is characterized by a curvature anomaly of the refractive media such that parallel incident light rays do not converge at a point but are drawn apart to form a line.

Epidemiology. Forty-two percent of humans have astigmatism greater than or equal to 0.5 diopters. In approximately 20%, this astigmatism is greater than 1 diopter and requires optical correction.

Correction of hyperopia

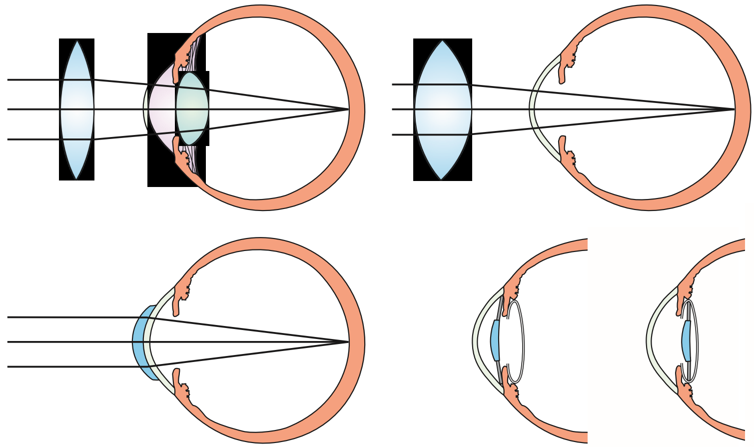


Fig. 16.**11** **a** Correction with converging lenses (plus lenses). **b**–**d** Correction of aphakia with a cataract lens (**b**), contact lens (**c**), anterior chamber intraocular lens (**d**), or posterior chamber intraocular lens (**e**).

Pathophysiology. The refractive media of the astigmatic eye are not spherical, but *refract differently along one meridian than along the meridian perpendicular to it* (Fig. 16.**12**). Any amount of astigmatism at the axis orientation introduces a Sturm conoid into the image system. This produces two focal points. A *punctiform object* is therefore represented as a sharply defined *line segment* at the focal point of the first meridian, but also appears as a sharply defined line segment rotated 90 at the focal point of the second meridian. Midway between these two focal points is what is known as the "*circle of least confusion*." This refers to the location at which the image is equally distorted in every direction—i.e., the location with the least loss of image definition.

The aggregate system *lacks a focal point*.

The combined astigmatic components of all of the refractive media comprise the **total astigmatism** of the eye. These media include:

Anterior surface of the cornea.
Posterior surface of the cornea.
Anterior surface of the lens.
Posterior surface of the lens.

Rarely, nonspherical curvature of the retina may also contribute to astigmatism.

Image formation with an astigmatic cornea (Sturm conoid)

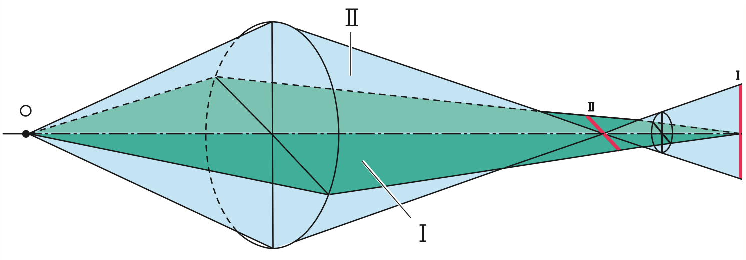


Fig. 16.**12** The two main meridians (I and II) are perpendicular to each other. A punctiform object (o) is represented as a line segment Y′ and Y′ at the focal points of the two meridians. Midway between these two focal points is the "circle of least confusion" (Kr), the location with the least loss of image definition.

Classification and causes. Astigmatism can be classified as follows:

External astigmatism. Astigmatism of the anterior surface of the cornea.

Internal astigmatism. The sum of the astigmatic components of the other media.

■ The degree of astigmatism and its axis can change during life.

Astigmatism can also be classified *according to the location of the meridian of greater refraction*:

With-the-rule astigmatism (most common form). The meridian with the greater refractive power is vertical—i.e., between 70 and 110.

Against-the-rule astigmatism. The meridian with the greater refractive power is horizontal—i.e., between 160 and 200.

Oblique astigmatism. The meridian with the greater refractive power is oblique—i.e., between 20 and 70 or between 110 and 160.

The discussion up to this point has proceeded from the assumption that the anomaly is a **regular astigmatism** involving only two meridians approximately perpendicular to each other (Fig. 16.**12**). This is presumably caused by excessive eyelid tension that leads to astigmatic changes in the surface of the cornea.

The condition above should be distinguished from **irregular astigmatism**. Here, the curvature and the refractive power of the refractive media are *completely irregular* (Fig. 16.**13a**). There are multiple focal points, which produces a completely blurred image on the retina. This condition may be caused by the following diseases:

Corneal ulcerations with resulting scarring of the cornea.

Penetrating corneal trauma.

Advanced keratoconus.

Cataract.

Lenticonus.

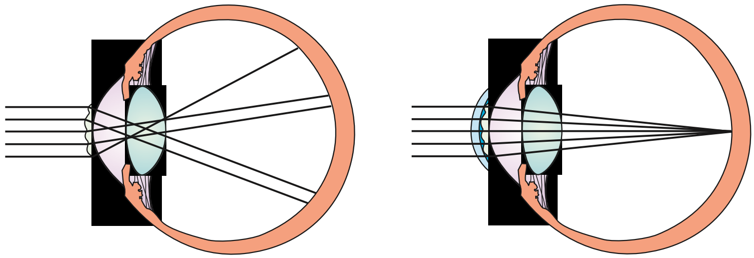


Fig. 16.**13** **a** Curvature and refractive power of the refractive media are totally irregular, resulting in multiple focal points.**b** Correction of irregular corneal astigmatism with a rigid contact lens.

Symptoms. Patients with astigmatism see everything distorted. Attempts to compensate for the refractive error by accommodation can lead to asthenopic symptoms such as a burning sensation in the eyes or headache.

Diagnostic considerations. The **keratoscope** (Placido disc) permits *gross estimation* of astigmatism. The examiner evaluates the mirror images of the rings on the patient's cornea. In *regular astigmatism*, the rings are *oval*; in *irregular astigmatism*, they are *irregularly distorted*. Computerized corneal topography (**videokeratoscopy**) can be used to obtain an image of the distribution of refractive values over the entire cornea (see Fig. 5.**3**). A **Helmholtz** or **Javal ophthalmometer** can be used to *measure the central corneal curvature*, which determines the refractive power of the cornea (Fig. 16.**14**).

Treatment. Early correction is crucial. Untreated astigmatism in children will eventually lead to uncorrectable refractive amblyopia because a sharp image is not projected on the retina.

Treatmentofregularastigmatism. The purpose of the correction is to bring the "focal lines" of two main meridians together at one focal point. This requires a lens that *refracts in only one plane*. **Cylinder lenses** are required for this application (Fig. 16.**15a**). Once the two "focal lines" have been converged into a focal point, **additional spherical lenses** can be used to shift this focal point onto the retina if necessary.

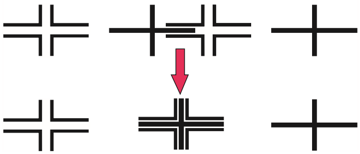


Fig. 16.**14** The diagram shows the corneal reflex images (outline cross, 1, and solid cross, 2) of the Zeiss ophthalmometer. These images are projected onto the cornea; the distance between them will vary depending on the curvature of the cornea. The examiner has to align the images by changing their angle of projection. After aligning them, the examiner reads the axis of the main meridian, the corneal curvature in millimeters, and the appropriate refractive power in diopters on a scale in the device. This measurement is performed in both main meridians. The difference yields the astigmatism. In irregular astigmatism, the images are distorted, and often a measurement cannot be obtained.

Diagnosis of corneal astigmatism with an ophthalmometer

Correction of regular astigmatism with cylinder lenses

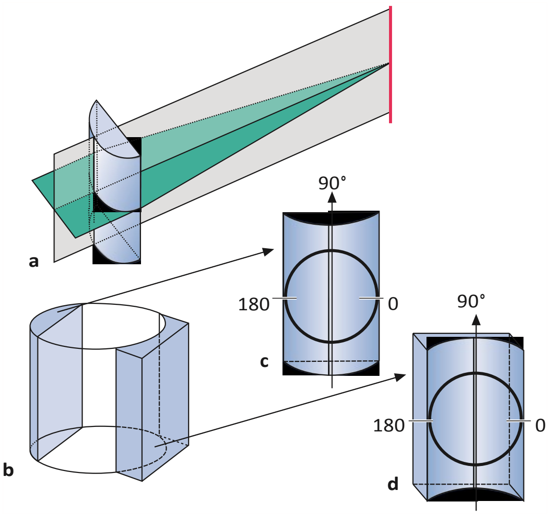


Fig. 16.**15** **a** Cylinder lenses refract light only in the plane perpendicular to the axis of the cylinder. The axis of the cylinder defines the nonrefracting plane. **b–d** Cylinder lenses can be manufactured as plus cylinders (**c**) or minus cylinders (**d**).

Treatment of irregular astigmatism. This form *cannot* be corrected with eyeglasses. *External astigmatism* can be managed with a rigid contact lens (Fig. 16.**13b**), keratoplasty, or surgical correction of the refractive error. Irregular *internal astigmatism* is usually lens-related. In this case, removal of the lens with implantation of an intraocular lens is indicated.

Only regular astigmatism can be corrected with eyeglasses.

Anisometropia

Definition: In anisometropia, there is a difference in refractive power between the two eyes.

Epidemiology. Anisometropia of at least 4 diopters is present in less than 1% of the population.

Etiology. The reason for the varying development of the two eyes is not clear. This primarily congenital disease is known to exhibit a familial pattern of increased incidence.

Pathophysiology. In anisometropia, there is a difference in refractive power between the two eyes. This refractive difference can be corrected separately for each eye with different lenses as long as it *lies below 4 diopters*. Where the difference in refraction is greater than or equal to 4 diopters, the size difference of the two retinal images becomes too great for the brain to fuse the two images into one. Known as **aniseikonia**, this condition jeopardizes binocular vision because it can lead to development of amblyopia (*anisometropic amblyopia*). The aniseikonia, or differing size of the retinal images, depends not only on the degree of refractive anomaly but also depends significantly on the **type of correction**. The closer to the site of the refraction deficit the correction is made, the less the retinal image changes in size. Correction with *intraocular lenses* results in almost no difference in image size. Contact lenses produce a slight and *usually irrelevant difference in image size*. However, *eyeglass correction* resulting in a difference of *more than 4 diopters* leads to *intolerable aniseikonia* (see Table 7.**4**).

Symptoms. Anisometropia is usually congenital and *often asymptomatic*. Children are not aware that their vision is abnormal. However, there is a tendency toward strabismus as binocular functions may remain underdeveloped. Where the correction of the anisometropia results in unacceptable aniseikonia, patients will report unpleasant visual sensations of *double vision*.

Diagnostic considerations. Anisometropia is usually diagnosed during routine examinations. The diagnosis is made on the basis of refraction testing.

Treatment. The refractive error should be corrected. Anisometropia exceeding 4 diopters cannot be corrected with **eyeglasses** because of the clinically relevant aniseikonia. **Contact lenses** and, in rare cases, surgical treatment are indicated. Patients with unilateral aphakia or who do not tolerate contact lenses will require implantation of an **intraocular lens**.

> Correction of unilateral aphakia with unilateral glasses is usually contraindicated because it results in aniseikonia of approximately 25%.

16.4 Impaired Accommodation

Accommodation Spasm

> ***Definition:*** An accommodation spasm is defined as inadequate protracted contraction of the ciliary muscle.

Etiology. Accommodation spasms are *rare*. They may occur as *functional impairment* or they may occur *iatrogenically* when treating young patients with parasympathomimetic agents (miotic agents). The functional impairments are frequently attributable to heightened sensitivity of the accommodation center, which especially in children (often girls) can be psychogenic. *Rarely* the spasm is due to *organic* causes. In these cases, it is most often attributable to irritation in the region of the oculomotor nuclei (from cerebral pressure or cerebral disorders) or to change in the ciliary muscle such as in an ocular contusion.

Symptoms. Patients complain of deep eye pain and blurred distance vision (lenticular myopia).

Diagnostic considerations and differential diagnosis. The diagnosis is made on the basis of presenting symptoms and refraction testing, including measurement of the range of accommodation. This is done with an accommodometer, which determines the difference in refractive power between the near point and far point. A *differential diagnosis* should exclude latent hyperopia. In children, this will frequently be associated with accommodative esotropia and accommodative pupil narrowing.

Treatment. This depends on the underlying disorder. Cycloplegic therapy with agents such as tropicamide or cyclopentolate may be attempted in the presence of recurrent accommodation spasms.

Prognosis. Iatrogenic spasms are completely reversible by discontinuing the parasympathomimetic agents. The prognosis is also good for patients with functional causes. Spasms due to organic causes require treatment of the underlying disorder but once treatment is initiated the prognosis is usually good.

Accommodation Palsy

■ ***Definition:*** Failure of accommodation due to palsy of the ciliary muscle.

Etiology. This *rare* disorder is primarily due to one of the following causes:

Iatrogenic drug-induced palsy due to parasympatholytic agents such as atropine, cyclopentolate scopolamine, homatropine, and tropicamide.

Peripheral causes. Oculomotor palsy, lesions of the ciliary ganglion, or the ciliary muscle.

Systemic causes. Damage to the accommodation center in diphtheria, diabetes mellitus, chronic alcoholism, meningitis, cerebral stroke, multiple sclerosis, syphilis, lead or ergotamine poisoning, medications such as isoniazid or piperazine, and tumors.

Symptoms. The failure of accommodation leads to blurred near vision and may be associated with mydriasis where the sphincter pupillae muscle is also involved. The clinical syndromes listed below exhibit a specific constellation of clinical symptoms and therefore warrant further discussion.

Post-diphtheriaaccommodationpalsy. This transitory palsy is a toxic reaction and occurs *without* pupillary dysfunction approximately 4 weeks after infection. Sometimes it is associated with palsy of the soft palate and/ or impaired motor function in the lower extremities.

Accommodation palsy in botulism. This is also a toxic palsy. It *does* involve the pupil, producing *mydriasis,* and can be the first symptom of botulism. It is associated with speech, swallowing, and ocular muscle dysfunction accompanied by double vision.

Tonic pupillary contraction is associated with tonic accommodation.

Sympathetic ophthalmia is characterized by a decrease in the range of accommodation, even in the unaffected eye.

> Measurement of the range of accommodation is indicated whenever sympathetic ophthalmia is suspected.

Diagnostic considerations. In addition to measuring the range of accommodation with an accommodometer, the examiner should inquire about other ocular and general symptoms.

Treatment. This depends on the underlying disorder.

Prognosis. The clinical course of **tonic pupillary contraction** is chronic and results in irreversible loss of accommodation. The **toxic accommodation palsies** are reversible once the underlying disorder is controlled.

16.5 Correction of Refractive Errors

Eyeglass Lenses

Monofocal Lenses

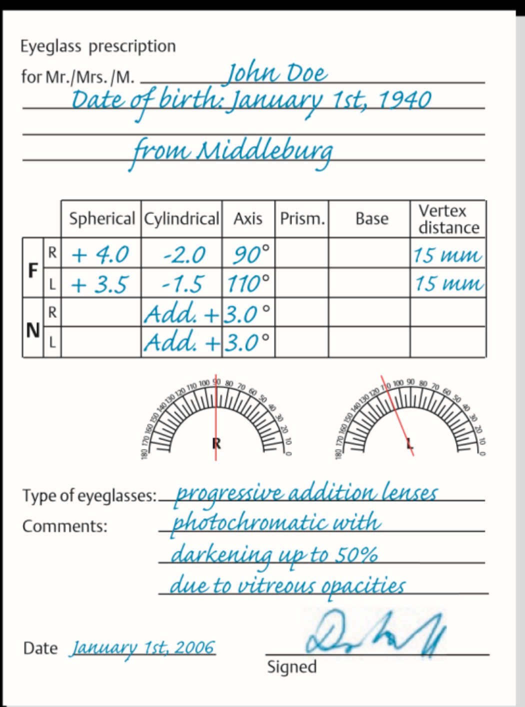
There are two basic types.

Spherical lenses refract light equally along every axis

Toric lenses (known as cylindrical lenses) refract light only along one axis Spherical and toric lenses can be combined where indicated.

The **refractive power of the lenses** is measured manually or automatically with an optical interferometer. The measured refraction is specified as *spherocylindrical combination*. By convention, the specified axis of the cylindrical lens is perpendicular to its axis of refraction (Fig. 16.**15c**, **d**). The orientation of this axis with respect to the eye is specified on a standardized form
(Fig. 16.**16**).

Eyeglass prescription



Eyeglass prescription

for Mr./Mrs./M. John Doe

Date of birth: January 1st, 1940

from Middleburg

		Spherical	Cylindrical	Axis	Prism.	Base	Vertex distance
F	R	+ 4.0	-2.0	90°			15 mm
	L	+ 3.5	-1.5	110°			15 mm
N	R		Add. +	3.0 °			
	L		Add. +	3.0 °			

Type of eyeglasses: progressive addition lenses

Comments: photochromatic with darkening up to 50% due to vitreous opacities

Date January 1st, 2006

Signed

Fig. 16.**16** The refraction values for the right eye have been filled in. The cylindrical axis has also been entered (red line). The diagram specifies the position of the cylindrical axis with respect to the eye. A perpendicular cylindrical axis (red line) corresponds to 90° on the standard form.

Example. + 4.00 diopters – 2.00 diopters/90 means that the lens represents a combination of converging lens (+ 4 diopters) and cylindrical lens (– 2 diopters) with its axis at 90.

Eyeglass lenses exhibit typical characteristics when moved back and forth a few inches in front of one's eye. Objects viewed through minus lenses appear to move in the same direction as the lens; objects viewed through plus lenses move in the opposite direction. A cylindrical lens produces image distortions when turned.

Multifocal Lenses

Multifocal lenses differ from the monofocal lenses of uniform refractive power discussed in the previous section in that different areas of the lens have different refractive powers. These lenses are best understood as *combinations of two or more lenses in a single lens*.

Bifocals. The *upper and middle portion of the lens* is ground for the *distance correction*; the lower portion is ground for the *near-field correction* (Fig. 16.**17**). Patients are able to view distant objects in focus and read using *one pair* of eyeglasses, eliminating the need to constantly change glasses. The gaze is lowered and converged to read. This portion of the lens contains the nearfield correction. This near-field correction can be placed in a different part of the lens for special applications.

Trifocals. These lenses include a *third refractive correction* between the distance and near-field portions. This intermediate portion *sharply images the intermediate field between distance vision and reading range* without any need for accommodation (Fig. 16.**17**).

Progressive addition lenses. These lenses were developed to *minimize abrupt image changes* when the gaze moves through the different correction zones of the lens while *maintaining a sharp focus at every distance* (Fig. 16.**17**).

These eyeglasses also offer cosmetic advantages. They produce *well focused images in the central region* but have a *high degree of peripheral astigmatism*. However, many patients learn to tolerate this peripheral distortion.

Presbyopic patients tolerate progressive addition lenses better when they still have only slight presbyopia and have not previously worn bifocals.

Special Lenses

The following types of lens have been developed for special applications:

Plastic lenses. These lenses reduce the weight of eyeglasses where severe ametropia must be corrected. Another advantage is that these lenses are largely shatterproof, which is why they are preferred for children. However, they are easily scratched.

Multifocal lenses

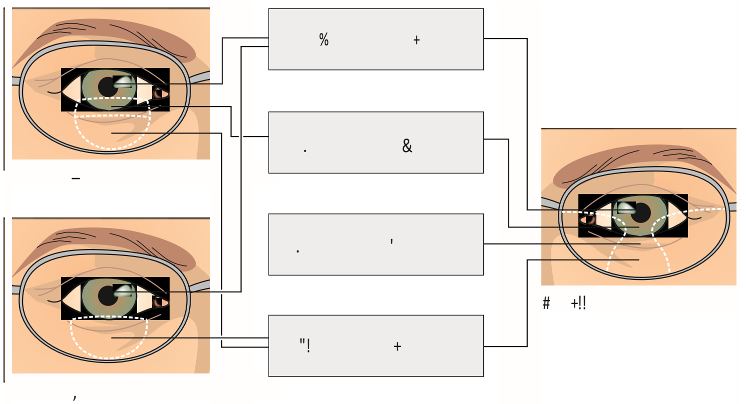


Fig. 16.**17** **Trifocals, bifocals, progressives**

Absorption lenses. These lenses are indicated in patients with *increased sensitivity to glare*. Operating motor vehicles in twilight or at night with eyeglasses that absorb more than 20% of incident light is dangerous because of the resulting reduction in visual acuity.

Photochromatic lenses. These lenses darken in response to the intensity of ultraviolet light. The lenses become darker at low temperatures than at high temperatures; they lighten more slowly at low temperatures and more rapidly at high temperatures. Light attenuation ranges between 15 and 50% in some lenses and between 30 and 65% in others.

> Photochromatic lenses pose problems for patients operating motor vehicles. The lenses darken only slightly in a warm car with the windows closed, due to the lack of ultraviolet light. Dark lenses lighten too slowly when the car enters a tunnel.

Coated lenses. Extremely thin coatings of magnesium fluoride can be applied to lenses to reduce surface reflection on the front and back of the lens.

Subjective Refraction Testing for Eyeglasses

While the patient looks at vision charts, the examiner places various combinations of lenses in front of the patient's eye. The patient reports which of two lenses produces the sharper image. The better of the two is then compared with the next lens. This incremental method identifies the optimal correction. It is expedient to use the patient's objective refraction as the starting point for subjective testing. Refraction testing is performed either with a series of **test lenses** from a case or with a **Phoroptor**, which contains many lenses that can be automatically or manually placed before the patient's eye. The examination proceeds in three stages:

Monocular testing. The optimal refraction for achieving best visual acuity is determined *separately for each eye*. The weakest possible minus lens is used in *myopic patients*, and the strongest possible plus lens in *hyperopic patients*. The red–green chromatic aberration test can be used for fine refraction. In this test, the patient compares optotypes on green and red backgrounds. Fine adjustment of refraction permits precise shifting of the focal point of the light on the retina. Optotypes on both red and green backgrounds then appear equally sharply defined.

Binocular testing. The objective of this stage is to achieve a *balance* between both eyes.

Near point testing. The final stage of the examination determines the patient's *near visual acuity*, and, if necessary, the *presbyopic addition*. Allowance is made for the patient's preferred reading and working position.

The values determined by this examination are entered in the eyeglass prescription (see Fig. 16.**16**). The **vertex distance** at which refraction was performed is an important additional parameter for the optician. This is the *distance between the back surface of the test lens and the anterior surface of the cornea*. If the manufactured eyeglasses have a different vertex distance, then the strength of the lenses should be altered accordingly. This is because the optical effect of eyeglass lenses varies according to the distance from the eye.

Before the lenses are fitted into the frame, the **distance between the pupils** must be measured to ensure that the lenses are properly centered. The *center of the lens* should be *in front of the pupil*. The prismatic effects of eccentric lenses might otherwise cause asthenopic symptoms such as headache or a burning sensation in the eyes.

> To facilitate early detection of glaucoma, intraocular pressure should be measured in any patient over the age of 40 presenting for refraction testing for eyeglasses.

Contact Lenses

Advantages and Characteristics of Contact Lenses

Contact lenses are in immediate contact with the cornea. Although they are foreign bodies, most patients adapt to properly fitted contact lenses. Contact lenses differ from eyeglasses in that they correct the refractive error closer to the location of its origin. For this reason, the *quality of the optical image viewed through contact lenses is higher than that viewed through eyeglasses*.

Contact lenses have significantly less influence on the size of the retinal image than does correction with eyeglasses. Lenses do not cloud up in rainy weather or steam, and peripheral distortion is minimized. The cosmetic disadvantage of thick eyeglasses in *severe ametropia* is also eliminated. *Severe anisometropia* requires correction with contact lenses for optical reasons— i.e., to minimize aniseikonia.

Contact lenses are defined by the following **characteristics:**

- Diameter of the contact lens
- Radius of curvature of the posterior surface
- Geometry of the posterior surface—i.e., spherical, aspherical, complex curvature, or toric
- Refractive power
- Material
- Oxygen permeability of the material (Dk value)

The cornea requires oxygen from the precorneal tear film. To ensure this supply, *contact lens materials must be oxygen-permeable*. This becomes all the more important the less the contact lens moves and permits circulation of tear fluid. Contact lenses can be made of *rigid* or *flexible* materials.

Rigid Contact Lenses

These contact lenses have a stable, nearly unchanging shape. Patients *take some time to become used to them* and should therefore wear them often. The goal is to achieve the best possible intimacy of fit between the posterior surface of the lens and the anterior surface of the cornea (Fig. 16.**18**). This allows the contact lens to float on the precorneal tear film. Every time the patient

Fitting of a rigid contact lens

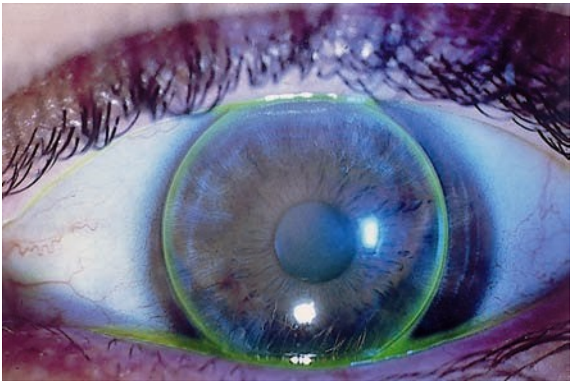


Fig. 16.**18** There is a tear film between the anterior surface of the cornea and the posterior surface of the lens (visualized by fluorescein dye).

blinks, the lens is displaced superiorly and then returns to its central position. This permits circulation of the tear film.

Previously, polymethylmethacrylate (PMMA) was used as a material. However, this is practically impermeable to oxygen. The lenses were fitted in small diameters with a very shallow curvature; the central area maintained contact with the cornea while the periphery projected. This allowed excellent tear film circulation, and patients were able to wear the lenses for surprisingly long periods. *Today*, highly oxygen-permeable materials such as silicone copolymers are available. This eliminates the time limit for *daily wearing*. These lenses may also remain in the eye overnight in special cases, such as aphakic patients with poor coordination (*prolonged wearing*).

Rigid contact lenses can be manufactured as *spherical lenses and toric lenses*. **Spherical** contact lenses can almost completely compensate for **corneal astigmatism of less than 2.5 diopters**. This is possible because the space between the posterior surface of the spherical contact lens and the anterior surface of the astigmatic cornea is filled with tear fluid that forms a "*tear lens*." Tear fluid has nearly the same refractive index as the cornea. **More severe corneal astigmatism** or **internal astigmatism** requires correction with **toric** contact lenses. Rigid contact lenses can even correct severe **keratoconus**.

Soft Contact Lenses

The material of the contact lens, such as hydrogel, is soft and pliable. Patients find these lenses *significantly more comfortable*. The *oxygen permeability* of the material depends on its water content, which may range from 36 to 85%. The higher the water content, the better the oxygen permeability. However, it is typically *lower* than that of *rigid lenses*. The material is more permeable to foreign substances, which can accumulate in it. At 12.5–16 mm, flexible lenses are larger in diameter than rigid lenses. Flexible lenses are often supported by the limbus. The lens is often displaced only a few tenths of a millimeter when the patient blinks. This *greatly reduces the circulation of tear film under the lenses*. This limits the *maximum daily period* that patients are able to wear them and requires that they be removed at night to allow regeneration of the cornea. Deviation from this principle is only possible in exceptional cases under the strict supervision of a physician.

As the lenses are almost completely in contact with the surface of the cornea, *corneal astigmatism cannot be corrected with spherical soft lenses*. This requires toric soft lenses.

Special Lenses

The following types of special lens are available for specific situations:

Therapeutic contact lenses. In the presence of **corneal erosion,** soft ultra-thin (0.05 mm) contact lenses act as a bandage and thereby accelerate reepithelialization of the cornea. They also reduce pain. Soft contact lenses may also be used in patients receiving topical medication as they store medication and only release it very slowly.

Corneal shields. These are collagen devices that resemble contact lenses. These shields are gradually broken down by the collagenase in the tear film.
They are used as **bandages** and **substrates for topical medication** in the treatment of anterior disorders, such as erosion or ulcer.

Iris print lenses. These colored contact lenses with a clear central pupil are used in patients with **aniridia** and **albinism.**

They produce good cosmetic results, reduce glare, and can correct a refractive error where indicated.

Bifocalcontactlenses. These lenses were developed to allow the use of contact lenses in presbyopic patients. As in eyeglasses, a *near-field correction* is ground into the lens. This near-field portion is always located at the bottom of the lens because the lens is heavier there. When the patient gazes downward to read, the immobile lower eyelid pushes this near-field portion superiorly where it aligns with the pupil and becomes optically effective. Another possibility is *diffraction* (bending of light rays as opposed to refraction) through concentric rings on the posterior surface of the contact lens. This produces two images, a distant refractive image and a near-field diffractive image. The patient chooses the image that is important at the moment. It is also possible to correct one eye for distance vision and the fellow eye for near vision (*monocular vision*).

Disadvantages of Contact Lenses

Contact lenses exert mechanical and metabolic influences on the cornea. Therefore, they require the *constant supervision of an ophthalmologist*.

Mechanical influences on the cornea can lead to *transient changes in refraction*.
"Spectacle blur" can result when eyeglasses suddenly no longer provide the proper correction after removing the lens. Contact lenses require careful *daily cleaning* and disinfection. This is more difficult, time-consuming, and more expensive than eyeglass care and is particular important with soft lenses.

Metabolic influences on the cornea. The macromolecular mesh of material absorbs proteins, protein breakdown products, low-molecular-weight substances such as medications and disinfectants, and bacteria and fungi. Serious complications can occur where daily care of the contact lenses is inadequate. With their threshold oxygen permeability, soft contact lenses interfere with corneal metabolism. Contact lenses are less suitable for patients with symptoms of keratoconjunctivitis sicca.

Contact Lens Complications

Complications have been observed primarily in patients wearing *soft* contact lenses. These include the following:

Infectious keratitis (corneal infiltrations and ulcers) caused by bacteria, fungi, and protozoans.

> *Acanthamoeba* keratitis is a serious complication affecting wearers of soft contact lenses and often requires penetrating keratoplasty.

Giant papillary conjunctivitis. This is an allergic reaction of the palpebral conjunctiva of the upper eyelid to denatured proteins. It results in proliferative "cobblestone" conjunctival lesions. Corneal vascularization can be regarded as resulting from an inadequate supply of oxygen to the cornea.

Severe chronic conjunctivitis. This usually makes it impossible to continue wearing contact lenses.

Prisms

Prisms can change the direction of parallel light rays. The optical strength of a prism is specified in *prism diopters*. Prism lenses can be combined with spherical and toric lenses. When prescribing eyeglasses, the ophthalmologist specifies the strength and the position of the base of the prism. Prism lenses are used to correct heterophoria (latent strabismus) and ocular muscle palsies, and in preparation for surgery to correct strabismus.

A 1 diopter prism deflects a ray of light 1 cm at a distance of 1 m from the base of the prism.

Magnifying Vision Aids

The **reduction in central corrected visual acuity** as a result of destruction of the fovea with a central scotoma requires magnifying vision aids. However, magnification is always associated with a *reduction in the size of the visual field*. As a result, these vision aids require patience, adaptation, motivation, and dexterity. Cooperation between ophthalmologist and optician is often helpful. The following **systems** are available in order of magnification:

Increased near-field corrections. The stronger the near-field correction, the shorter the reading distance. Magnification (V) is a function of the refractive power of the near-field correction (D) and is determined by the equation V = D/4.

Example. Eyeglasses with a 10 diopter near-field correction magnify the image two and one-half powers. However, the object must be brought to within 10 cm of the eye.

Magnifying glasses are available in various strengths, with or without illumination.

Monocular and binocular loupes, telescopes, and prism loupes. An optical magnifying system is mounted on one or both eyeglass lenses. The optical system functions on the principle of Galilean or Keplerian optics.

Closed-circuitTVmagnifier. This device displays text at up to 45 power magnification.

16.6 Aberrations of Lenses and Eyeglasses

Optical lens systems (eyeglasses or lenses) always have minor aberrations. These aberrations are not material flaws, rather they are due to the laws of physics. Expensive optical systems can reduce these aberrations by using many different lenses in a specific order.

Chromatic Aberration (Dispersion)

This means that the **refractive power of the lens varies according to the wavelength of the light.**

Light consists of a blend of various wavelengths. Light with a *short wavelength* such as blue is refracted more than light with a *long wavelength* such as red (Fig. 16.**19**). This is why monochromatic light (light of a single wavelength) produces a sharper image on the retina.

> Chromatic aberration is the basis of the red–green test used for fine refraction testing.

Spherical Aberration

This means that the **refractive power of the lens varies according to the location at which the light ray strikes the lens.**

> Patients may report being able to see better when looking through a disc with a pinhole (a stenopeic aperture) than without it. This usually is a sign of an uncompensated refractive error in the eye.

The further peripherally the light ray strikes the lens, the more it will be refracted (Fig. 16.**20**). The iris intercepts a large share of these peripheral light rays. A narrow pupil will intercept a particularly large share of peripheral light rays, which improves the *depth of field*. Conversely, *depth of field is significantly poorer* when the pupil is dilated.

■ Patients who have received mydriatic agents should refrain from driving.

Chromatic aberration

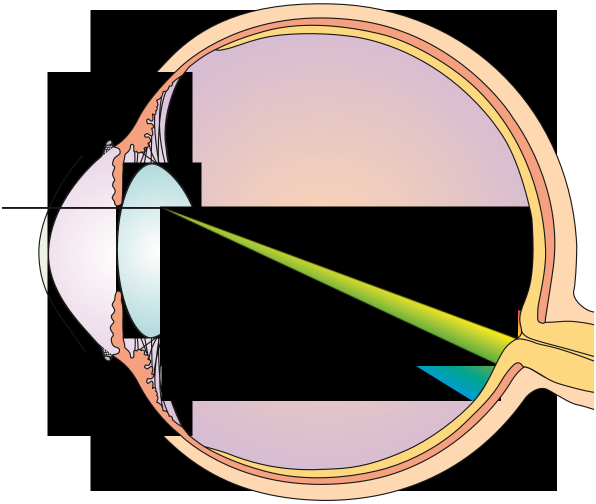


Fig. 16.**19** Chromatic aberration splits white light into its component spectral colors. Red is refracted least, and blue is refracted most.

Astigmatic Aberration

A punctiform object **viewed through a spherical lens** appears as a line.

If one looks through a lens obliquely to its optical axis, it will act as a *prism* (Fig. 16.**21**). A prism refracts a light ray toward its base (Fig. 16.**21b**). In addition to this, the light is split into its component spectral colors. Light with a *short wavelength* (blue) is refracted more than light with a *long wavelength* (red). Astigmatic aberration is an undesired side effect that is present whenever one looks through a lens at an oblique angle.

This phenomenon should be distinguished from *astigmatic or toric lenses*, which correct for astigmatism of the eye when the patient looks through them *along the optical axis*.

Curvature of Field

This means that the **magnification of the image changes as one approaches the periphery.** The result is a sharp image with peripheral curvature. Convex or plus lenses produce *pincushion distortion*; concave or minus lenses produce *barrel distortion* (Fig. 16.**22**).

16.5 Correction of Refractive Errors

Spherical aberration

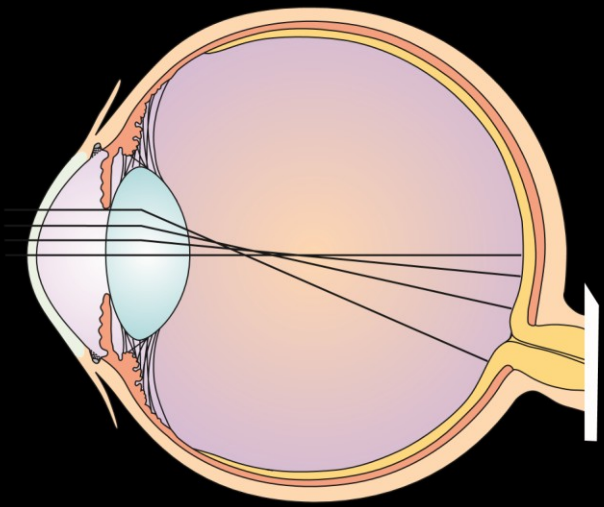


Fig. 16.**20** Due to spherical aberration, the refraction of light rays increases the further peripherally they strike the lens.

Astigmatic aberration

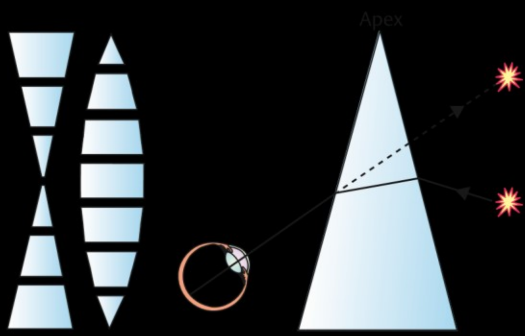


Fig. 16.**21** **a** Lenses can be regarded as consisting of a large number of prisms, which explains many of the optical phenomena of lenses, such as dispersion. **b** A prism refracts a light ray toward its base twice (solid line). However, it appears to the observer that the object is shifted toward the apex of the prism (dashed line).

Curvature of field

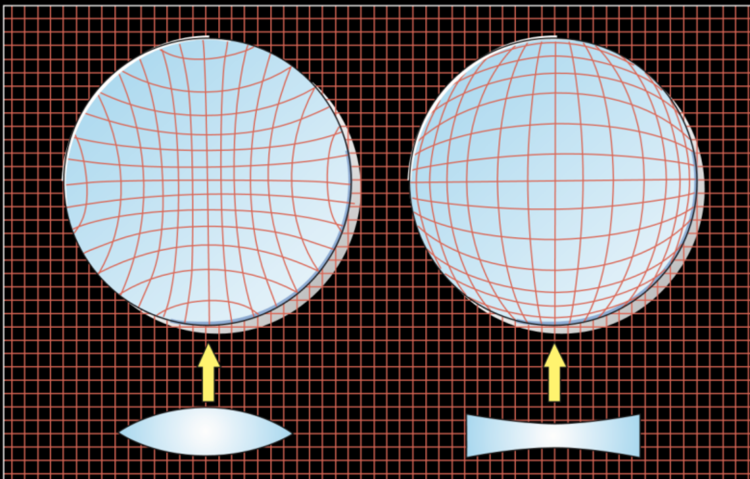


Fig. 16.22 Viewing an object through plus lenses produces pin-cushion distortion of the image, whereas minus lenses produce barrel distortion.