lary margin in much the same way as in testing the edge-light pupil cycle time. The pupils of almost all eyes with normal optic nerves can generally be induced to cycle at regular intervals, whereas the pupils of almost all eyes with optic nerve disease show altered responses, such as complete failure to cycle or prolonged pauses in the cycle. We have found the results of testing edge-light pupil cycle time and pupil cycle induction difficult to interpret, not particularly reproducible, and less sensitive than the results of a simple swinging flashlight test. We thus use these tests only when assessing monocular patients.

PHARMACOLOGIC TESTING

A few cautionary comments should be made regarding the interpretation of pupillary responses to topically instilled drugs.

First, the test variables must be carefully controlled whenever possible, both before and after pharmacologic testing. This means that the ambient lighting should be optimal for the test performed, the patient must fixate in the distance for at least 1 minute to minimize miosis and relax the pupil, and the patient should be alert throughout the test, because the psychic state of the individual can influence pupillary size (e.g., the pupils tend to be miotic in persons who are tired or listless and mydriatic in patients who are upset or anxious) (70).

Second, the pupil sizes must be measured as accurately as possible. The CU-5 camera manufactured by the Polaroid Company allows the direct measurement of pupillary size; however, one can simply paste or tape a ruler on the patient’s brow and then use any camera to obtain photographs from which accurate measurements can be made. Pupilometers also provide accurate measurements but are not well suited to most clinical practices.

Third, it is ideal, whenever possible, to use the presumably normal pupil as an internal control. For instance, if a judgment is to be made about the dilation or constriction of one of the pupils in response to a drop of some topical agent, such as 0.1% pilocarpine, 10% cocaine, or 5% hydroxyam-

phetamine (see Chapter 16), the drug should be placed in both eyes so that the responses of the two eyes can be compared. When the condition is bilateral, no such comparisons are possible, but an attempt should be made to make certain that the observed response is indeed caused by the instilled drug. In such cases, the drug may be placed in one eye only so that the responses of the medicated and unmedicated eyes can be compared. Occasionally, in patients with presumed bilateral pupillary abnormalities, we and others (22) place drops in both of the patient’s eyes and also in one of our own, to serve as a type of external control.

Finally, the drug should always be placed in the eye of concern first and then placed in the contralateral eye so that if there is no response in the presumably abnormal eye, one cannot blame squeezing or tearing as the cause.

Problems can occur when performing pharmacologic testing of the pupil using topical drugs. The drug may be outdated and thus more or less potent. The patient may develop sufficient tearing that the strength of the drug is altered by dilution, or it is washed out of the inferior conjunctival sac before it can be absorbed. The patient may squeeze the eyes tightly during instillation of the drug, thus preventing a sufficient amount of drug from being placed in the inferior conjunctival sac. Penetration of the drug through the cornea may be altered, especially if other topical medications have been used; e.g., anesthetics for testing of intraocular pressure, or if the integrity of the corneal epithelium has been altered by manipulation of the cornea during tonometry or testing of corneal sensation. One must also consider individual variations in the action of the drug on patients of different ages or with different colored irides.

Determining the results of pupillary testing can also be difficult depending on the initial size of the pupil. Differences in pupillary diameter or area can have profound results on the ultimate outcome in pharmacologic testing (Table 15.2).

Finally, it is important to remember why a particular test is being performed in the first place (Table 15.2). The correct drug must be used and placed in the eyes in the proper fashion.

ASSESSMENT OF ACCOMMODATION, CONVERGENCE, AND THE NEAR RESPONSE

Most visual problems associated with accommodation occur because accommodation is too great, too little, or too slow. Disturbances of the other two components of the near response—convergence and pupillary miosis—also can be of importance if they are too active or if they have reduced activity.

HISTORY

The symptoms of patients with disturbances of accommodation tend to be nonspecific but some aspects of the history may be important. Patients with accommodative insufficiency, for instance, usually complain of blurred vision at near but not in the distance. Patients with the most common problem with accommodation—presbyopia—may report that the farther away they hold an object, the better they can see it. Some patients with accommodative insufficiency report monocular diplopia; others complain of discomfort during attempted reading, a noticeable delay in focusing when changing fixation from a distant to a near or a near to a distant object, or a combination of these symptoms. Some patients report headache, light intolerance, and other asthenopic symptoms (71). Frequently, presbyopia and other accommodative insufficient states can be precipitated with medications having anticholinergic effects.

Accommodative excess or spasm is typically associated with clear vision at near and poor distance vision. Objects may look larger or smaller (macropsia or micropsia) than normal in this setting. In addition, patients with accommodative excess or spasm often complain of brow ache (72). When convergence also is affected, other symptoms may be present. For example, convergence excess often is associated with diplopia in the distance, blurring of vision, oscillopsia,
and/or pain; whereas convergence insufficiency most often is associated with trouble reading, diplopia at near, blurred vision that clears when either eye is covered, and pain or discomfort during near tasks.

In patients with spasm of the near reflex, symptoms are related to dysfunction of all three components. Such patients have accommodative spasm (up to 8–10 diopters), extreme miosis, an esotropia in primary position, and apparent but inconsistent bilateral limitation of abduction. These patients tend to complain of blurred or dim vision, binocular horizontal diplopia at both distance and near, temple or diffuse headache, pain in the eyes, and even trouble walking (73,74). Spasm of the near reflex is discussed in detail in Chapter 16 of this text.

EXAMINATION

Accommodation is the ability of the lens to change its refractive power in order to keep the image of an object clear on the retina. The primary stimulus for accommodation is blurring (75), and most tests of accommodation depend on producing or eliminating blur. There are, however, stimuli for accommodation other than blur, including chromatic aberration and perceived nearness (76), and these can also be used to test accommodation.

General Principles Related to the Components of the Near Triad

Accommodation is part of a complex triad that maintains clear near vision and is called the near response or the near reflex. Even though the components of the near response—accommodation, convergence, and pupillary miosis—normally work together during near viewing, each component can be tested separately. For example, one can weaken the stimulus to accommodation with plus lenses or strengthen the stimulus to accommodation with weak minus lenses without stimulating convergence or miosis. One can use weak base-out prisms to stimulate convergence without changing accommodation. Under certain conditions, one can test accommodation without inducing pupillary constriction (77). In addition, even in presbyopia in which accommodation fails, convergence and miosis continue. Furthermore, if one paralyzes accommodation with drugs, convergence remains intact. Relative accommodation is the term used to describe the amount of accommodation that is unrelated to convergence; relative convergence describes the amount of convergence unrelated to accommodation (78).

Depth of focus is slightly different from accommodation. It is the distance for any given accommodative state that an object can be viewed without a change in acuity or generation of blur. Depth of focus is more dependent on pupillary size and amount of illumination than is accommodation. For example, accommodation is not significantly affected by miosis and bright illumination; however, in patients with small pupils and bright illumination, the depth of focus is increased. Thus, a patient over 60 years of age will have very little, if any, accommodation; however, if one compares two patients, one with large pupils and the other with small pupils, the patient with the smaller pupils will have an increased depth of focus, and this increased depth of focus may be mistaken for accommodation. Many traditional tests of accommodation thus may overestimate the amount or range of accommodation in a patient because the tests cannot distinguish true accommodation from combined accommodation and depth of focus (79).

Accommodation

There are actually three aspects of accommodation: the near point of accommodation, the accommodative amplitude, and the range of accommodation. The near point of accommodation (NPA) is the point closest to the eye at which a target is sharply focused on the retina. The accommodative amplitude is the power of the lens that permits such clear vision. This power is measured in units called diopters (D) and is calculated by dividing the NPA in centimeters into 100. The accommodative amplitude is thus simply the reciprocal of the NPA (e.g., a patient with an NPA of 25 cm has an accommodative amplitude of 100/25 = 4 D). The range of accommodation is the distance between the furthest point an object of a certain size is in clear sight and the nearest point at which the eye can maintain that clear vision.

Convergence

Convergence is a vergence adduction movement that increases the visual angle to permit single binocular vision during near viewing. Convergence can be voluntary but need not be; i.e., no stimulus need be present to elicit it. It is also reflexive and a co-movement in the near response. Accommodation and convergence are related; a unit change in one normally causes a unit change in the other (80).

Convergence may be separated into four subtypes: (a) tonic convergence; (b) accommodative convergence; (c) fusional convergence; and (d) voluntary convergence.

The eyes normally tend to diverge. Keeping the eyes straight thus requires increased tone in the medial rectus muscles. This tone is tonic convergence (81).

Accommodative convergence is the amount of convergence elicited for a given amount of accommodation. The relationship between accommodation and convergence is usually expressed as the ratio of accommodative convergence in prism diopters (PD) to accommodation in diopters: the AC/A ratio. Because accommodation decreases with age, the AC/A ratio increases with age (72,82). Just as convergence can be stimulated by accommodation, so accommodation can be stimulated by convergence. The ratio of convergence accommodation in diopters to convergence in PD is called the CA/C ratio.

Fusional convergence is convergence that is stimulated not by changes in accommodation but by disparate retinal images (81). It is thought to be used to “fine tune” normal convergence. Pupillary constriction can occur with fusional vergence, but the amplitude of this form of convergence is not as great as that of accommodative convergence.

Voluntary convergence is measured by determining the near point of convergence (NPC)—the nearest point to which the eye can converge. It is closer to the eyes than
the near point of accommodation and, in general, does not deteriorate with age as does the NPA. The NPC usually is 10 cm or less.

Miosis

The pupil constricts when changing fixation from distance to near. This movement can occur in darkness, is slower than the light reflex, and is maintained as long as the near reaction is maintained. Miosis improves the range through which an object is seen clearly without any change in accommodation; i.e., the depth of field (see above). The miotic response to the near effort is directly dependent on that effort. Normal persons usually need a visible target to view to reach maximal pupillary miosis and accompanying accommodation. This miotic response also can be inadvertently stimulated by forceful eyelid closure (83). In patients with presbyopia, pupil size continues to decrease even when accommodation has reached its maximum. This probably occurs because aging changes limit alterations in the lens or ciliary muscles, whereas the pupillary sphincter is still functional and responsive to stimulation (84). On the other hand, artificially induced miosis (e.g., pharmacologic) reduces the amplitude of accommodation (85).

In testing accommodation and the near vision response, the above relationships must be remembered. Furthermore, one must remember that accommodation is never measured or tested in an absolute sense, but rather in response to how it changes under certain testing conditions (86).

Testing Techniques

The techniques one uses to determine the range and amplitude of accommodation, degree of convergence, etc. depend in part on the setting and the questions to be answered.

Accommodation

The principal handicaps in the clinical application of adequate tests of accommodation are the subjective nature of the end points and the number of variables that must be controlled. The first step in any testing of components of accommodation or the near triad, is to perform an adequate refraction for both distance and near viewing. For children and some adults, a cycloplegic refraction with an agent such as cyclopentolate (Cyclogyl) is needed to prevent the patient from accommodating and thus increasing the degree of myopia requiring correction during the refraction (87,88). Indeed, this "pseudomyopia" may be the first clue to accommodative spasm. Conversely, excellent distant vision and near vision may indicate accommodative insufficiency or presbyopia.

The NPA is most easily measured clinically using a scale device such as the Prince, Krimsky, or Berens rules (89–91). These instruments are simply rulers with markings in both centimeters and diopters on which there is a small sliding chart containing Snellen letters (Fig. 15.11). The technique of testing accommodation with them is called the "push-up method" (92) and is performed as follows.

Wearing an optimum distance refraction and with the opposite eye occluded, the patient fixes on small (usually 5 point) type on a card that is attached to the rule and that can be slid forward and backward. The size of the type is important, because the smallest type will evoke the strongest accommodative response (93). The zero point of the rule should be 11–14 mm in front of the cornea. This corresponds to the approximate position of the spectacle correction. The card is moved from a distance to the closest point at which the patient can see the print before it starts to blur. This is the NPA and, as noted above, is expressed in centimeters. The maneuver is repeated several times until the test gives reproducible results.

Once the NPA is determined, the accommodative amplitude in diopters, as indicated above, is calculated by dividing 100 by the NPA in centimeters. Using the push-up method, Duane (94) developed age-related normative data for the accommodative amplitude that are still in use today (Fig. 15.12).

Although the push-up method of determining the NPA and the accommodative amplitude has the disadvantage of overestimating accommodation, it is the most widely used method, the quickest in clinical practice, and the most popular. When interpreting the results of testing of accommodation using the push-up method, the examiner must be sure that the patient fully cooperated with the testing. Nevertheless, if, on repeated testing, the NPA (and thus the accommodative amplitude) is consistently out of the range considered to be normal for age, the results should be considered truly abnormal (94).

Adequate room lighting obviously must be available when testing accommodation, and it usually is recommended that the light be directed over the right shoulder when testing the right eye and over the left shoulder when testing the left eye. Indeed, illumination is a critical factor in performing the test. By increasing illumination from 1 to 25 foot-candles, the accommodative range can be increased by 28% in non-presbyopes and by 73% in presbyopes (95).

The range of accommodation can be tested in a fashion similar to that used to test the accommodative amplitude. The patient is instructed to indicate when the object blurs at near (the near point or NPA) and when it blurs in the distance (the far point). The range of accommodation is then calculated by determining the far point and near point in dioplers (i.e., dividing each of the distances in centimeters into 100) and by subtracting the far point from the near point. For an emmetrope, the range of accommodation corresponds to the accommodative amplitude because the far point is at infinity. For a myope whose near point is 10 cm and whose far point is 50 cm in front of the eye, the range of accommodation is 100/10 − 100/50 = 10 − 2 = 8 D. For a hyperope with a near point of 10 cm and a far point of 25 cm behind the eye, the range of accommodation is 100/10 − (−100/25) = 10 − (−4) = 10 + 4 = 14 D. If the patient is too presbyopic or myopic to do the test, corrective lenses should be used. One must then adjust the results to reflect the correction. If a minus lens has been used, the diopler power of the lens is added to the result; if a plus lens has been used, the diopler power is subtracted.

The push-up method of measuring the NPA and the ac-
Age Accommodation

Numerical Values of Limits for Each Age

Figure 15.12. The relationship between accommodation and age. Note the relatively linear decrease in accommodation with age until about age 52, when almost all accommodation has been lost. (Graph data from Duane A. The accommodation and Donders curve and the need of revising our ideas regarding them. JAMA 1909;52:1992–1996.)

Commodative amplitude is not the only one that can be used. A second method is the method of the spheres. In this test, the patient fixates on a reading target at 40 cm, and accommodation is stimulated by progressively adding minus (i.e., concave) lenses until the print blurs. Accommodation is then relaxed by adding stronger plus (i.e., convex) lenses until the print again blurs. The sum of the lenses is the measure of the accommodative amplitude. For example, if a patient accepts up to a \(-4.0\) D sphere before print blurs and then accepts the addition of \(+2.50\) D sphere before print again blurs, the total accommodative amplitude is \(4.0 \, \text{D} + 2.5 \, \text{D} = 6.50 \, \text{D}\) (72). Like the push-up method for determining the NPA and the accommodative amplitude, the method of the spheres depends on patient cooperation.

The most objective method of measuring accommodation is the use of refractometers (96,97). Most of these machines use increasingly minus lenses to stimulate accommodation and measure the accommodative response. Alternatively, one can stimulate accommodation not with lenses but pharmacologically by using a topical agent muscarinic agonist like pilocarpine and measure the response using a refractometer (98).

**Convergence**

Like accommodation, there is a near point of convergence (NPC), a convergence amplitude, and a range of convergence. In general, however, the only measurement of importance is the NPC. This measurement usually is determined by having the patient fixate on an accommodative target held 33 cm from the eyes. The target then is moved toward the nose, with the patient being instructed to try to keep the target in focus. The endpoint of the test is when the patient reports horizontal diplopia. The distance at which this occurs is then measured with a millimeter ruler placed alongside the patient's nose.

The NPC also can be determined by placing a red glass over one eye and moving a light forward until the patient experiences diplopia (99) or, more objectively, by performing the above test and noting the distance from the nose at which one of the inward turning eyes is observed to turn suddenly outward. In normal persons, the NPC is usually between 5–10 cm (100). An NPC greater than 30 cm indicates convergence insufficiency.

Yet another way to determine if convergence is normal is to perform a cover-uncover test (see Chapter 18) while the patient is reading. This is helpful only if the patient has full versions and no previous strabismus.

In addition to determining the NPC, it may be useful to determine if a patient's convergence is sufficient for the amount of accommodation; i.e., the AC/A ratio. There are two different methods for measuring the AC/A ratio.

The gradient method determines the AC/A ratio by the
change in deviation in prism diopters (PD) that occurs when a lens of a specific power is placed over both eyes to stimulate or relax accommodation (101). An accommodative target must be used, and the working distance is held constant. Plus or minus lenses are used to vary the accommodative requirement, and the difference between the ocular alignment with and without the lens, divided by the power of the lens, is the AC/A ratio. For example, a patient’s ocular alignment is measured with the patient viewing the accommodative target at a specific distance such as 33 cm, and the patient is found to have an esophoria of 2 PD. A −1.00 D spherical lens is placed over each eye, and ocular alignment is again measured with the patient viewing the same target at the same distance. The patient is now found to have an esophoria of 6 PD. The difference between the ocular alignment with and without the lens, divided by the power of the lens, is the AC/A ratio and is $6 - 2/1 = 4/1 = 4$. This means that when 1 diopter of accommodation was stimulated in this patient by placing a −1.00 D spherical lens in front of the eyes, the patient’s convergence, measured at the same distance from the eyes, increased from 2 to 6 PD. In another patient, a +3.00 sphere might be used to reduce accommodation, and a change in deviation from an exotropia of 4 PD to an exotropia of 10 PD might be noted. The AC/A ratio then would be $10 - 4/3 = 6/3 = 2$.

The second method for determining the AC/A ratio is the heterophoria method. This method uses the distance-near relationship to determine the AC/A ratio. Instead of measuring ocular alignment at near with and without a specific power lens, ocular alignment is measured at distance and near, and the difference in alignment in PD between distance and near viewing is divided by the fixation distance used for near viewing as expressed in diopters. Normal persons should have the same ocular alignment when viewing both distant and near objects. If a patient is more exotropic or less esotropic at near compared with distance, this indicates less convergence, or a low AC/A ratio; if the patient is more esotropic or less exotropic at near compared with distance, this indicates a high AC/A ratio. For example, if a patient has an esophoria of 5 PD at distance and an esophoria of 4 PD at 33 cm, the AC/A ratio is $5 - (-4/3) = 9/3 = 3$.

The normal AC/A ratio is between 3 and 6, regardless of the method of testing that is used (72). It should be noted, however, that the AC/A ratio varies from person to person and from day to day or hour to hour in a given individual depending on that person’s level of fatigue or alertness. In addition, the AC/A ratio rises sharply after the age of 40 as accommodation begins to be lost but convergence remains stable (102). Nevertheless, values above 6 usually indicate an excess of convergence per unit of accommodation, whereas values below 3 suggest convergence insufficiency. An elevated AC/A ratio in a cooperative child is a risk factor for the rapid onset of myopia (103).

Testing convergence accommodation; i.e., the CA/A ratio, requires that the patient experience no blur during the test. This can be accomplished by the use of a pin hole device (104), performing the test in dim illumination (105), or using a Gaussian target (106). In this test, accommodation is measured as convergence is produced using progressively stronger base-out prisms. Unlike accommodation, convergence does not decline significantly with age (102). Thus, just as the AC/A ratio increases with age, the CA/C ratio decreases with age (102,105).

**ASSESSMENT OF LACRIMATION**

The most anterior optical surface of the eye, the tear film, is also one of the greatest optical powers of the eye, and a deficient tear film thus is one of the most common causes of fluctuating blurred vision in clinical practice. In fact, optical aberrations caused by an early break-up of the tear film have been shown objectively to diminish image quality (107).

The tear film is a trilaminar structure consisting of a superficial lipid layer, an aqueous middle component that accounts for over 90% of the film, and a mucin component in the innermost layer. In order to discern a problem of the tear secretion, one must attempt to determine if only one layer is affected or all the layers are affected.

The main function of the lipid layer is to retard evaporation of the tear film. Removal of this layer causes a 19-fold increase in evaporation (108,109).

The aqueous layer, being the thickest component of the tear film, contributes the most to its volume, and most of the tests that measure the quantity of the tear film test this layer. The aqueous layer of the tear film is produced by both the primary lacrimal gland located in the lacrimal fossa in the superior lateral orbit and the accessory lacrimal glands of Krause and Wolfring that are similar in structure to the main lacrimal gland but are much smaller in size. The glands of Krause are located in the upper fornix, whereas the glands of Wolfring are situated further down on the eyelid, above the tarsus. The relative importance of the main and accessory lacrimal glands in the maintenance of normal tear secretion is somewhat controversial. It generally is accepted that the main lacrimal gland, having an efferent parasympathetic innervation, functions primarily during reflex tear secretion, whereas the accessory lacrimal glands provide basal tear secretion (110,110a).

The mucin layer is a biphasic layer that allows the aqueous component to adhere to the hydrophobic cornea epithelium. This layer thus helps to maintain the integrity of the aqueous component of tears and the quality of the tear film. Abnormalities in this layer (and also in the oil layer) can create tear film disturbances despite good aqueous tear production. The mucin layer is produced by goblet cells located in the conjunctiva.

The normal basal tear volume is 5–9 μL, and the normal flow rate averages 0.5 to 2.2 μL/min (111). In general, neither basal tear volume nor flow changes with increasing age, but reflex tearing decreases with age (112).

The main disturbances of lacrimation relate to excess or insufficient tear production and to obstruction of the normal passage of tears through the lacrimal drainage apparatus. Thus, the assessment of patients with difficulties should be oriented to an evaluation of tear production and drainage.