ACCOMMODATION

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INTRODUCTION AND OVERVIEW

This chapter includes a review of:

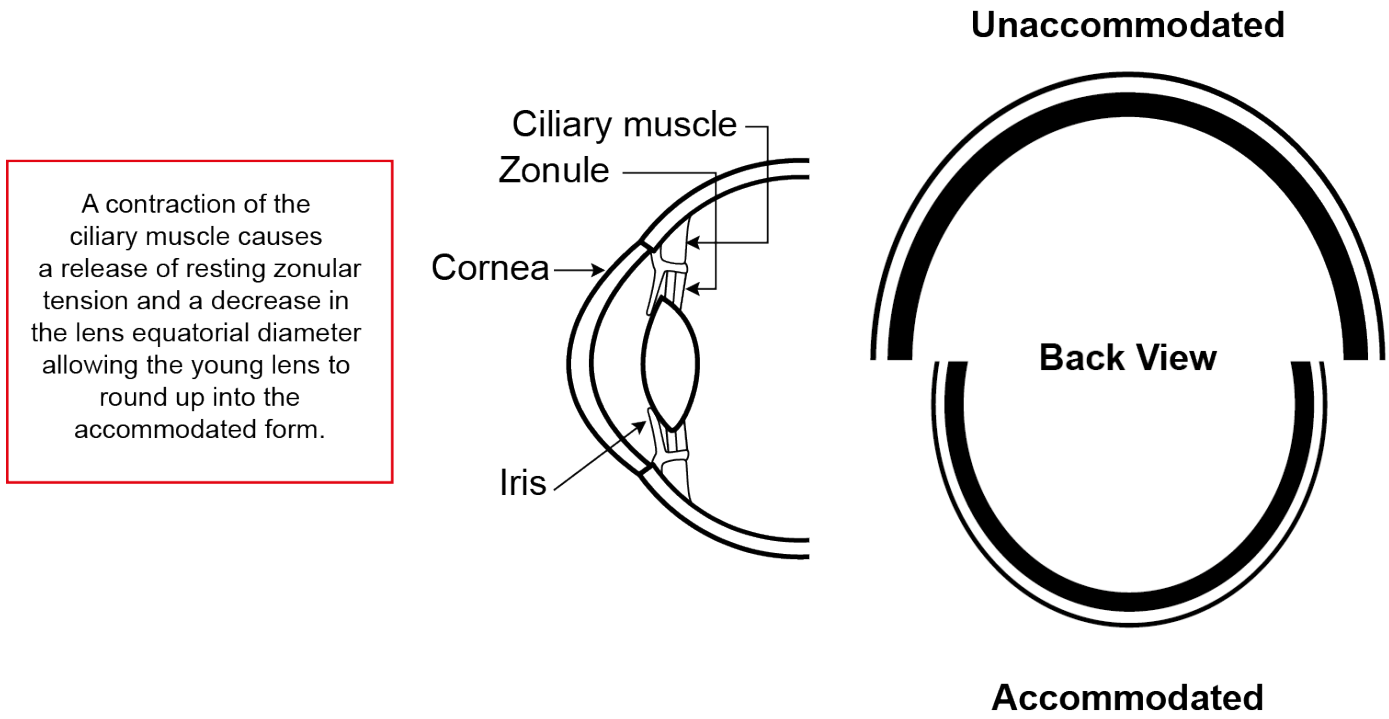
- Mechanism of accommodation
- Lenticular and optical changes in accommodation
- Spectacle versus ocular accommodation
- Effects of accommodation on retinal image size

Accommodation is the process by which the dioptric power of the eye is altered to bring objects at different distances into focus. The increase in total refractive power associated with focusing from a distant object (e.g. at the eye's far point) to a near object is called **positive accommodation**. The term **negative accommodation** refers to the decrease in total power associated with focusing from a near object to a more distant object.

MECHANISM OF ACCOMMODATION

The crystalline lens in a young individual consists of a soft and easily molded cellular material enclosed within an elastic capsule. The shape of the lens is determined primarily by the contractile forces of the elastic capsule which, if unopposed, tends to mold the lens to a more spherical shape. In the eye, the elastic forces of the capsule are counteracted by the traction forces of the zonular fibres (i.e. Zonule of Zinn). The degree of tension exerted on the crystalline lens is determined by the state of contraction of the ciliary muscle.

When the eye is in its unaccommodated state (i.e. when the far point is conjugate with the retina), the ciliary muscle is in its relaxed, uncontracted state and the muscle lies flat against the inner surface of the sclera. In this uncontracted state, the zonular fibres exert a pulling force primarily on the equatorial portion of the lens capsule. These pulling forces counteract the contractile forces of the lens capsule and, thus, maintain the lens in a relatively flat physical shape. During positive accommodation, the ciliary muscle contracts. The action of the ciliary muscle causes the ciliary body to move slightly forward and inward toward the crystalline lens (see Figure 6.1). Both of these movements bring the attachments of the zonular fibres toward the lens and, consequently, reduce the tension that the zonule exerts on the lens capsule. The elastic lens capsule then is allowed to contract and increase the convexity of the lens. The reduction in the radii of curvature of the lens surfaces results in an increase in positive refracting power.



A contraction of the ciliary muscle causes a release of resting zonular tension and a decrease in the lens equatorial diameter allowing the young lens to round up into the accommodated form.

Figure 6.1: *Mechanism of accommodation*

LENTICULAR AND OPTICAL CHANGES IN ACCOMMODATION

When the eye accommodates from distance to near, the following changes can be observed in the crystalline lens:

1. The radii of curvature of both the anterior and posterior surfaces of the lens decrease. However, the changes in curvature of the front surface are much greater than those that take place at the posterior lens surface (remember that during accommodation the size of the third Purkinje image changes much more than that of the fourth Purkinje image). Moreover, the changes in curvature that occur, particularly on the front surface, are not uniform, i.e. not spherical. Instead, as illustrated in Figure 6.2, the central portion of the anterior lens surface increases in curvature to a much greater degree than the more peripheral parts of the lens (i.e. there is a greater increase in positive refracting power in the central, pupillary zone of the lens). This conical bulging of the central part of the lens is sometimes referred to as **physiological anterior lenticonus**. The asymmetric changes in the surface of the lens are believed to be caused primarily by variations in the thickness of the lens capsule. The peripheral lens capsule is thicker than the central capsule (see Fig 6.3). It is thought that, during accommodation, the thicker 'ring' of the capsule that surrounds the thinner central portions exerts a greater inward contractile force on the lens. As a result, the weaker central portion allows the lens to bulge forward in a pronounced fashion at its anterior pole.
2. The lens gets thicker in its anterior-posterior dimension, but its equatorial diameter decreases. Since the position of the posterior surface of the lens does not change during accommodation, the increase in thickness causes an effective forward displacement of the lens closer to the cornea (i.e. there is a decrease in the depth of the anterior chamber).

   (**Note:** Moving two plus lenses closer together will increase their total equivalent power. Therefore, this effective forward displacement will result in a small increase in the eye's refractive power)
3. If the degree of accommodation is sufficiently large (i.e. if there is a sufficient decrease in the tension exerted by the zonule), the lens will sink in the direction of gravity.
4. The effective radii of curvature of the core of the lens also decrease. During accommodation, the changes in the curvature of the exterior surfaces alone are not sufficient to account for the total increase in the effective power of the whole crystalline lens. An additional increase in power is produced by changes in the curvature of the internal lens zones that have higher refractive indices than the lens cortex.
5. The increase in power of the lens produced by accommodation is reflected by a decrease in the eye's focal lengths, a backward displacement of the eye's principal planes, and a forward displacement of nodal points.

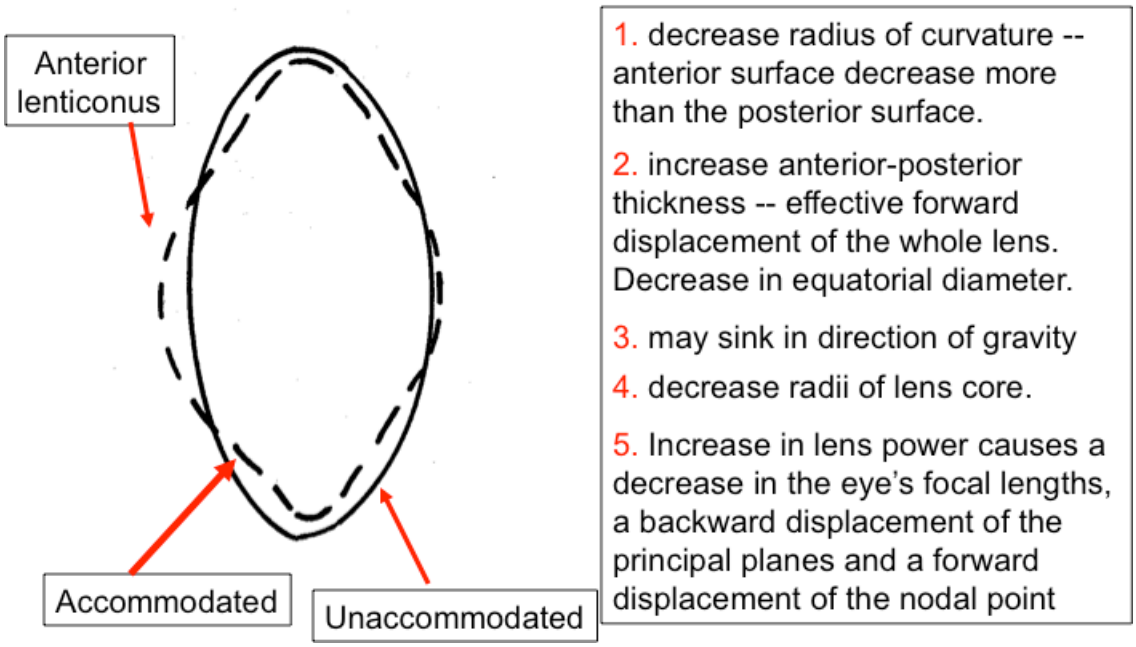


Figure 6.2: *Summary of lens changes during accommodation*

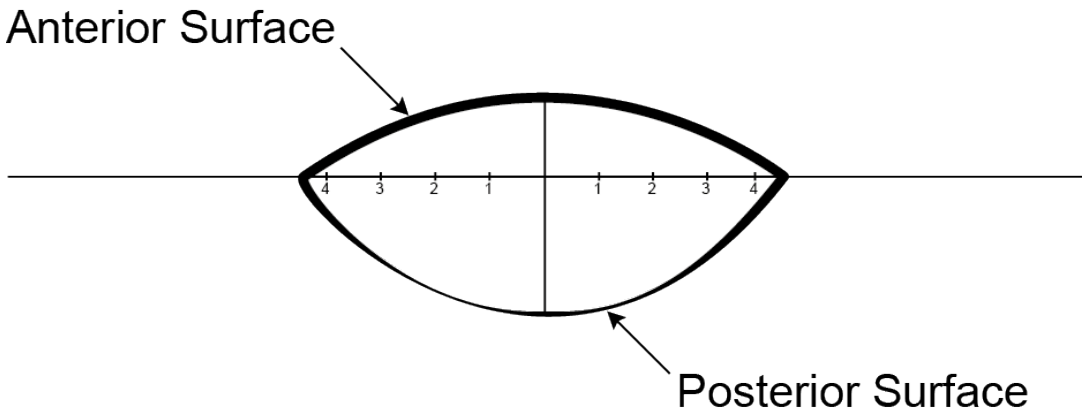


Figure 6.3: *Lens capsule variations in thickness*

SPECTACLE VERSUS OCULAR ACCOMMODATION

An individual's accommodative amplitude or the amount of accommodation that an individual must exert to focus on a particular plane in space (i.e. the accommodative demand) is usually specified in one of two ways.

1. **Ocular accommodation** refers to the changes in the eye's dioptric power measured or specified with respect to the eye's principal plane (sometimes ocular accommodation is referred to as principal plane accommodation). Ocular accommodation reflects the true accommodative effort (i.e. the true change in power) that an eye must exert in order to focus on a near object.
2. **Spectacle accommodation** indicates the accommodative demand or the required changes in the eye's power measured with respect to the spectacle plane. In clinical settings, the patient's accommodative amplitude and the accommodative demands for near tasks are always specified with respect to the spectacle plane (or more typically, the plane of the phoropter). Although specifying accommodative demands and amplitudes in terms of spectacle accommodation can be somewhat misleading, it has several practical advantages over employing measures of ocular accommodation.

EMMETROPIC OBSERVERS

Figure 6.4a and 6.4b illustrate the relationship between spectacle accommodation and ocular accommodation. Assume that the patient is emmetropic and the phoropter is positioned 15 mm in front of the eye's principal plane. Also assume that with a ‘push-up’ technique the patient's near point (i.e. punctum proximum, the point conjugate to the retina when the eye is fully accommodated) was 10 cm in front of the spectacle plane (i.e. the phoropter). What is this patient's spectacle and ocular amplitudes of accommodation?

The spectacle amplitude of accommodation is simply the accommodative demand associated with the patient's measured near point specified with respect to the phoropter (i.e. the vergence of light associated with the near point measured at the phoropter. More precisely, the difference in the vergence of light from optical infinity and from the near point measured with respect to the spectacle plane).

$$\text{Spectacle amplitude} = \frac{1}{0.01\ \text{m}} = 10.0\ \text{D}$$

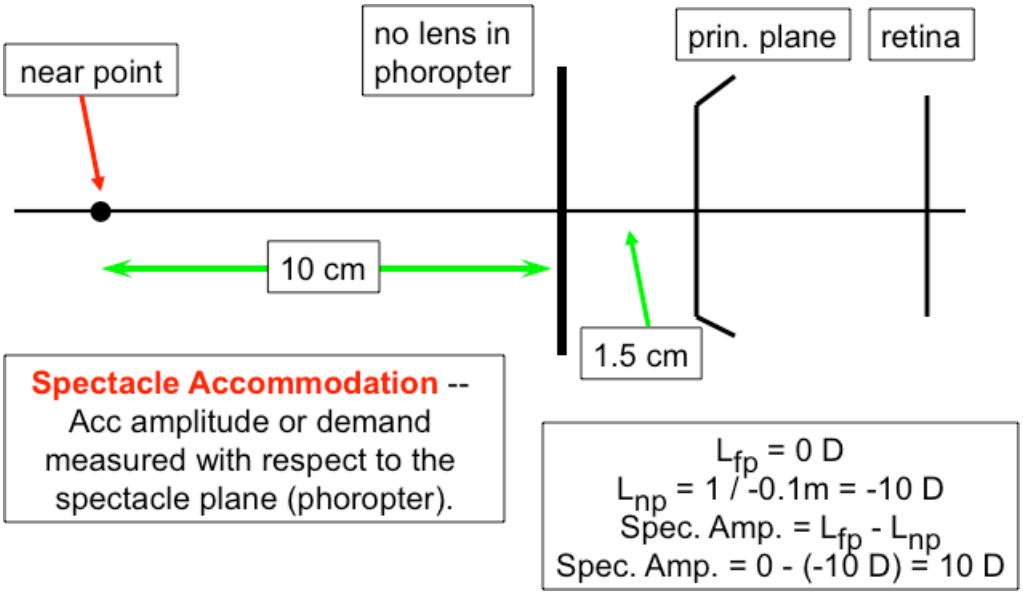


Figure 6.4a: *Spectacle accommodation in an emmetropic observer*

However, the patient does not have to increase the power of their eye by 10.00 D in order to focus from infinity to the measured near point. In order to determine the required increase in the eye's dioptric power, it is necessary to determine the patient's ocular amplitude of accommodation (i.e. the vergence of light associated with the near point measured at the eye's principal plane. Or again, more precisely, the difference in the vergence of light from optical infinity, the eye's far point, and from the near point measured with respect to the eye's principal plane.).

$$\text{Ocular amplitude} = \frac{1}{(0.10+0.015)\ \text{m}} = 8.7\ \text{D}$$

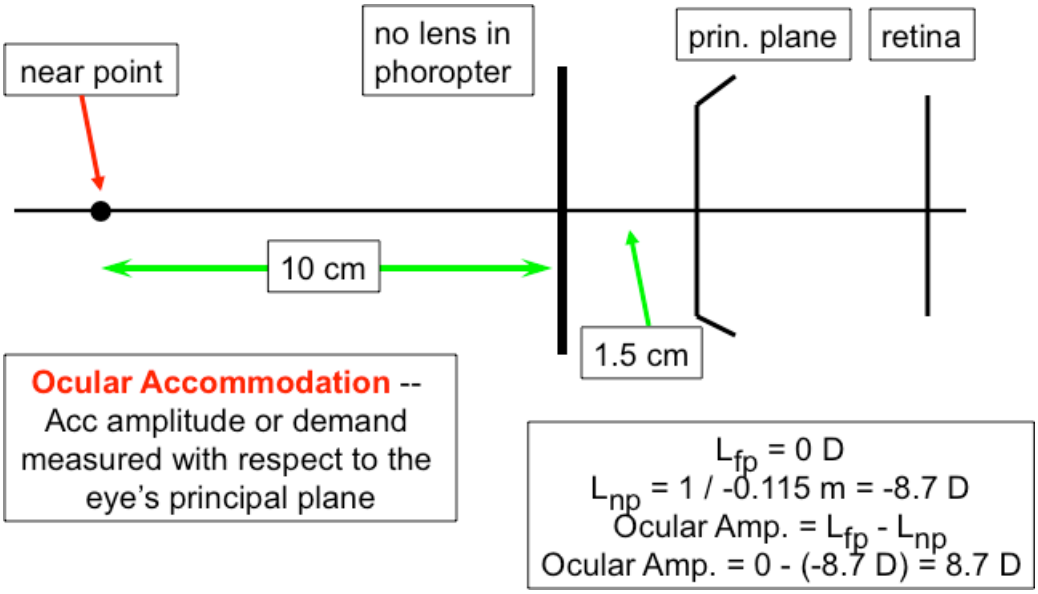


Figure 6.4b: *Ocular accommodation in an emmetropic observer*

Although in a clinical setting this patient's amplitude of accommodation would be specified as 10 D, this patient would only have the ability to increase the power of their eye by 8.7 D. For emmetropic individuals or uncorrected ametropes, the amplitude of spectacle accommodation will always be greater than their ocular amplitude of accommodation. The magnitude of this difference will depend on two factors, the vertex distance (i.e. the position of the phoropter with respect to the eye's principal plane) and the patient's ocular amplitude of accommodation. The larger the vertex distance, the greater is the difference between spectacle and ocular accommodation. Because dioptric vergence is determined by the reciprocal of the distance in question, the farther away the near point (i.e. the lower the ocular amplitude of accommodation), the smaller is the difference between ocular and spectacle accommodation.

AMETROPIC INDIVIDUALS CORRECTED WITH SPECTACLES

The amount of ocular accommodation that an ametropic eye must exert to focus on a near object is significantly affected by correcting lenses positioned in the spectacle plane. The examples below illustrate the influence of the power of the correcting lens on the relationship between ocular and spectacle accommodation.

Myopic patients

A myopic patient has −5.00 D spectacle plane refractive error

(**Note:** The nature of the refractive error, i.e. whether it is axial or refractive, is not important.).

With the -5.00 D lens in the phoropter (15 mm in front of the eye's principal plane), the patient's measured near point is 10 cm in front of the spectacle plane (Figure 6.5). What are the patient's spectacle and ocular amplitudes of accommodation?

$$\text{Spectacle amplitude} = \frac{1}{0.01\ \text{m}} = 10.0\ \text{D}$$

The spectacle amplitude is simply the dioptric distance between the measured near point and the spectacle plane.

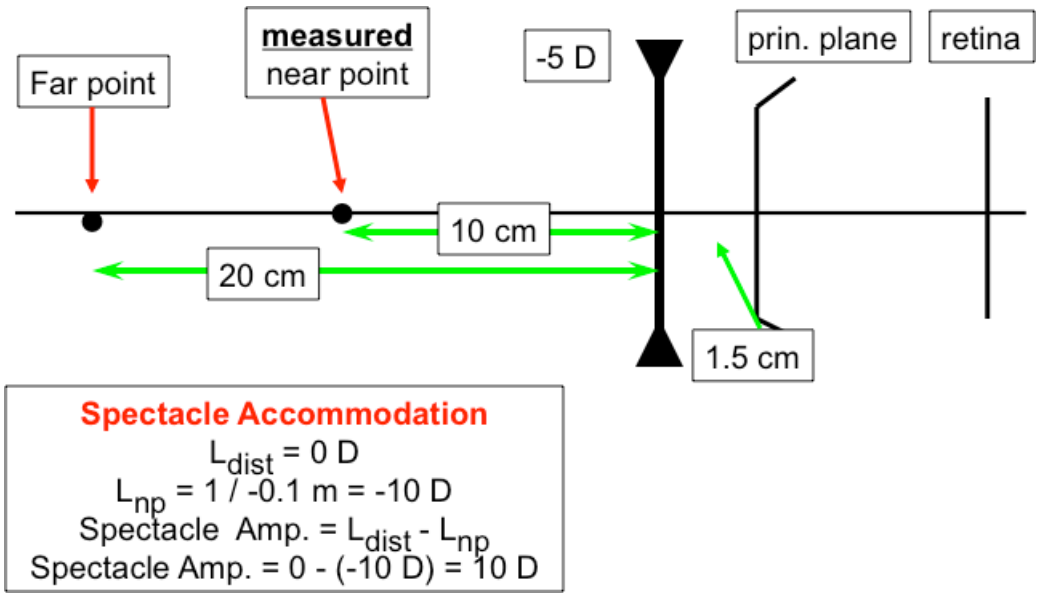


Figure 6.5: *Spectacle accommodation in a corrected myope*

However, in this case the ocular amplitude is not simply the reciprocal of the distance between the measured near point and the eye's principal plane. To determine the patient's ocular amplitude of accommodation, the influence of the correcting lens must be taken into account. The ocular accommodative amplitude can be calculated by determining the dioptric interval between the eye's **true** far point (PR) and its **true** near point (PP)(i.e. the difference in the vergence of light from the true far point and the true near point measured at the eye's principal plane.).

Note: The eye's true far point is the point in space conjugate to the retina in the unaccommodated and **uncorrected** case. The eye's true near point is the point conjugate to the retina when the eye is fully accommodated, but **uncorrected**.

With the correcting lens in place, this dioptric interval can be calculated by determining the vergence of light at the eye's principal plane for an object at infinity and an object placed at the patient's **measured** near point. The difference in the vergence of light for these two objects would equal the ocular amplitude of accommodation, because after refraction by the spectacle lens the images of these objects would be formed on the eye's true far point and true near point.

To determine the vergence of light at the eye's principal plane for an object at infinity, first, calculate the position of the image formed by refraction by the spectacle lens.

$L_{(dist)} = 0$
$F_{(lens)} = -5.00$ D
$L' = F_{(lens)} + L_{(dist)} = -5.0$ D

Hence,

$l' = n' / L' = 1 / -5.0D = -0.20$ m

i.e. the image is formed at the eye's true far point (fp) 20 cm in front of the spectacle plane or 21.5 cm in front of the eye's principal plane. Therefore, the vergence of light at the eye's principal plane for an object at infinity would be:

$L_{(fp)} = 1 / -0.215m = -4.65$ D

$L_{(fp)}$ is the dioptric interval between the eye's true far point and its principal plane.

To determine the vergence of light at the eye's principal plane for an object at the measured near point, determine the position of the image formed by refraction by the spectacle lens (see Figure 6.6).

$L_{(near)} = 1 / -0.1m = -10.0D$
$F_{(lens)} = -5.0$ D
$L' = -15.0$ D

Hence,

$l_{(near)} = 1 / -15.0$ D $= -0.0667$ m

i.e. the image is formed at the eye's true near point 6.67 cm in front of the correcting lens and 8.17 cm in front of the eye's principal plane. Therefore, the vergence of light at the eye's principal plane for an object at the measured near point, but viewed through the correcting lens, would be

$L_{(np)} = 1 / -0.0817m = -12.24$ D

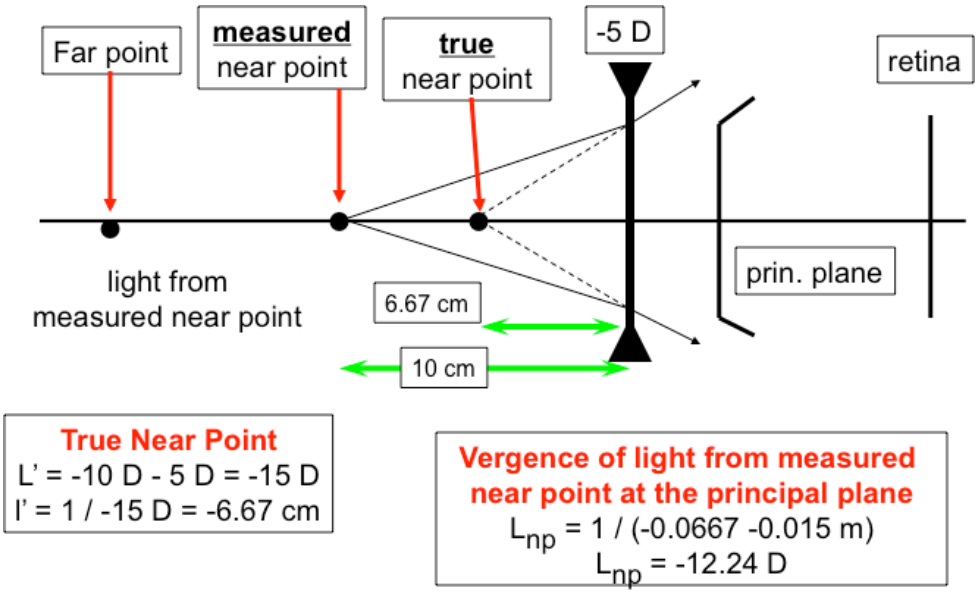


Figure 6.6: *Vergence of light from measured near point at the principal plane*

The total accommodative effort, the total ocular accommodation, required by this myopic eye to focus from distance to the measured near point would be:

$L_{(fp)} - L_{(np)} = -4.65\ D - (-12.24\ D)$
Ocular Amp = 7.59 D

Hyperopic patients

A hyperopic patient has a +5.00 D spectacle plane refractive error (15 mm in front of the eye's principal plane). With the +5.0 D lens in the phoropter, the measured near point is, again, 10 cm in front of the phoropter (Figure 6.7). What are the patient's spectacle and ocular amplitudes of accommodation?

$$\text{Spectacle amplitude} = \frac{1}{0.01\ \text{m}} = 10.0\ \text{D}$$

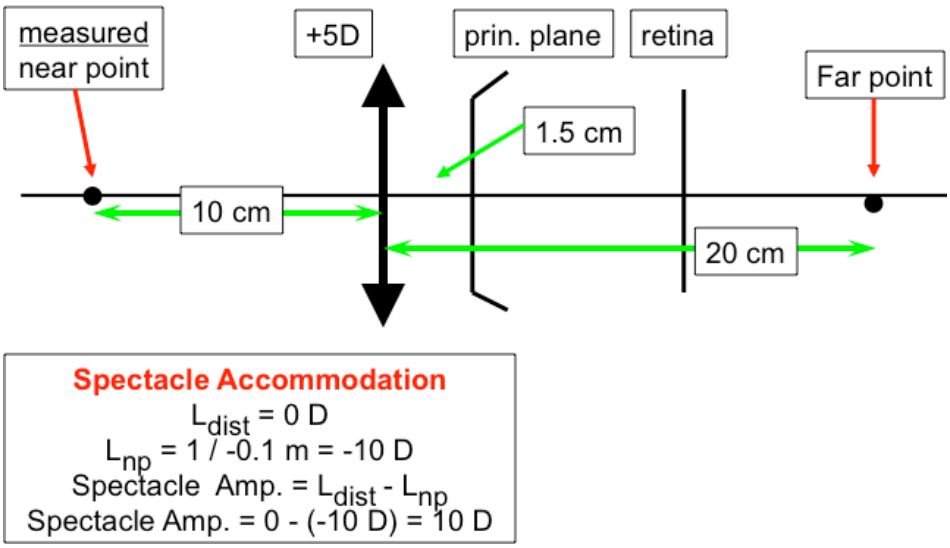


Figure 6.7: *Spectacle accommodation in a corrected hyperope*

To calculate ocular amplitude, first determine the vergence of light at the eye's principal plane for an object at infinity (i.e. determine the dioptric distance for the eye's true far point).

$L_{(dist)}$ = 0.0 D
$F_{(lens)}$ = +5.0 D
L' = +5.0 D

Hence,

l' = 1 / +5.0 D = 0.20 m

i.e. this hyperopic eye's true far point is 20 cm beyond the spectacle lens or 18.5 cm behind the eye's principal plane. Therefore, the vergence of light at the eye's principal plane for an object at infinity would be:

$L_{(fp)}$ = 1 / 0.185 m = +5.41 D

The position of the eye's true near point can be calculated from the position of its measured or artificial near point.

$L_{(near)}$ = 1 / −0.1m = −10.0 D
$F_{(lens)}$ = +5.0 D
L' = −5.0 D

Hence,

l' = 1 / −5.0 D = −0.2 m

i.e. the eye's true near point is 20 cm in front of the spectacle plane and 21.5 cm in front of the eye's principal plane (see Figure 6.8). Therefore, the vergence of light at the eye's principal plane for an object at the measured near point, but viewed through the lens, would be:

$L_{(np)}$ = 1 / −0.215 m = −4.65 D

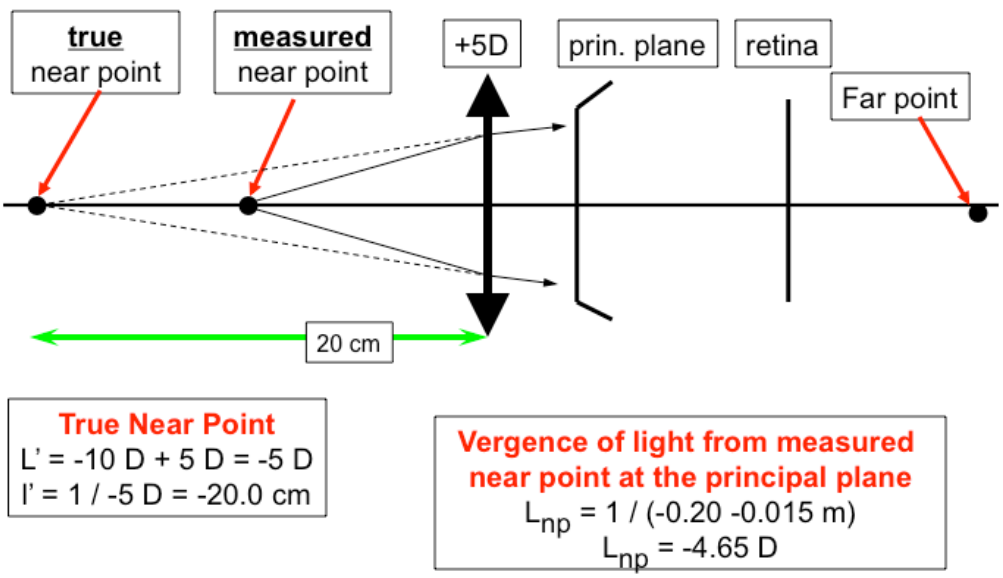


Figure 6.8: *Spectacle accommodation in a corrected hyperope*

The ocular accommodation required by the hyperopic eye to focus from infinity to the measured near point (i.e. the ocular accommodative amplitude) would be:

Ocular amplitude = 5.41 D − (−4.65 D) = 10.06 D

The above examples illustrate several important points concerning ocular and spectacle accommodation.

1. The magnitude of spectacle accommodation is independent of the power of the correcting lens and independent of the type of refractive error.

[**Note:** Although spectacle accommodation does not indicate the eye's true focusing efforts, it is reasonable to use it as a measure of accommodative amplitude in clinical settings. First, it is easy to measure because the spectacle plane can be readily identified. It is not influenced by the patient's distance correction. It provides a functional measure of the patient's range of clear vision in space. Moreover, in patients with low amplitudes of accommodation (i.e. when accommodative concerns are particularly important), spectacle amplitude will be close to the true ocular amplitude].

2. Hyperopes corrected with spectacles will have to exert more ocular accommodation (i.e. actually increase the power of their crystalline lenses more) than either emmetropes or corrected myopes to focus on a given near object.

3. When corrected with spectacles, myopes will have to exert less ocular accommodation to focus on a near object than either emmetropes or corrected hyperopes.

When ametropes are corrected with contact lenses, the correcting lens essentially renders the eye emmetropic and, thus, has no effect on ocular accommodation (assuming that the contact lens coincides with the eye's principal plane). For a given point in space, the ocular accommodative demands for an ametropic eye corrected with a contact lens will be identical to that for an emmetropic eye. Consequently, one must be cautious when changing the form of a patient's correcting lens when the patient has a relatively low accommodative amplitude (i.e. a presbyope or pre-presbyope). What would happen to a presbyopic myope's measured near point if the patient was switched from spectacles to contact lenses? In effect, the contact lens would result in a functional reduction in the measured amplitude of accommodation and, thus, functionally make the patient more presbyopic.

EFFECTS OF ACCOMMODATION ON RETINAL IMAGE SIZE

UNCORRECTED EYES

Consider a unaccommodated emmetropic eye that is viewing an object that is 1 cm in size and positioned 10 cm in front of the eye's principal plane. What will happen to the size of the retinal image when the eye accommodates for the near object?

First calculate the image size in the unaccommodated state.

The visual angle associated with the object is:

1cm / 10cm = 0.1 radians

Hence, the angle subtended by the image at the eye's principal plane is:

0.1 rad / 1.333 = 0.075 rad

Since the distance between the emmetropic eye's principal plane and retina is 22.22 mm, the out-of-focus image size will be:

Image size = (0.075 rad) (22.22 mm) = 1.67 mm

To calculate the size of the image in the accommodated state you must consider what happens to the position of the principal plane relative to the retina. As the eye accommodates for near, the principal plane moves closer to the retina. As a result, it is not possible to simply represent an increase in positive accommodation as an increase in the power of the equivalent refracting surface (i.e. in a sense, there is a small axial component). Assume that during accommodation, the principal plane of our reduced eye moved back 0.44 mm (the mean backward displacement of the principal planes for the accommodated version (about 10 D) of Gullstrand's #1 Exact Eye.). The backward displacement would alter the retinal image size in two ways. First, the angle of incidence of the chief rays would be slightly reduced. Second, the distance between the equivalent refracting surface and the retina would be reduced.

New angle of incidence at the principal plane would be:

i = 1 cm / 10.044 cm = 0.0996 radians

Hence, the angle subtended by the image after refraction would be:

i' = 0.0996 rad/1.3333 = 0.07467 radians
Image size = (0.07467) (21.78mm) = 1.63 mm

The above calculations indicate that, based on considerations of refractive power alone, the retinal image size was decreased by 0.04 mm during accommodation from distance to the 10 cm object. However, in a practical sense there are really no substantial image size changes. Since the position of the entrance pupil is essentially unaffected by accommodation, the defined image size will not change substantially between unaccommodated and accommodated states.

AMETROPIC EYES CORRECTED WITH SPECTACLES

Assume an axial myope with a -5.0 D principal plane refractive error is accommodated on a 1 cm object that is located 10 cm in front of the spectacle plane. The correcting lens is 15 mm in front of the eye's principal plane, therefore, the power of the correcting lens is -5.41 D. What is the size of the retinal image?

Since the actual size of the object is known, the size of the retinal image can be calculated by determining the linear magnification for both the correcting lens and eye.

Note: Equations for Spectacle Magnification and Relative Spectacle Magnification cannot be used to determine image size in accommodated eyes because the relationships for these magnification factors only apply for objects at optical infinity.

Linear magnification,

$$M = h'/h = L/L'$$

Magnification for the lens is:

$$M_{(lens)} = -10.0\ D / -15.41\ D = 0.649$$

To calculate the linear magnification for the eye, the position of the near object formed by the correcting lens and, subsequently, the vergence of light impinging on the eye's principal plane, must be determined.

$$L'_{(vergence\ after\ refraction\ by\ lens)} = -10\ D - 5.41\ D = -15.41\ D$$

hence, the position of the image of the object after refraction by the lens is:

$$l' = 1 / -15.41\ D = -6.5\ cm \text{ in front of the correcting lens}$$

The vergence of the light at the eye's principal plane is:

$$L = 1 / (-0.065 - 0.015\ m) = -12.5\ D$$

Since the eye is accommodated for the near object, we know that the image is focused on the retina. Hence, the vergence of light after refraction at the eye's principal plane must be appropriate for the distance between the eye's principal plane and its retina (for a 5 D axial myope, 24.24 mm).
Hence, the vergence of light within the eye is:

$$L' = 1.3333 / 0.02424 = +55.00\ D$$

Hence, the linear magnification for the eye is:

$$M_{(eye)} = -12.50\ D / 55.0\ D = -0.2273$$

(**Note:** The minus sign indicates that the image is inverted.)

The total magnification for the eye-lens combination is equal to:

$$M_{(eye)} \times M_{(lens)} = (-0.2273)\ (0.649) = -0.014752$$

Therefore, the final retinal image size is:

$$h' = (\text{object size})\ (\text{total magnification})$$
$$h' = 1.0\ cm\ (-0.014752) = -1.475\ mm$$