RETINAL IMAGE SIZE

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INTRODUCTION AND OVERVIEW

This chapter includes a review of:

- Image size formed by the optics of the eye
- Retinal image size (clear retinal image)
- Image size in uncorrected axial ametropia
- Image size in uncorrected refractive ametropia
- Image size in corrected ametropias
- SM and RSM in corrected ametropic eyes
- Axial ametropias corrected with spectacles
- Axial ametropias corrected with contact lenses
- Refractive ametropias corrected with spectacles
- Refractive ametropias corrected with contact lenses
- Retinal image size in various conditions
- Image size calculations

In addition to providing a clear retinal image, correcting lenses almost always alter the size of the retinal image produced by a given object. While lens-induced changes in retinal image magnification can in some cases improve visual performance, lenses that effectively minify the retinal image or that produce an imbalance in the size of the retinal images between the two eyes can interfere with optimal visual performance. Consequently, it is important for optometrists to have a good working knowledge of the effects of correcting lenses on retinal image size.

There is a variety of ways to determine the size of the image formed by the eye's optical system and the size of the retinal image. The schematic eyes described in VSII-5, particularly Emsley's reduced eye, are very useful in image size calculations. Exactly which eye is selected and which approach is used to calculate image size is somewhat dependent on the specific situation to be studied (e.g. is the retinal image ‘in focus’ or ‘out of focus’? Do you want to know the size of the retinal image or simply the image size produced if the retina were not present?). The following is a series of examples of how to calculate image size under a variety of different conditions.

IMAGE DIZE FORMED BY THE OPTICS OF THE EYE

The size and position of the image formed by the optics of the eye (assuming that the retina does not interfere with image formation) is easily determined using Gullstrand's exact or simplified schematic eyes and a classic geometrical-optics-type approach. For example, assume a 10 cm object is positioned 1.0 m in front of the first principal plane of Gullstrand's simplified schematic eye, the unaccommodated version. Since the eye is emmetropic, the image plane will be behind the retina. What would be the size of the clear image (i.e. the image that would be formed behind the eye if the retina did not interfere with image formation) and where would the image be formed? In the diagram in Figure 4.1 the position, attitude, and size of the image is located by construction. A ray from the top of the object is directed toward the anterior focal point (f) of the eye. This ray intersects the first principal plane (p) and emerges from the second principal plane (p') parallel to the optic axis. A second ray directed toward the first nodal point (N) undergoes refraction at the first principal plane. It emerges from the second principal plane and passes through the second nodal point (N') traveling in the same direction as the ray directed toward N in object space. A third ray that is parallel to the optic axis, leaves the second principal plane and passes through the secondary focal point of the eye (f').

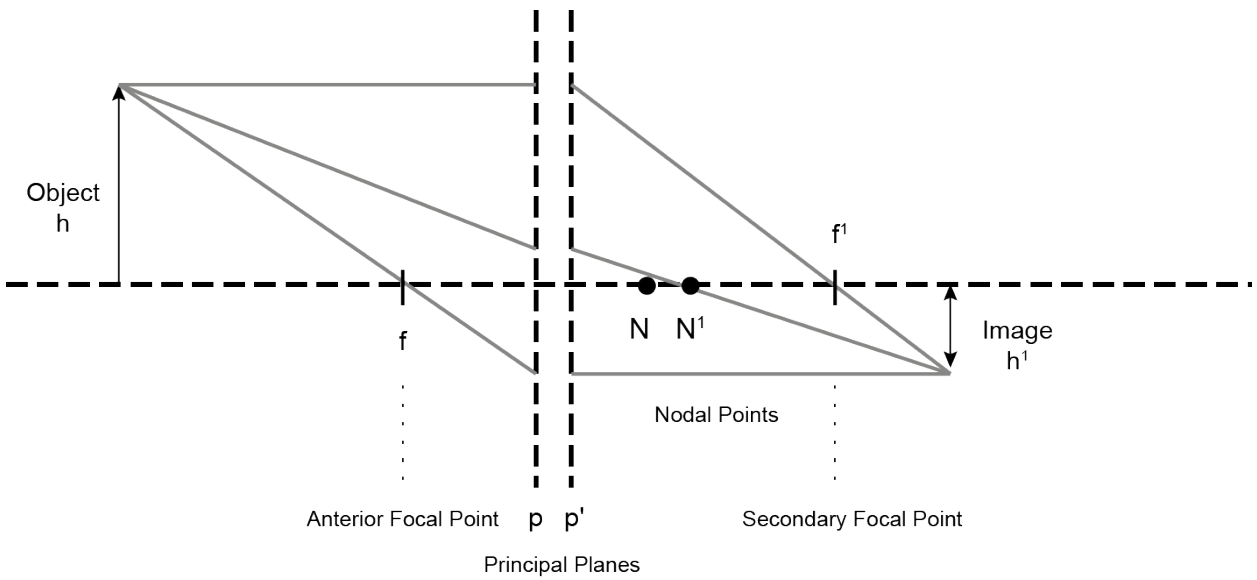


Figure 4.1: *Ray diagram of the position, size and attitude of the retinal image*

Note: Since this eye is emmetropic, the second focal point corresponds with the intersection of the retina and the optic axis). The intersection of these three rays in image space indicates the plane in which the image will be formed (assuming that the retina does not block the light).

To determine the position of the image with respect to the retina requires knowledge of the characteristics of the schematic eye and involves solving a relatively simple vergence problem. The following information concerning the schematic eye is required:

Equivalent power of the eye:	F = +59.6 D
Position of the second principal plane:	p' = 1.75 mm
Refractive index of image space:	n' = 1.336
Axial Length:	fovea = 24.17 mm

The first step in solving the problem is to determine the vergence of light in object space (L).

$L = n/l$

n = refractive index of object space (1.0 for air)
l = distance from p to the object; following sign convention -1.0 m

$L = 1.0/-1.0 \text{ m} = -1.0 \text{ D}$

By determining the vergence of light in image space (L'), it will be possible to calculate the distance of the image from p' (i.e. l').

$L' = L + F$
$L' = -1.0 \text{ D} + 59.6 \text{ D} = +58.6 \text{ D}$

The image distance $l' = n'/L'$.

$l' = 1.336/+58.6 \text{ D} = 0.0228 \text{ m}$

i.e. the image is formed 22.8 mm from p', the second principal plane. Since p' is 1.75 mm from the cornea, the image is formed 24.55 mm (1.75 mm + 22.8 mm) from the pole of the cornea. The axial length of the eye is 24.17 mm. Therefore, the image plane will be 0.38 mm behind the retina.

The size of the image can be determined using the equation for linear magnification.

$M = L/L' = h'_{(image)}/ h_{(object)}$
$M = -1.0 \text{ D}/+58.6 \text{ D}$
$M = -0.01706$

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

Hence,

$h' = h(M)$
$h' = 10 \text{ cm } (-0.01706) = -0.1706 \text{ cm}$

i.e. the size of the image is 1.706 mm.

It is important to realize that this procedure does not determine the size of the blurred image that would, in this example, be formed on the retina. Although the size of the image formed by the optics of the eye (not necessarily the retinal image) is of some interest in certain situations, it is generally not of interest in clinical situations.

RETINAL IMAGE SIZE (CLEAR RETINAL IMAGE)

When the image formed on the retina is 'in focus' (i.e. when the object is conjugate with the retina), the size of the retinal image can be easily found using the reduced eye and the rays from the extremities of the object that pass through the nodal point of the eye (sometimes these rays are referred to as principal rays). Since you know that the image is formed on the retina, you only need to determine the intersection with the retina of one ray out of a number of possible rays. The rays through the nodal point provide a straightforward approach to the problem since these rays are not deviated during refraction. Therefore, the angle the object subtends at the nodal point will be equal to the angle the retinal image subtends at the nodal point.

Note: A single spherical refracting surface has one principal point that corresponds to the vertex of the refracting surface and one nodal point that corresponds to the centre of curvature of the refracting surface.

Figure 4.2 illustrates how the size of the retinal image can be calculated using the rays through the nodal point of the reduced eye. The reduced eye shown is Emsley's emmetropic eye. Assume an object at infinity subtends a **visual angle** of 0.1 radians (rad).

Note: The visual angle subtended by an object is classically defined as the angle formed by the extremities of the object at the nodal point. Sometimes the visual angle subtended by an object is referred to as its apparent size. However, when the retinal image is not in focus, its size is determined by the ray through the centre of the entrance pupil. Thus, the visual angle is sometimes measured with respect to the centre of the entrance pupil.

Note: In general, it is much easier to specify visual angles in terms of radians rather than in degrees. Since image size calculations usually involve paraxial rays, little error is introduced into the calculations.

Since the object subtends 0.1 rad at the nodal point, the image must also subtend 0.1 rad at the nodal point (i.e. q□= q'). Hence, to calculate the size of the image, q' is multiplied by the distance between the nodal point and the retina. For Emsley's emmetropic reduced eye, this distance is equal to 16.67 mm (22.22 mm - 5.55 mm).

Therefore:

image size = (0.1 rad) x (16.67 mm) = 1.67 mm.

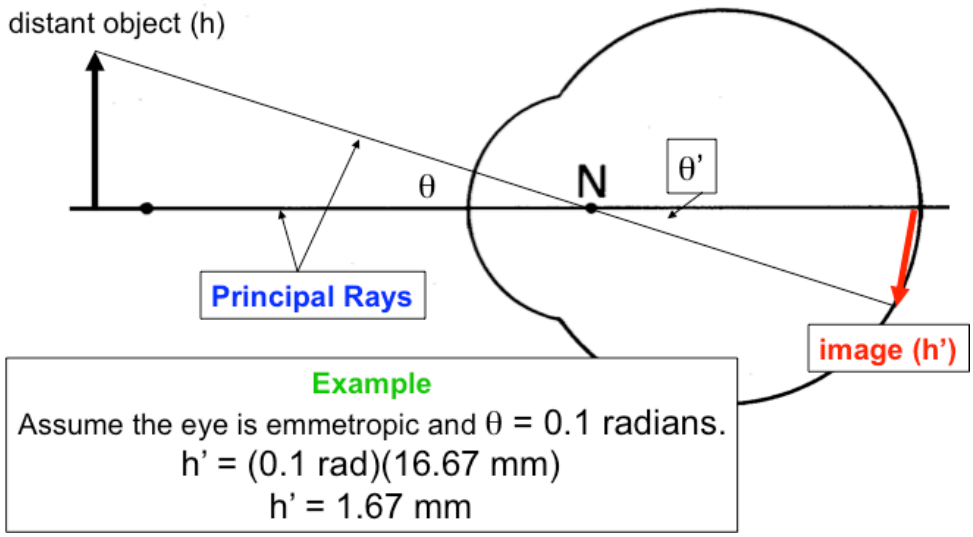


Figure 4.2: *Using Emsley's emmetropic reduced eye to calculate image size*

IMAGE SIZE IN UNCORRECTED AXIAL AMETROPIA

In examining the retinal images in ametropic eyes, the presence of a refractive error has traditionally been attributed to one of two causes – an abnormal axial length (i.e. an axial ametropia) or an abnormal refractive component (a refractive ametropia). In reality, the etiologies of refractive errors cannot be segregated in a clear-cut manner into two such distinct categories. Nonetheless, this artificial dichotomy provides insight into the characteristics of ametropic eyes. Therefore, by definition, an **axial ametropia** is a refractive error that is caused by an inappropriate axial length. The refractive power (i.e. the optics of the eye) of an axial ametrope is normal. So in terms of a schematic model, an axial ametropia may be represented by the same equivalent refracting surface as that in the emmetropic eye, but the retina will be at a different position. For **axial myopes**, the axial length will be greater than normal. For **axial hyperopes**, the axial length will be shorter than normal. In comparison, a **refractive ametropia** is a refractive error caused by an abnormal optical component. The axial length is normal, however the eye has either too much refracting power (i.e. a **refractive myope**) or too little refracting power (i.e. a **refractive hyperope**). Reduced schematic models for refractive ametropias have the same axial length as the emmetropic reduced eye; but the curvature of the equivalent surface is different. The radius of curvature for the refracting surface is shorter than normal for refractive myopes and *vice versa* for refractive hyperopes.

The diagram in Figure 4.3 illustrates 3 schematic reduced eyes representing an emmetrope, a 5.0 D **axial** myope, and a 5.0 D **axial** hyperope. Since the later two are axial ametropias, the dioptric powers of the eyes are the same as Emsley's standard emmetropic eye and, therefore, the nodal points and the refracting surfaces for all three eyes are identical. Assume that we take 3 different objects, place one at infinity that subtends a visual angle of 0.1 rad at the nodal point of the emmetropic eye, place one at the far point of the myopic eye so that it also subtends 0.1 rad, and place a third object (a virtual object) at the far point of the hyperopic eye that again subtends 0.1 rad (see Figure 4.4). Under these circumstances the rays from the extreme points of the objects through the nodal points can be used to calculate the retinal image size. Moreover, these rays provide a direct comparison of image sizes in these 3 types of eyes. Since the intersections of the rays through the nodal points with the respective retinas demarcate the retinal image sizes, it can be seen that in **uncorrected axial ametropia, the size of the retinal image is directly proportional to axial length**. The image in the myopic eye will be larger than that in the emmetropic eye which, in turn, will be larger than the image in the hyperopic eye.

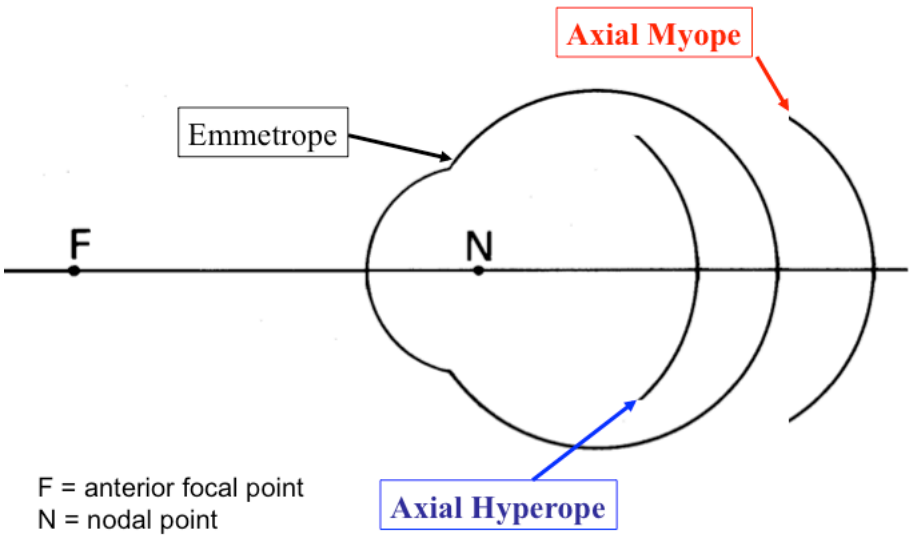


Figure 4.3: *Shows the different axial length in axial hyperopia, emmetropia and myopia. Note the anterior focal point and nodal point are equivalent*

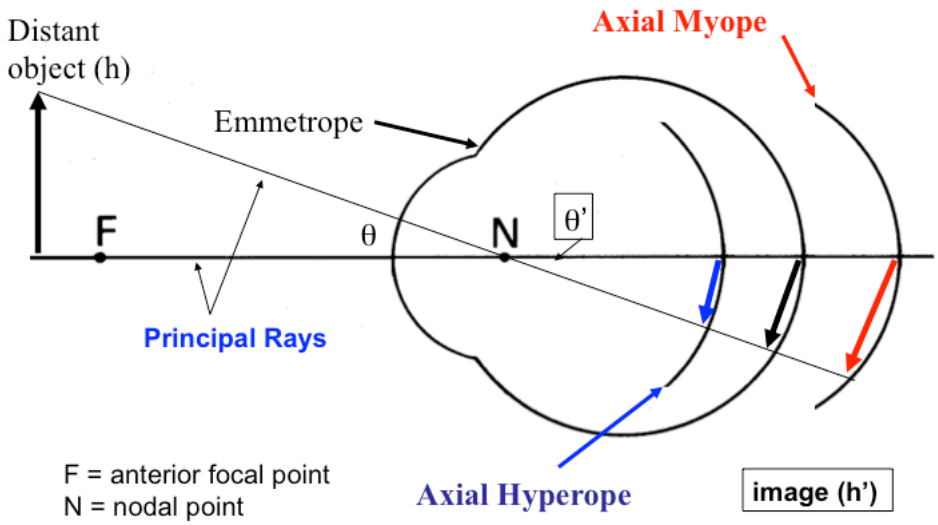


Figure 4.4: *The image size in an axial ametropia is directly proportional to axial length*

To calculate the retinal image size in ametropic eyes, the distance between the nodal point and the retina must be determined. (For the emmetropic eye this distance is 16.67 mm and simply a characteristic of Emsley's reduced eye). This distance can be determined from the vergence of light in image space **required** to focus light on the retinas of the ametropic eyes (see Figure 4.5). The conjugate focus equation can be used to calculate the appropriate image space vergence.

$$L' = L + F$$

Where:

L' = image space vergence
L = object space vergence
F = eye's refractive power

Since these are axial ametropias, the refracting power in all three eyes is the same, i.e. +60.0 D. For the myope, the vergence of light in object space (L) must equal -5.0 D for light to come to focus on the retina.

Therefore, for the myope:

$$L' = -5.0\ D + 60.0\ D$$
$$L' = +55.0\ D$$

i.e. light must leave the refracting surface with a +55.0 D vergence to come to a focus on the retina. The image distance (l') associated with the above image space vergence can be calculated as follows:

$$L' = n'/l'$$
$$l' = 1.333/+55.0\ D$$
$$l' = 0.02424\ m = 24.24\ mm$$

i.e. the distance from the refracting surface to the retina is 24.24 mm. The distance from the refracting surface to the nodal point for all three eyes is 5.55 mm. Hence, the distance between the nodal point and the myopic retina is:

24.24 mm −5.55 mm = 18.69 mm

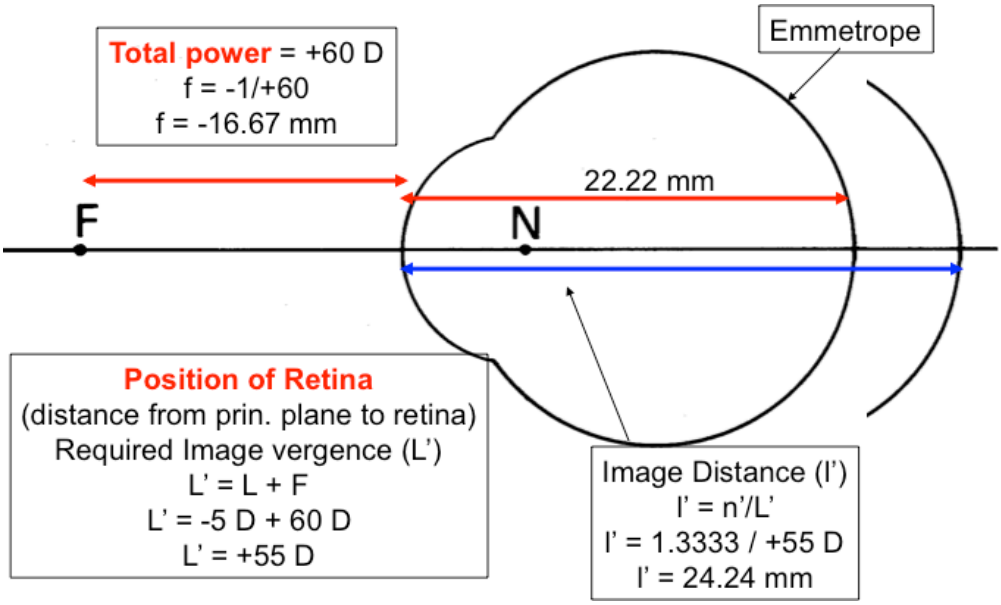


Figure 4.5: *Determination of the image distance from the refractive surface in a 5 D axial myope allows subsequent calculation of the distance from the nodal point to the retina and the image size*

The size of the retinal image (h') in the myopic eye is found simply by multiplying the angle subtended by the image at the nodal point (0.1 rad) by the distance from the nodal point to the retina.

h' = (18.69 mm) x (0.1 rad)
h' = 1.87 mm

We previously determined that the image produced in the emmetropic eye by an object that subtended a visual angle of 0.1 rad is 1.67 mm (page 4). A comparison between the myope and the emmetrope shows that the image in the myopic eye is about 12% larger than that in the emmetropic eye.

For the hyperopic eye:

L' – the vergence of light required in image space to focus an image on the retina

L' = +5.0 D + 60.0 D
L' = +65.0 D

l' – the distance between the refracting surface and the retina (see Figure 4.6).

l' = 1.333/+65.0 D
l' = 20.51 mm

The distance between the nodal point and the retina of this hyperopic eye is:

20.51 mm - 5.55 mm = 14.96 mm

h' – the retinal image size.

h' = (14.96 mm) x (0.1 rad)
h' = 1.50 mm

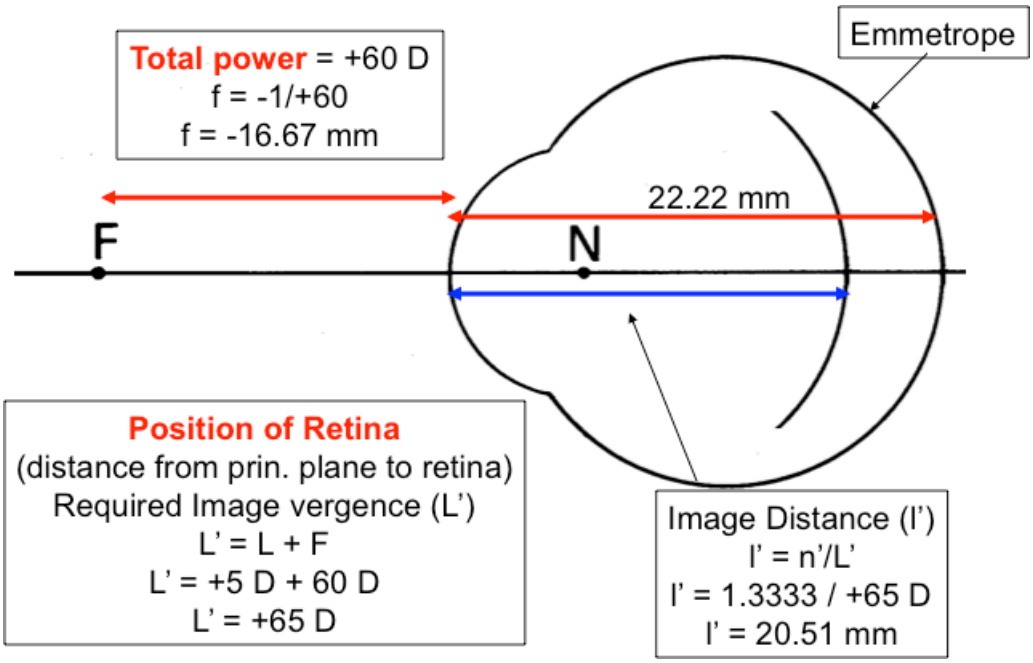


Figure 4.6: *Determination of the image distance from the refractive surface in a 5 D axial hyperope allows subsequent calculation of the distance from the nodal point to the retina and the image size*

Note. In the above examples, the magnitude of the refractive error was specified with respect to the principal plane of the eye. Refractive corrections specified in this manner are referred to as **principal plane refractions** or **ocular refractions**. In standard clinical situations, the magnitude of a patient's refractive error is specified with respect to the spectacle plane (actually the plane of the phoropter) and is referred to as **spectacle plane refraction**. The ocular refractions can be calculated from the spectacle plane refraction if the vertex distance is known and *vice versa*. Unless otherwise specified, refractive errors in these notes will be specified with respect to the principal planes.

IMAGE SIZE IN UNCORRECTED REFRACTIVE AMETROPIA

When an object is not conjugate with the retina, the image formed on the retina will not be in focus and each object point will be represented by a blur circle. For an object at infinity, the size of the blur circle will depend primarily on the magnitude of the refractive error and the size of the pupil. In certain situations it is desirable to determine the size of the blurred image. In this case, the image size can not be determined using the ray through the eye's nodal point. Instead, the rays from the object's extremities that pass through the **centre of the entrance pupil** (the **chief rays**) are utilized to determine the retinal image size. The chief rays are used because the size of a blurred retinal image is defined as the distance between the centres of the blur circles associated with the extremities of the object. Whereas, the rays through the nodal point do not form the **centres** of the blur circles, the chief rays do intersect the retina at the centre of a given blur circle. In this respect, the chief ray can also be used to determine the size of a clear retinal image. However, it is important to realize that the image size determined by the chief ray does not represent the true physical size of the blurred image. As illustrated in Figure 4.7, the **physical size** of the image will be equal to the size of the image indicated by the chief ray plus the diameter of one of the blur circles.

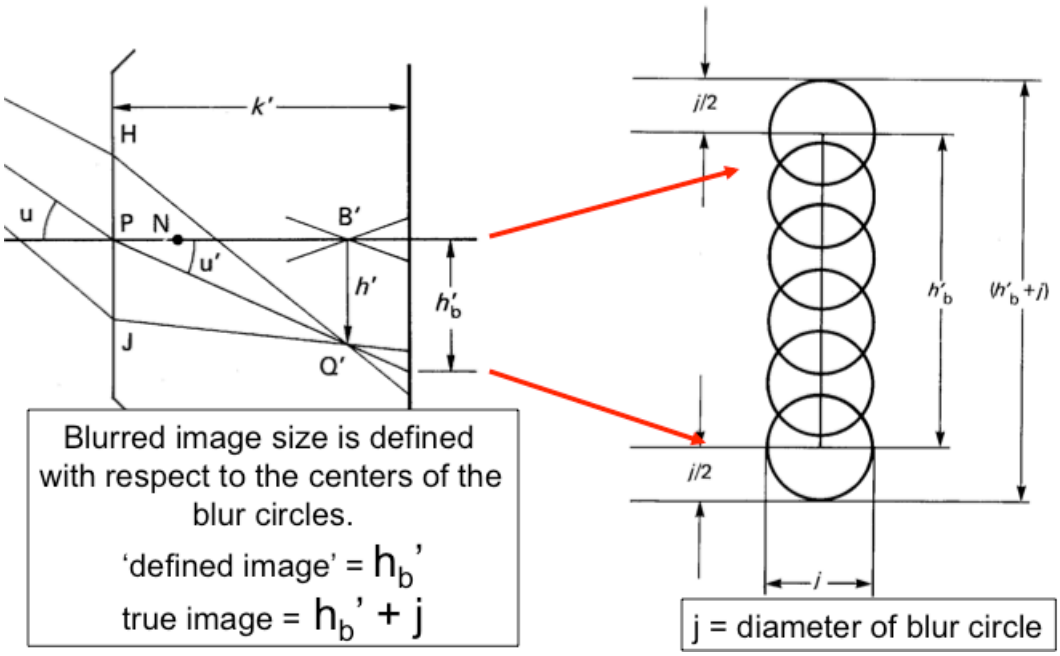


Figure 4.7: *The physical size of the image will be equal to the size of the image indicated by the chief ray plus the diameter of one of the blur circles*

The following is an example of how the chief ray can be used to determine the retinal image size. Assume there is an object at infinity that subtends an angle of 0.1 rad at the entrance pupil of Emsley's emmetropic reduced eye. Unlike the ray through the nodal point, the chief ray will be deviated upon refraction at the principal plane. So the angle subtended by the image at the entrance pupil will be less than 0.1 rad (see Figure 4.8).

To calculate the size of the retinal image, the distance between the principal plane and the retina must be known and the angle of refraction of the chief ray must be calculated. A simplified version of Snell's Law can be used to determine the angle of refraction.

Snell's law,

$$n(\sin(i)) = n'(\sin(i'))$$

Since the angles of incidence for paraxial rays are going to be relatively small, the angles can be expressed in radians and the sine functions may be dropped. Hence,

$$ni = n'i'$$
$$i' = ni/n'$$

Since n = 1 and n' = 4/3 (for Emsley's reduced eye):

$$i' = 3/4(i) = 0.75i$$

For the example illustrated above:

$$i' = 0.1 \text{ rad}(3/4) = 0.075 \text{ rad}$$

The size of the retinal image (h'):

h' = i'(distance between the principal plane & retina)
h' = 0.075 x 22.22 mm
h' = 1.67 mm

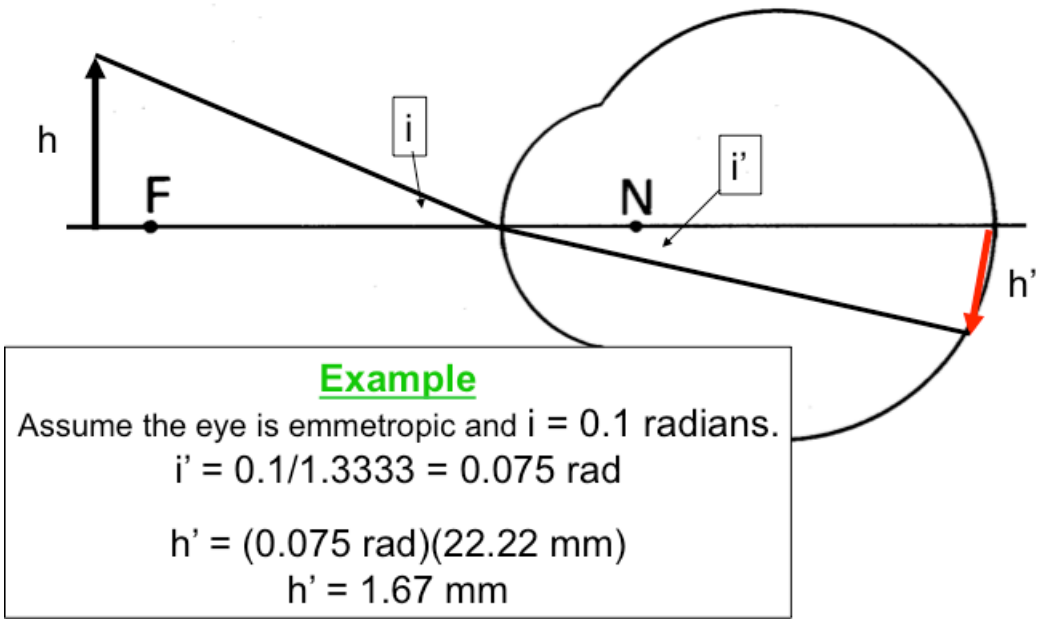


Figure 4.8: *Using the angle of refraction of the chief ray to calculate image size*

One of the important characteristics of the chief ray is that it can be used to demonstrate the relationship between the size of the retinal image formed in an **uncorrected refractive ametropic eye** and that formed in an **emmetropic eye**. Consider the retinal image formed in a 5.0 D refractive myope's eye by an object at infinity that subtends a 0.1 rad angle at the centre of the entrance pupil. As illustrated in Figure 4.9, the axial length of a 5.0 D refractive myope is identical to that of the emmetropic eye, however the total refractive power is 5.0 D greater (i.e. F = +65.0 D) than that for the emmetropic eye. As a result a clear image of the object at infinity will be formed at point X. Light will subsequently diverge from X to form a blur circle on the retina. By definition, the size of the image in this uncorrected refractive myope will be determined by the chief ray. Since the angle of incidence of the chief ray is 0.1 rad, the angle that the chief ray assumes following refraction will be 0.075 rad. In this case, the angle of refraction will be the same for the uncorrected ametrope and the emmetrope.

The axial length will also be the same (22.22 mm; really the distance between the principal plane and the retina). As a result, the 'defined' size of the image in the uncorrected ametropic eye will be equal to the image size in the emmetropic eye (i.e. 22.22 mm x 0.075 rad = 1.67 mm retinal image).

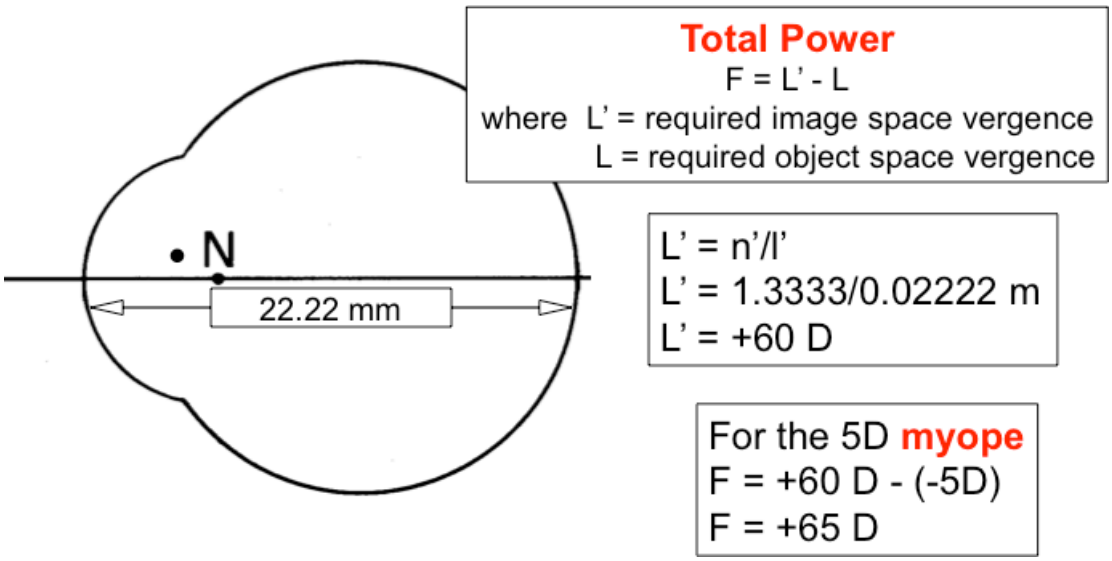


Figure 4.9: *The axial length of a 5.0 D refractive myope is identical to that of the emmetropic eye, however, the total refractive power is 5.0 D greater (i.e. F = +65.0 D)*

However, from Figure 4.7 it should be obvious that the **physical size** (not the defined image size) of the blurred image in the refractive myope will be larger than the clear image formed by the same object in the emmetropic eye. The true physical size of the blurred image can be determined by calculating the diameter of one of the blur circles. If we assume that the pupil of the 5.0 D refractive myope is 5 mm in diameter (remember that the pupil coincides with the refracting surface in the reduced eye), the size of the blur circle can be calculated using the relationships for similar triangles. To do this, the position of point X must be determined as follows:

$$L' = L + F$$

(Since the object is at infinity L = O)

$$L' = O + 65.0 \text{ D} = +65.0 \text{ D}$$
$$l' = n'/L'$$

(l' = distance from the refracting surface to X)

$$l' = 1.333/+65.0 \text{ D}$$
$$l' = 20.51 \text{ mm}$$

Since triangle ABX is similar to triangle CDX, the ratio of the bases of the triangles (i.e. the ratio of the pupil size to the size of the blur circle) will equal the ratio of the altitudes of the triangles (i.e. ratio of distances from the principal plane to X and from X to the retina).

$$\frac{\text{CD (blur circle)}}{\text{5 mm (pupil size)}} = \frac{\text{1.71 mm (X to the retina)}}{\text{20.51 mm (principal plane to X)}}$$

$$CD = 0.417 \text{ mm}$$

(i.e. the diameter of the blur circle = 0.417 mm)

Thus, the true physical size of the blurred image is:

0.417 mm + 1.67 mm = 2.087 mm

IMAGE SIZE IN CORRECTED AMETROPIA

The primary purpose of a spectacle lens is to focus light from infinity at the far point of an ametropic eye. In addition to eliminating retinal blur, spectacle lenses also alter the size of the image formed in the ametropic eye. The effect of the power of a correcting lens on the size of the retinal image can be described by two factors, **spectacle magnification** and **relative spectacle magnification**.

Spectacle magnification (SM) describes how the correcting lens affects the size of the uncorrected image. It is defined as the ratio of the size of the image of a **distant** object in the **corrected ametropic eye** to the size of the blurred image in the **uncorrected ametropic eye**. i.e.:

$$SM = \frac{\text{Corrected image size}}{\text{Uncorrected image size}}$$

It can be shown that SM also equals:

$$SM = \frac{\text{distance between PR and the spectacle lens}}{\text{distance between PR and the 1st principal plane}}$$

(PR = Punctum Remotum, i.e. the far point)

The above relationship indicates that SM depends on the magnitude of the refractive error and the position of the correcting lens. SM is always a positive number. For hyperopes, since the far point is behind the eye while the spectacle plane is always in front of the eye, SM will always be greater than 1.0 (however see the section on aphakic eyes). For myopes, both the far point and the spectacle plane are in front of the eye and since the far point is usually farther from the eye than the correcting lens, SM will be less than 1.0. For both hyperopes and myopes, the greater the vertex distance, the greater the effect of the lens on the size of the uncorrected image, i.e. the more SM will deviate from 1.0.

Spectacle magnification is referred to as **angular magnification** (in contrast to linear magnification, i.e. M = h'/h = L/L') because the contribution of the optics of the ametropic eye to the image size is the same in both the corrected and uncorrected state. The ratio of images (corrected/uncorrected) simply reflects the difference in the angles subtended by the **chief rays** at the refracting surface in the corrected and uncorrected conditions.

Note: From a clinical point of view, SM is important because it can be used to predict some of the alterations in space perception produced by spectacle lenses. For example, assume a previously uncorrected young hyperope has the accommodative ability to compensate for their refractive error. When corrected with spectacles, objects at distance will be clear (now the eye is unaccommodated), but larger than in the uncorrected state. In general, when an object is magnified, the visual system interprets the change in size as a change in the object's position. Thus, when the spectacles are first worn, objects will be perceived to be closer than they were in the uncorrected state.

Relative Spectacle Magnification (RSM) describes how the image size in the **corrected ametropic eye** compares to that in the **average emmetropic eye**. It is defined as the ratio of the retinal image sizes produced by a distant object in the corrected ametropic eye and in the average emmetropic eye, i.e.:

$$\text{RSM} = \frac{\text{equivalent power of the emmetropic eye}}{\text{equivalent power of the ametropic eye \& correcting lens}}$$

Note: From a clinical point of view, RSM is important because the ratio of the RSMs determined for the right and left eyes of a patient indicates the relative sizes of the images in the two eyes.

For any optical system, the size of the image of a distant object will be **directly proportional** to the **equivalent** focal length of the optical system. And since the focal length of any optical system is the reciprocal of its equivalent refracting power (assuming that the optical system is in air), image size is **inversely proportional** to the optical system's **equivalent refracting power**.

Therefore:

$$\text{RSM} = \frac{+60.00\ \text{D}}{F_{eye}+F_{lens}-d(F_{eye}).(F_{lens})}$$

The equivalent power of the ametropic eye-lens combination can be calculated using the following equation for the equivalent power of a lens system.

$$F_{eq} = F_{eye} + F_{lens} - d/n(F_{eye}).(F_{lens})$$

Where,

F_{eq} = total equivalent power
F_{eye} = power of the ametropic eye
F_{lens}= power of the correcting lens
n = refractive index between the lens and eye (usually 1.0)
d = distance (meters) between the second principal plane of the lens and eye's first principal plane

Note: d does **not** equal the vertex distance. Clinically the vertex distance of a spectacle lens is measured from the pole of the cornea to the back vertex of the lens.

Assuming that Emsley's reduced eye is used as the standard emmetropic eye, the above relationship for RSM becomes:

$$\text{RSM} = \frac{+60.00\ \text{D}}{F_{eye}+F_{lens}-d(F_{eye}).(F_{lens})}$$

(Remember that the equivalent power of Emsley's reduced emmetropic eye is +60.00 D.)

This relationship forms the basis for **Knapp's Law**, historically one of the most important clinical rules-of-thumb.

Knapp's Law: For **axial** ametropias, RSM will equal 1.0 when the second principal plane of the correcting lens coincides with the anterior focal point of the eye (see Figure 4.10).

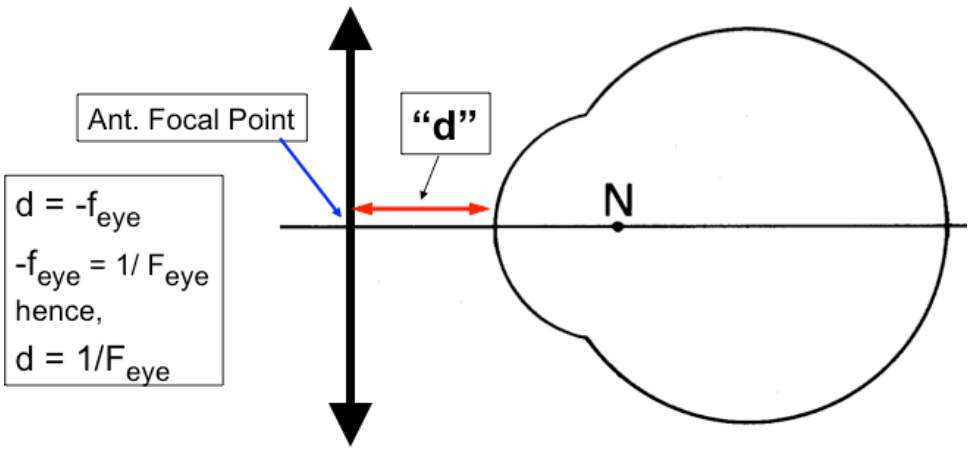


Figure 4.10: *Knapp's Law holds that for axial ametropias, RSM is equal to 1 when the second principal plane of the correcting lens coincides with the anterior focal point of the eye*

Consider what happens to the above equation for RSM when the correcting lens is placed at the anterior focal point of the eye. With the correcting lens at the anterior focal point, d is equal to the anterior focal length of the eye (f_{eye}).

Since:

$$f_{eye} = -1 / F_{eye} = -d$$

(**Note.** d will always be a positive value)

Substitute $1/F_{eye}$ for d

$$RSM = \frac{F(\text{emmetropic eye, i.e.+60.0 D})}{F_{eye}+F_{lens}-(1/F_{eye}).(F_{lens})}$$

And simplify

$$RSM = \frac{+60.0\ D}{F_{eye}+F_{lens}-F_{lens}}$$

$$RSM = \frac{+60.0\ D}{F_{eye}}$$

$$RSM = \frac{(\text{power of the schematic eye})}{(\text{power of the ametropic eye})}$$

In other words, when a correcting lens is fitted at the anterior focal point of the eye, the equivalent power of the eye-lens combination is equal to the power of the ametropic eye alone. Since the refracting power of an axially ametropic eye is equal to the power of an emmetropic eye (i.e. +60 D when you are using Emsley's reduced eye):

$$RSM = \frac{+60.0\ D}{+60.0\ D} = 1.0$$

So when the correcting lens is placed at the anterior focal point of an **axial ametrope**, the size of the clear retinal image in the ametropic eye will be equal to the size of image formed in the emmetropic eye. This point can be illustrated graphically. In Figure 4.11, three eyes (an emmetrope, an axial hyperope, and an axial myope) are superimposed. Because the refracting power of each of these eyes is the same, the anterior focal lengths will also be equal. To demonstrate that RSM = 1.0 for the myope and hyperope corrected at the anterior focal point, consider the rays from the extreme points of a distant object that are directed at the anterior focal points of the three eyes. The optical centres of the correcting lenses for the myope and hyperope will coincide with the anterior focal points and, thus, the rays directed toward the anterior focal points will pass through the optical centres of the lenses undeviated. The rays will intersect the principal planes of the three eyes and be refracted parallel to the optical axis. Since the images formed in the three eyes are all in focus, the intersection of the rays through the anterior focal point and the respective retinas of each eye will delineate the sizes of the clear retinal images. Since after refraction the ray through the anterior focal point is parallel to the optical axis, the retinal image size will be independent of the eye's axial length.

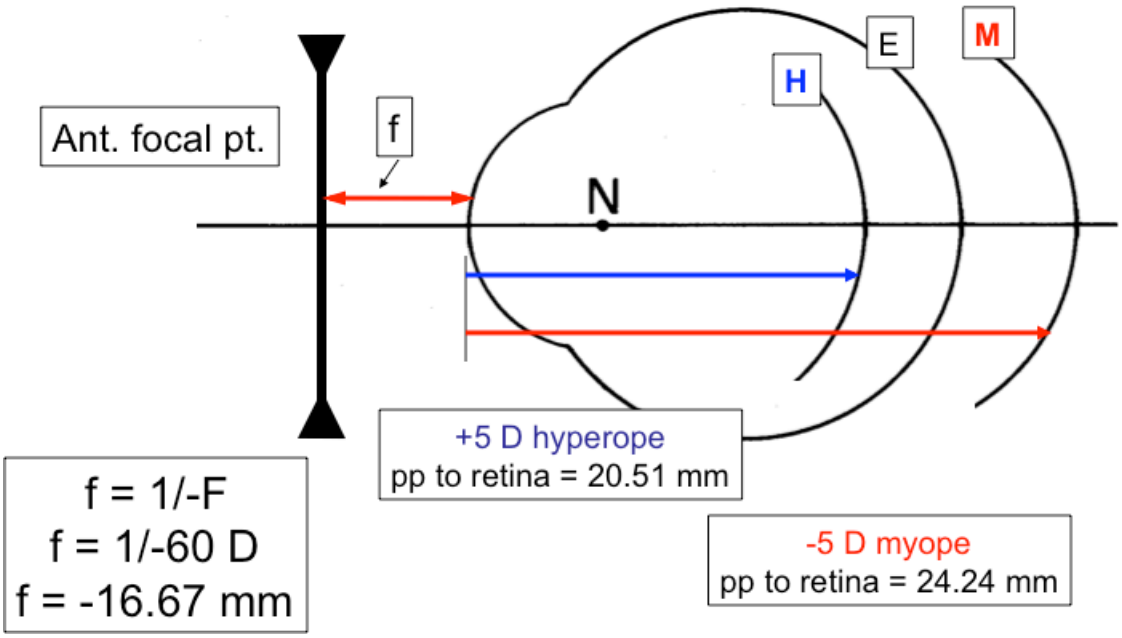


Figure 4.11: *Axial ametropias corrected at the anterior focal point*

SM AND RSM IN CORRECTED AMETROPIC EYES

The following examples will illustrate:

1. The effects of correcting lenses on retinal image size in both axial and refractive types of ametropia,
2. The differences in image size in corrected myopic vs. corrected hyperopic eyes, and
3. The differences in image size associated with correcting the ametropic eye at the anterior focal point (i.e. with spectacle lenses) vs. at the eye's principal plane (i.e. with contact lenses).

Note. In the majority of patients the anterior focal point will be close to, but slightly in front of the spectacle plane (compare the position of the anterior focal point of Gullstrand's #1 eye with a 13 or 14 mm spectacle vertex distance). It should also be noted that since the principal planes of the eye are in the aqueous, it is really not possible to place the correcting lens at the principal plane (assuming you are not using an intraocular lens). But the approximate effect of contact lenses can most easily be demonstrated by considering the correction to be at the principal planes of Emsley's reduced eye.

AXIAL AMETROPIAS CORRECTED WITH SPECTACLES

Assume one patient has an ocular refraction (or **principal plane refraction**) of −5.00 D (i.e. a 5.00 D myope) and a second hyperopic patient has a +5.00 D ocular refraction. Assume that the spectacle plane coincides with the **anterior focal points** of the ametropic eyes (i.e. assume that the p' of the correcting lens coincides with f of the ametropic eyes).

Note: Remember that since these are axial ametropias, the anterior focal lengths of the ametropic eyes will be equal to the anterior focal length of the emmetropic eye.

$$f = 1/-F$$
$$F = +60.00 \text{ D}$$

Hence,

$$f = 1/-60.00 \text{ D}$$
$$f = -16.67 \text{ mm}$$

i.e. the anterior focal points are 16.67 mm in front of the principal plane (the equivalent refracting surface).

A variety of approaches can be used to calculate SM and RSM for these ametropic eyes. The first approach that will be illustrated involves calculating the sizes of the retinal images formed in the corrected and uncorrected ametropic eyes and the retinal image size formed by the same object in an emmetropic eye. In this case it is convenient to begin by calculating the sizes of the retinal images in the uncorrected state. Again for convenience, assume that the distant object in question subtends a visual angle of 0.1 radians.

Note: The size of the object selected is not critical –i.e. the values for SM and RSM are not dependent on the exact size of the object selected. Selecting an object that subtends 0.1 rad is convenient since it simplifies the mathematics.

In the diagram in Figure 4.12, the chief rays from the distant object are shown for the uncorrected ametropic eyes and the standard emmetropic reduced eye. In order to calculate the retinal image size for these three eyes, the angles subtended by the retinal images at the principal planes must be determined and the distance between the principal planes and the retinas must be known. The angle of refraction of the chief rays (i.e. the angle subtended by the retinal images at the refracting surface) can be calculated using Snell's Law, as simplified for paraxial rays.

$ni = n'i'$
$i' = i/n$
$i' = 0.1 \text{ rad}/1.333$
$i' = 0.075 \text{ rad}$

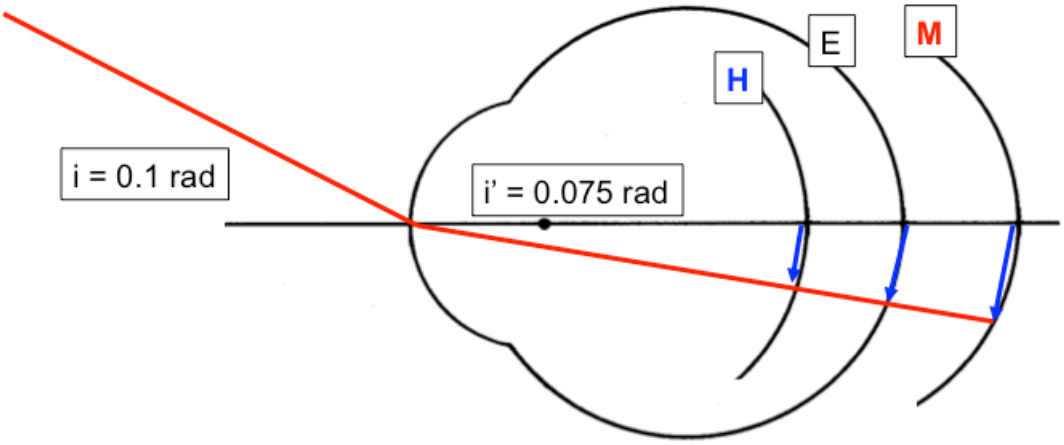


Figure 4.12: *The angle of refraction of the chief rays from a distant object can be calculated using Snell's Law for uncorrected ametropic eyes*

The distance between the refracting surface and the retina is 22.22 mm for Emsley's emmetropic reduced eye. This distance must be calculated for the myopic and hyperopic eyes. As shown previously (pages 6 & 7), this involves calculating the vergence of light in image space (L') that is required to come to a focus on the ametropic retinas and the image distance (l') associated with this image space vergence. The distance between the refracting surfaces and retinas for the 5 D axial myope and the 5 D axial hyperope are 24.24 mm and 20.51 mm, respectively.

The retinal image sizes (see Figure 4.13) for the emmetropic eye and the uncorrected ametropic eyes:

Emmetrope

$h' = (0.075 \text{ rad}) \times (22.22 \text{ mm})$
$h' = 1.67 \text{ mm}$

Uncorrected axial hyperope

$h' = (0.075 \text{ rad}) \times (20.51 \text{ mm})$
$h' = 1.54 \text{ mm}$

Uncorrected axial myope

$h' = (0.075 \text{ rad}) \times (24.24 \text{ mm})$
$h = 1.82 \text{ mm}$

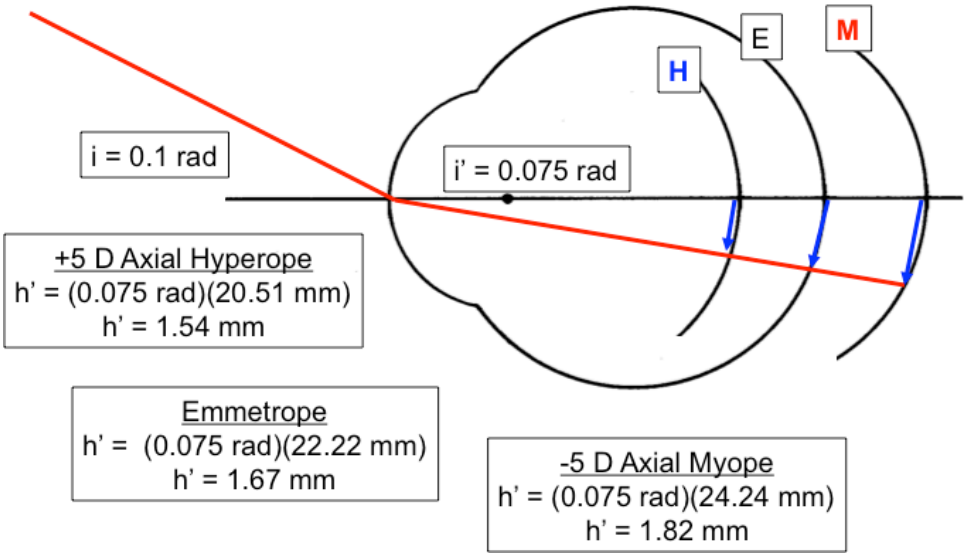


Figure 4.13: *The image size can be calculated using the distance between the refracting surface and the retina for axially ametropic eyes*

When these ametropic eyes are corrected with spectacles placed at the anterior focal point, the angles of incidence of the chief rays at the ametropic eyes' principal planes will be altered by refraction by the correcting lenses (see Figure 4.14). In the case of the myope, the new angle of incidence for the chief rays from the object's extremities will be less than 0.1 rad. For the hyperope, the angle of incidence will be greater than 0.1 rad. In this situation, the easiest rays to use to calculate the size of the retinal image are the rays through the anterior focal points of the ametropic eyes. If it is assumed that the correcting lens is infinitely thin and that the optical centre of the correcting lens coincides with the eye's anterior focal point, then rays from the distant object directed toward the anterior focal point will not be deviated by the correcting lens (i.e. q□=q'). When these rays reach the eyes' principal planes, they will be refracted parallel to the optical axes and will intersect the retinas delineating the sizes of the retinal images. Since these rays are parallel to the optical axes in image space, the distance between the intersection of these rays at the principal plane and the optical axes (the distance labeled X in Fig 4.14) will be equal to the size of the retinal image. To find the distance X, the angle subtended by the object at the anterior focal point and the anterior focal length must be known. Since the object is at optical infinity, it can be assumed that the object will subtend the same angle at the anterior focal point as it does at the centre of the entrance pupil (since the object is at optical infinity and since the difference between the object distances measured at the anterior focal point and the principal plane will be small, this assumption will not affect the calculations). Therefore, in order to calculate the image size in the corrected ametropic eyes, simply multiply the anterior focal length times the visual angle subtended by the object.

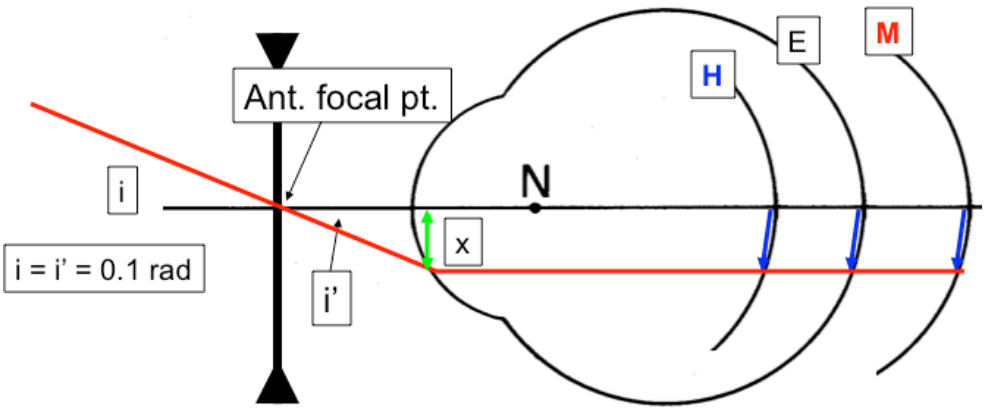


Figure 4.14: *In order to calculate the image size in the corrected ametropic eyes, simply multiply the anterior focal length times the visual angle subtended by the object*

Hyperope (corrected image size)

h' = (16.67 mm) × (0.1 rad)
h' = 1.67 mm

Hence,

SM = corrected image size / uncorrected image size
SM = 1.67 mm / 1.54 mm = 1.08

i.e. the corrected image size is about 8% larger than the uncorrected image size.

RSM = corrected image size / emmetropic image size
RSM =1.67 mm / 1.67 mm = 1.0

Myope (corrected image size)

h' = (16.67 mm) × (0.1 rad)
h' = 1.67 mm

Hence,

SM = 1.67 mm / 1.82 mm
SM = 0.92

RSM = 1.67 mm / 1.67 mm
RSM = 1.0

AXIAL AMETROPIAS WITH CONTACT LENSES

In this example we will consider the same two axial ametropias employed in the last section (i.e. a 5.0 D myope and 5.0 D hyperope) and we will assume that the contact lenses are effectively fitted on the eyes' principal planes. Figure 4.15 illustrates the effects of principal-plane correcting lenses on the retinal image sizes in the axial hyperopic and myopic eyes. Assuming that the ametropic eyes and the correcting lenses are 'centred' (i.e. the optical centres of the refracting surfaces lie on a common axis), then the optical centres of the correcting lenses will coincide with the vertexes of the eyes' equivalent refracting surface (the centres of the entrance pupils). As a result, the chief rays from the extremities of the object will intersect the optical centres of the correcting lenses and will, thus, not be deviated by the correcting lenses. Of course, these rays will be deviated by refraction (bend toward the optical axis) at the eyes' equivalent refracting surfaces. However, because the correcting lenses did not deviate the chief rays, their angles of incidence will be the same in this corrected state as they were in the uncorrected state. Therefore, the angles the images subtend at the eyes' principal planes will be the same in the corrected and uncorrected conditions (these values were calculated previously on page 17). Since the sizes of the uncorrected images were not altered by the correcting lenses (the lenses simply brought the images into focus), then,

SM = 1.0

For both the axial hyperope and the axial myope.

As indicated by Knapp's law, RSM in these axial ametropes corrected with contact lenses at the principal planes will not equal 1.0. Instead,

For the **hyperope**,

RSM_H = 1.54 mm / 1.67 mm
RSM_H = 0.92

For the **myope**,

RSM_M= 1.818 mm / 1.67 mm
RSM_M = 1.089

Note: The relatively large image size (i.e. an RSM > 1.0) that results when axial myopes are corrected with contact lenses is one reason why individuals with this type of refractive error receive their best vision (highest visual acuities) with contact lenses. At least with respect to image size, the opposite is true for axial hyperopes.

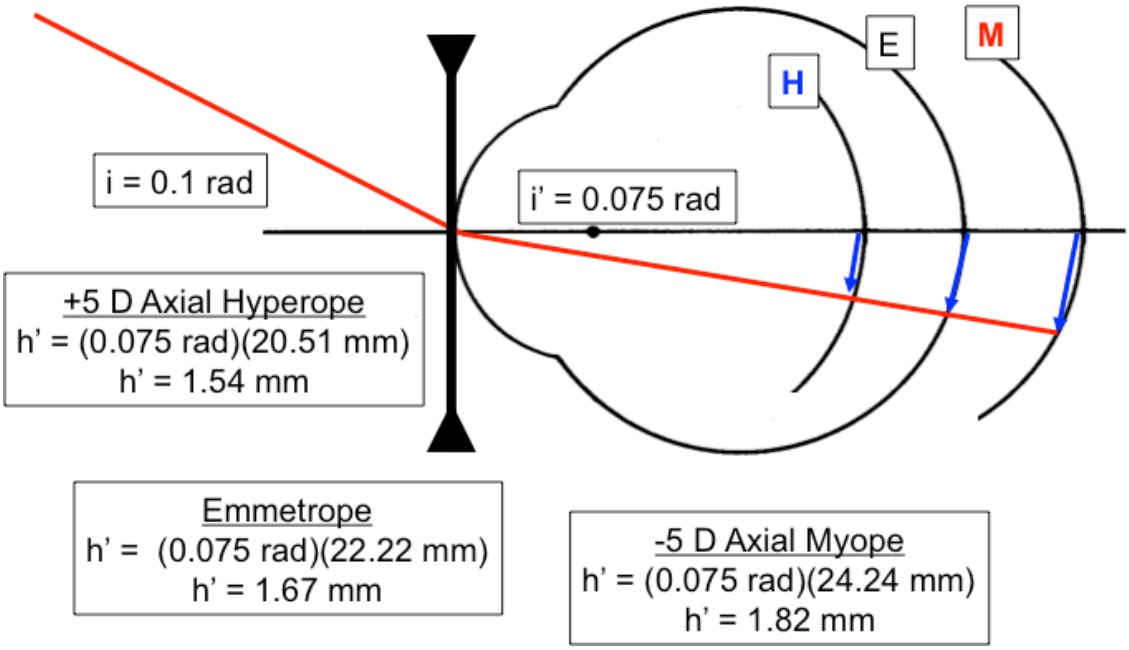


Figure 4.15: *If the correcting lens is placed at the principal plane the image size will be the same as in the uncorrected eye (as shown in Figure 4.13)*

REFRACTIVE AMETROPIAS CORRECTED WITH SPECTACLES

Assume that one patient has a 5.0 D refractive myopia and that a second patient has a 5.0 D refractive hyperopia. As in the last example with axial ametropias, we will first determine the sizes of the out-of-focus images in the uncorrected eyes.

Figure 4.16 demonstrates an important characteristic of refractive ametropias. In the uncorrected state, the chief rays from a standard, distant object (i.e. an object that subtends 0.1 radians) will be refracted the same amount in the ametropic eyes as it is in the standard emmetropic eye. As a result the angles subtended by the images at the eyes' principal planes will be the same as that in the standard emmetropic eye, regardless of the magnitude of the refractive error. Because, by definition, the axial lengths of refractive ametropic eyes are the same as the standard emmetropic eye, the uncorrected retinal images in the ametropic eyes will be equal to the size of the image formed in the emmetropic eye.

i.e. for a 0.1 rad object at infinity,

$$h' = (0.075 \text{ rad}) \times (22.22 \text{ mm}) = 1.67 \text{ mm}$$

Since the uncorrected image sizes in these ametropic eyes are the same as those formed in emmetropic eyes, regardless of how the refractive errors are corrected (contact lenses or spectacles), SM will equal RSM. This property of refractive ametropias is simply a product of the following relationships:

$$\text{SM} = \frac{\text{corrected image size}}{\text{uncorrected image size}}$$

$$\text{RSM} = \frac{\text{corrected image size}}{\text{emmetropic image size}}$$

Because the uncorrected image sizes are identical to the image size in the emmetropic eye, these relationships are obviously equivalent.

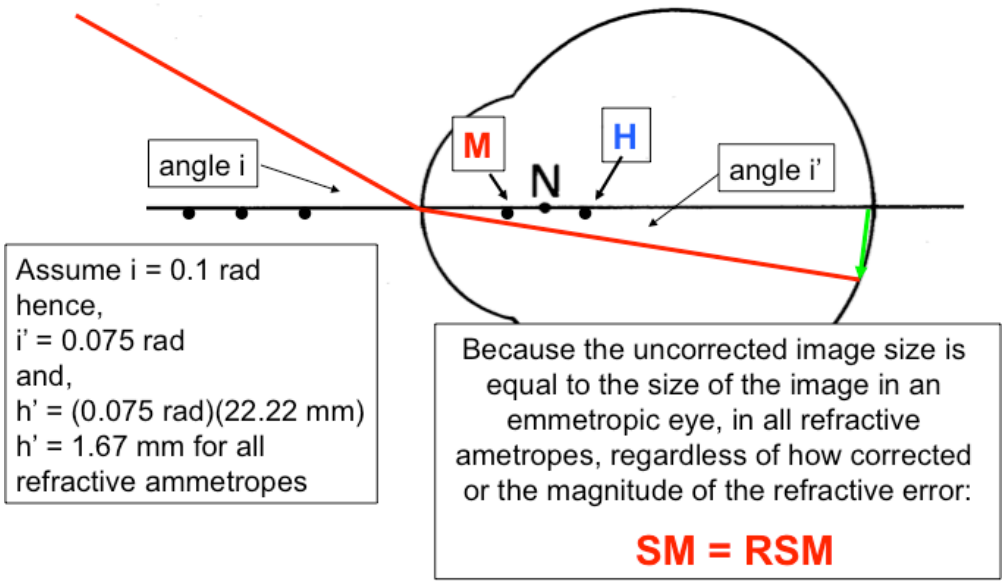


Figure 4.16: *For a given distant object, the angle of incidence and the angle of refraction of the chief rays will be the same for all refractive ametropes*

Figure 4.17 illustrates the effects on the size of the retinal image of placing the correcting lens at a refractive ametrope's anterior focal point. As shown, the anterior focal lengths for the refractive ametropes are not the same. The optical system of the refractive myope's eye is characterized by too much refracting power. In this case, a 5.00 D principal plane refractive error, the total equivalent refracting power of the myope's eye is +65.00 D. The anterior focal length for this eye is 1/65.00 D (assuming the eye is in air) or 15.4 mm. The optical system of the 5.00 D refractive hyperope does not possess enough power to focus parallel light in object space onto the retina. Since the hyperope's eye has less refracting power than the emmetropic or myopic eye, it will have a longer anterior focal length (1/55.0 D; 18.18 mm).

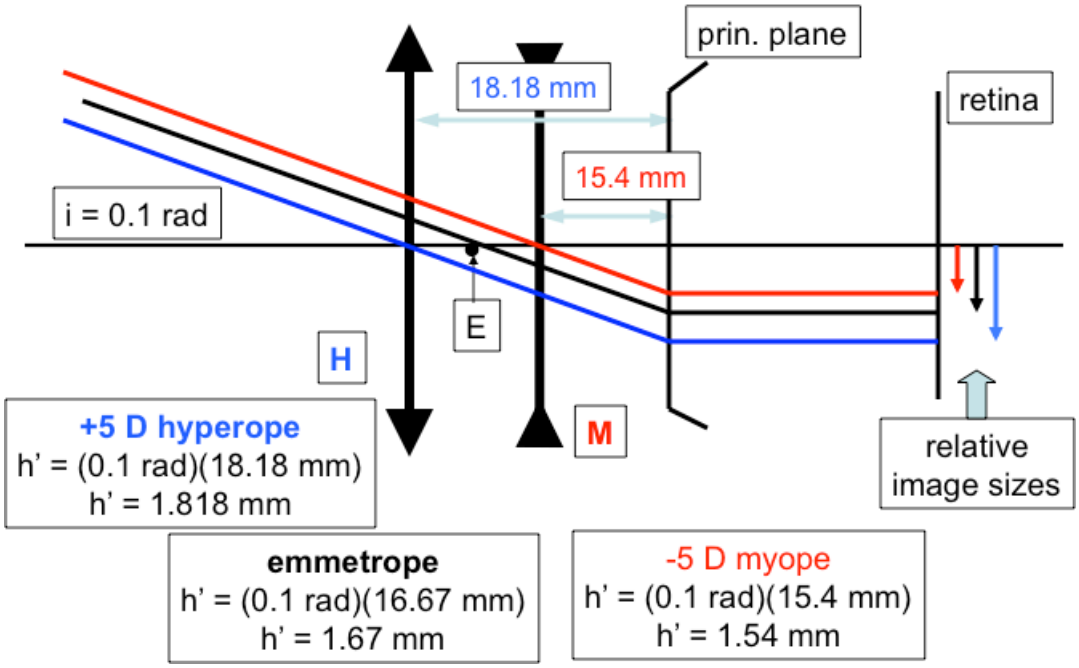


Figure 4.17: *Refractive ametropias corrected at the anterior focal point and their relative image sizes*

When these ametropic eyes are corrected with spectacle lenses placed at the anterior focal points, the sizes of the retinal images are directly proportional to the eyes' respective focal lengths. This point is illustrated by considering the rays through the anterior focal points of these eyes. Since the optical centres of the correcting lenses coincide with the anterior focal points, these rays will not be deviated by the correcting lenses. When these rays reach the equivalent refracting surfaces, they will be refracted parallel to the optical axes and their intersections with their respective retinas will demarcate the in-focus retinal images. It is obvious from the geometry of the situation that the ray through the anterior focal point of the hyperope's eye will intersect the eye's principal plane below the intersections of the corresponding rays for the eyes of the emmetrope and myope. The image size can be calculated by determining the distance between the optical axis (the ray from the bottom of the object) and the intersection of the rays from the extremities of the object at the refracting surface of the eye.

For the **hyperope**,

$$h' = (0.1 \text{ rad}) \times (18.18 \text{ mm})$$
$$h' = 1.818 \text{ mm}$$

For the **myope**,

$$h' = (0.1 \text{ rad}) \times (15.4 \text{ mm})$$
$$h' = 1.54 \text{ mm}$$

For the **emmetrope**,

h' = (0.1 rad) × (16.67 mm)
h' = 1.67 mm

Spectacle and relative spectacle magnification can be determined by calculating the appropriate image ratios. Hence,

For the **hyperope**,

$SM_H = RSM_H$ = 1.818 mm / 1.67 mm = 1.089

For the **myope**,

$SM_M = RSM_M$ = 1.54 mm / 1.67 mm = 0.92

An examination of the RSMs for refractive ametropias demonstrates that refractive hyperopes corrected with spectacles will benefit from the large image size provided by this correction strategy.

REFRACTIVE AMETROPIAS CORRECTED WITH CONTACT LENSES

With refractive ametropias, as the correcting lens is moved toward the eye's principal plane, both SM and RSM approach a value of one. As illustrated in Figure 4.18, when the correcting lens is positioned at the principal plane SM = RSM = 1.0. As discussed above, when the optical centre of the correcting lens coincides with the centre of the entrance pupil of the schematic eye (i.e. the vertex of the refracting surface), the correcting lens does not alter the path of the chief ray. Hence, the angle that the retinal image forms at the refracting surface is not affected by the presence of the correcting lens. In this respect, the correcting lens simply provides for an in-focus image. Because refractive ametropes have the same axial lengths as emmetropic eyes, the size of the in-focus images in refractive ametropia will be equal to the image size produced in the standard emmetropic eye.

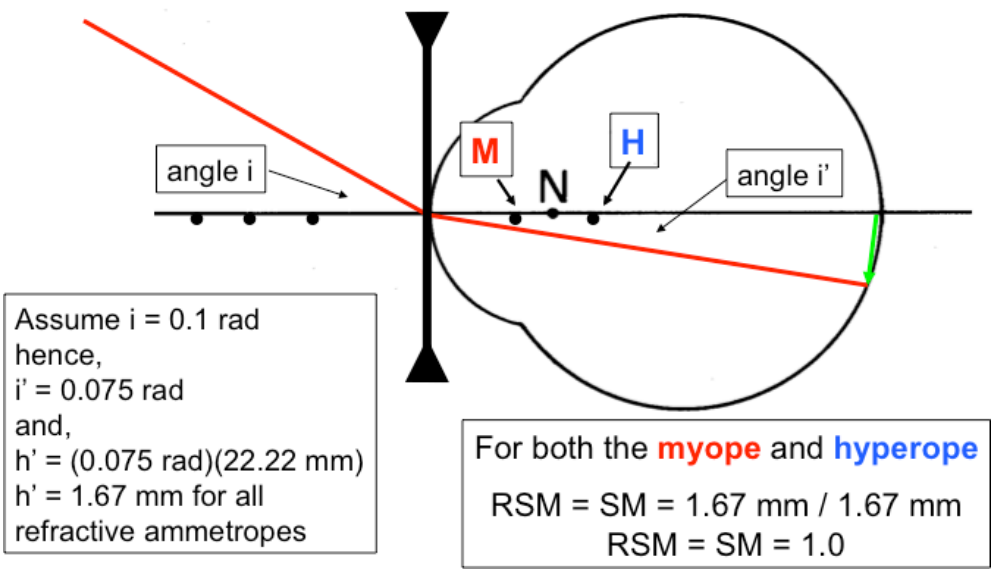


Figure 4.18: *With refractive ametropias, when the correcting lens is positioned at the principal plane, SM = RSM = 1.0*

CLINICAL COROLLARIES OF KNAPP'S LAW

1. If a patient has an anisometropia that is due to a difference in axial lengths between the two eyes (i.e. an axial anisometropia), the patient should be fitted with spectacle lenses to reduce the amount of anisekonia to a minimum.
2. If a patient has an anisometropia that is due to a difference in the refractive powers of the two eyes (i.e. a refractive anisometropia), the patient should be fitted with contact lenses to reduce the amount of anisekonia to a minimum.

CLINICAL RULE-OF-THUMB

If Knapp's Law is violated and an individual with an axial anisometropia is corrected with contact lenses, the correcting strategy will result in about a 2% difference in retinal image size between the left and right eyes for each 1 D of anisometropia. If a refractive anisometrope is fitted with spectacles, the correcting procedure will result in about a 1.5% interocular difference in image size for each diopter of anisometropia.

Note: It is very important to recognize that these clinical corollaries are based on the assumption that perceived image size is a simple function of the physical size of the retinal image. However, recent experiments suggest that changes in the density of retinal receptors can compensate for differences in physical retinal image size in individuals that have an axial anisometropia. It appears that as the eye gets larger, the retinal mosaic of neural elements stretches. As a result, in axial anisometropias, interocular axial length differences may produce different physical image sizes, but the same number (or proportion?) of neural receptors may be stimulated in each eye. If this idea is correct, then the best strategy for avoiding anisekonia is to correct anisometropes with contact lenses regardless of whether the interocular differences in refractive error are axial or refractive in nature.

RETINAL IMAGE SIZE IN VARIOUS CONDITIONS

LENS IS NOT AT THE ANTERIOR FOCAL POINT

In the section above, retinal image size and the values of SM and RSM were calculated for correcting lens positions that were convenient, but not necessarily practical. For example in a normal ametropic eye, it is not possible to place the correcting lens at the eye's principal plane. In the same sense, the anterior focal point is beyond the typical vertex distance for a spectacle correction. In this section, we will examine the procedures for calculating image size at a more traditional vertex distance.

EFFECTIVITY OF CORRECTING LENSES

For a given ametropic eye (i.e. for a given principal plane refraction), the refractive error can be corrected by any one of a series of different powered lenses set at different vertex distances. With many patients you will want to position the back vertex of the correcting lens at a different distance from where the phoropter was positioned during your examination. One must be able to determine the appropriate effective power required to correct the eye with respect to a specific vertex distance. A working knowledge of the effectivity of correcting lenses is also helpful in calculating retinal image size when the correcting lens is not at a convenient ocular landmark (i.e. the principal plane, etc.)

Note. In clinical settings, **back vertex power** is used to express the refractive power of a given lens (i.e. the power values shown on a phoropter are ‘back vertex powers’). Vertex distance is specified with respect to the back vertex of the correcting lens. Specifically, vertex distance is defined as the distance between the visual point of the lens (the intersection of the eye's visual axis with the back surface of the lens) and the cornea.

Typically text books supply the following formula for calculating the appropriate effective power for a spectacle lens.

$$F_{eff} = \frac{K}{1+d(K)}$$

Where,

F_{eff} = required effective power
K = is the principal plane refraction
d = desired vertex distance (in meter)

The following equation is typically provided to calculate the change in power that is required to compensate for a given change in the vertex distance of a correcting lens.

$$F_{new} = \frac{F_{old}}{1-(d_1-d_2)F_{old}}$$

Where,

F_{new} = the required effective power
F_{old} = power at the old vertex distance
d_1 = old vertex distance
d_2 = new vertex distance

For most ametropic corrections, the effects of changing the vertex distance of the correcting lens are relatively small and not clinically significant. However, for higher degrees of ametropia (e.g. greater than about 7.00 D), small changes in vertex distance can produce clinically significant changes in effective power. For example, consider the changes in effective power required to properly correct the hyperopic eye illustrated in Figure 4.19. Assume you conducted a examination of the patient with the phoropter positioned at a 15 mm vertex distance and found that the patient's refractive error was a +10.00 D. But to reduce the amount of magnification you decided to correct the patient at a 10 mm vertex distance. What is the required lens power for the 10 mm vertex distance?

$$F_{new} = \frac{+10.00\text{ D}}{1-(0.015\text{ m}-0.01\text{ m})10.0\text{ D}}$$

$$F_{new} = +10.53\text{ D}$$

i.e. when the correcting lens is positioned at a 10 mm vertex distance, the back vertex power must be increased 0.53 D to produce the desired effect.

Change in power required to compensate for a change in vertex distance.

$$F_{new} = \frac{F(old)}{1 - (d_1 - d_2)F_{old}}.$$

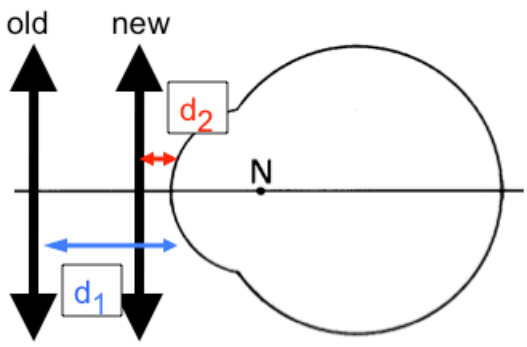
where

F_{new} = required power

F_{old} = power at old vertex

d_1 = old vertex

d_2 = new vertex distance



F_{old} = +10 D at a 15 mm vertex distance. What is the required power at a 10 mm vertex?

F_{new} = 10 D / [1 - 0.015 m -0.01 m)(10 D)]

F_{new} = +10.53 D

Figure 4.19: *Change in power required to compensate for a change in vertex distance in a +10 D hyperope*

This example and the equations above indicate that when the vertex distance of a correcting lens for a hyperope is decreased, the power of the lens must be increased to properly correct the patient's refractive error. For myope's, the power of the correcting lens must be decreased if the vertex distance is decreased.

In my experience, one invariably reverses d1 and d2 in the above equation and, thus, makes an error in determining the appropriate correcting lens power. My advice is that you do not memorize the above formulas, but instead simply remember the purpose of any correcting lens. If you understand the purpose of the correcting lens and the definition of the far point of the eye, it is easy to determine the required lens power for any vertex distance.

Far point: By definition, the far point of the eye is the point in space that is conjugate with the retina when the eye is in the unaccommodated state.

Purpose of correcting lenses: The purpose of any correcting lens is to focus light from an infinitely distant object at the eye's far point (i.e.form an image of the distant object at the eye's far point).

To meet the requirements for an adequate correcting lens, the focal length of the correcting lens must be equal to the distance between the eye's far point and the desired spectacle plane. The reciprocal of this distance is equal to the appropriate lens power.

IMAGE SIZE CALCULATIONS

Assume that the patient is a -5.00 D axial myope (principal plane refraction) who is going to be corrected with spectacles placed 10 mm in front of the principal plane (see Figure 4.20). Assume that the patient is viewing a distant object that subtends an angle of 0.1 radians at the refracting surface of the uncorrected eye. Calculate the size of the retinal image in the corrected state.

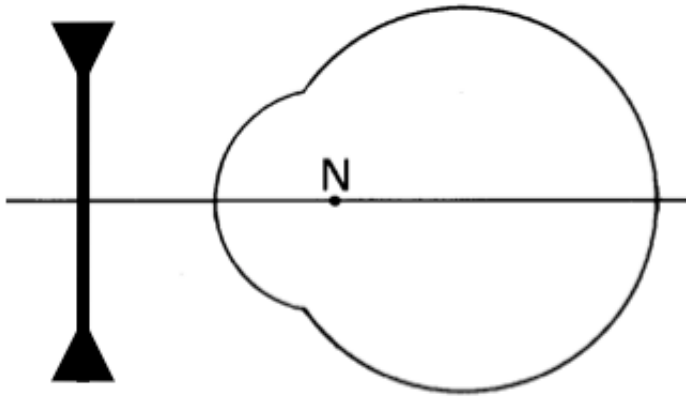


Figure 4.20: *Assume that the patient is a -5.00 D axial myope (principal plane refraction) who is going to be corrected with spectacles placed 10 mm in front of the principal plane*

GEOMETRICAL APPROACH

With this approach, the size of the image of the distant object formed at the eye's far point will be calculated. This image will then be treated as the object that generates the retinal image. By calculating the size of this new 'object' (i.e. the image of the distant object formed at the eye's far point by refraction at the correcting lens), the angle of incidence of the chief ray (at the eye's principal plane following refraction by the correcting lens) can be calculated. A simplified version of Snell's law can then be used to calculate the angle that the retinal image forms at the eye's refracting surface. Then, if the distance between the refracting surface and the retina is known, the retinal image can be readily calculated.

First, calculate the distance between the eye's refracting surface and the retina.

$l' = n'/L'$

$l' = 1.3333 / +55.0$ D

$l' = 24.24$ mm

Second, calculate the size of the image formed at the far point of the eye. You know that the image will be formed at the eye's far point (in this case 20 cm in front of the eye, i.e. the patient is a 5.00 D myope) and that the distance between the correcting lens and the far point is 19 cm (20 cm less the 1 cm vertex distance). To determine the image size, simply consider the ray from the top of the distant object that passes through the optical centre of the correcting lens. It will be undeviated and form the top part of the virtual object at the eye's far point (it is assumed that the bottom of the object coincides with the optical axis). Since you know that the image is formed in the far point plane, you only need to consider one ray. Since the angle of incidence of the ray through the lens' optical centre is 0.1 rad and it is undeviated by refraction, the image formed in the far point plane will also subtend an angle of 0.1 rad at the optical centre of the correcting lens. Hence, the size of the image formed in the far point plane can be easily calculated.

h' = (0.1 rad) x (19.0 cm)
h' = 1.9 cm

The image in the far point plane acts as the object for the eye. In this case, the angle subtended by this virtual object at the centre of the eye's entrance pupil can be calculated and the resulting retinal image size determined using the chief rays. The angle subtended by the virtual object,

angle = 1.9 cm/20 cm = 0.095 rad

i.e. the minus lens reduced the angle of incidence of the chief rays from the extremities of the object (from 0.1 rad to 0.095 rad).

The angle the retinal image forms at the eye's principal plane can be determined by calculating the angle of refraction of the chief ray using a simplified version of Snell's Law.

i' = i/n
i'= 0.095 rad / 1.333
i' = 0.07125 rad

The retinal image size can be calculated by multiplying i' times the distance between the eye's refracting surface and the retina.

h' = (0.07125 rad) x (24.24 mm) = 1.73 mm

The effects of the correcting lens on the retinal image size can be summarized by calculating SM and RSM.

$$SM = \frac{\text{1.73 mm (corrected image size)}}{\text{1.818 mm (uncorrected image size)}}$$

SM = 0.95

i.e. the correcting lens minified the size of the uncorrected retinal image.

$$RSM = \frac{\text{1.73 mm (corrected image size)}}{\text{1.67 mm (emmetropic image size)}}$$

RSM = 1.036

i.e. although the correcting lens caused a reduction in the size of the uncorrected retinal image, the resulting clear image was still larger (about 3.6%) than the retinal image formed in the standard emmetropic eye (see Figure 4.21).

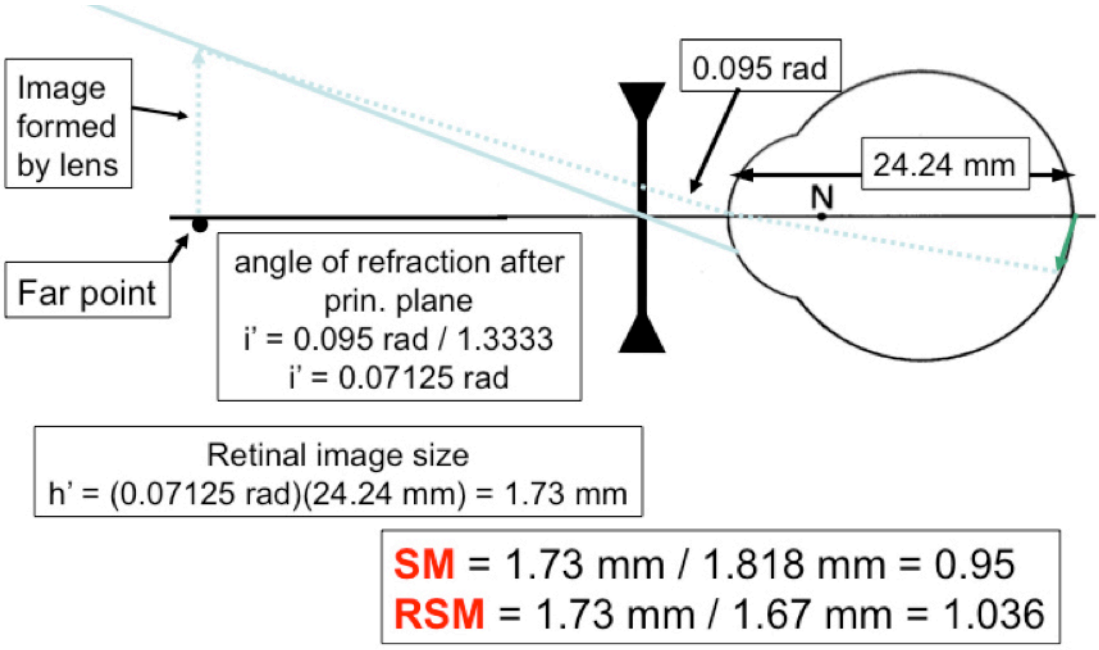


Figure 4.21: *The geometrical approach to retinal image size calculation*

LINEAR MAGNIFICATION APPROACH

Once you have determined the size of the image formed by the correcting lens in the eye's far point plane, the size of the retinal image can be calculated using standard formulas for linear magnification. It is, however, important to realize that this approach can only be used when the retinal image is in focus. (see Figure 4.22)

The first step in this approach is to calculate the magnitude of linear magnification.

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

i.e. magnification, the ratio of image (h') to object size (h), is equal to the ratio of the vergence of light in object and image space.

Object vergence (L)

(Assessed with respect to the eye's principal plane)

$$L = 1/ -0.2 \text{ m} = -5.0 \text{ D}$$

Image vergence (L')

$$L' = L + F = -5.0 \text{ D} + 60.0 \text{ D} = +55.0 \text{ D}$$

Magnification (M)

$$M = -5.00 \text{ D}/+55.0 \text{ D}$$
$$M = -0.09091$$

(Remember the minus sign indicates that the image is inverted)

Retinal image size (h')

h' = h(M)
h' = 1.9 cm (−0.09091)
h' = −1.73 mm

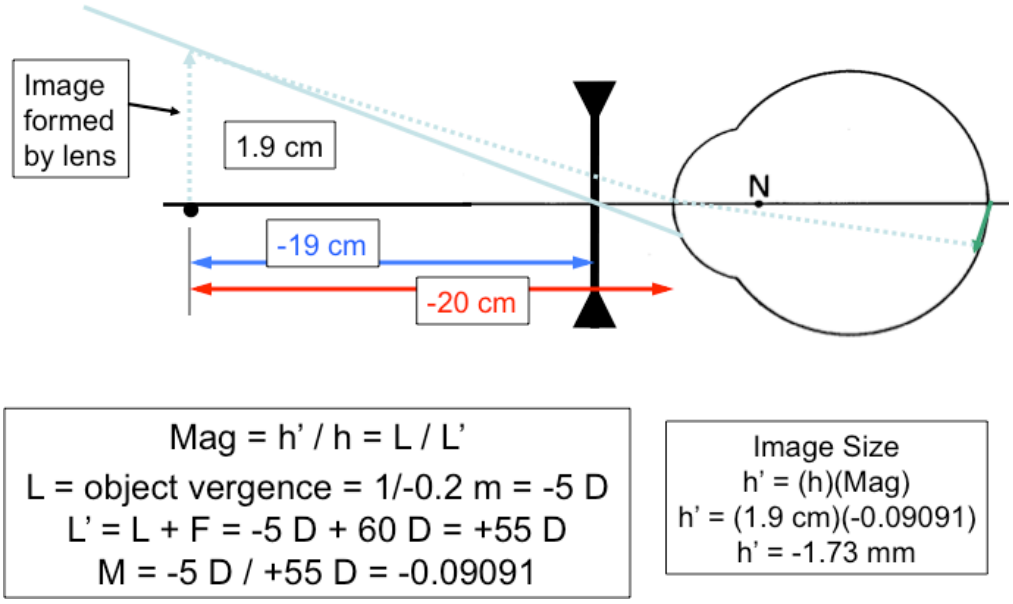


Figure 4.22: *The linear magnification approach to calculating retinal image size*

SPECTACLE MAGNIFICATION APPROACH

A relatively straightforward technique for determining the retinal image size involves first calculating SM and the size of uncorrected retinal image (see Figure 4.23). The following relationship can usually be employed to determine the SM:

$$SM = \frac{\text{distance between spectacle plane \& the far point}}{\text{distance between principal plane \& the far point}}$$

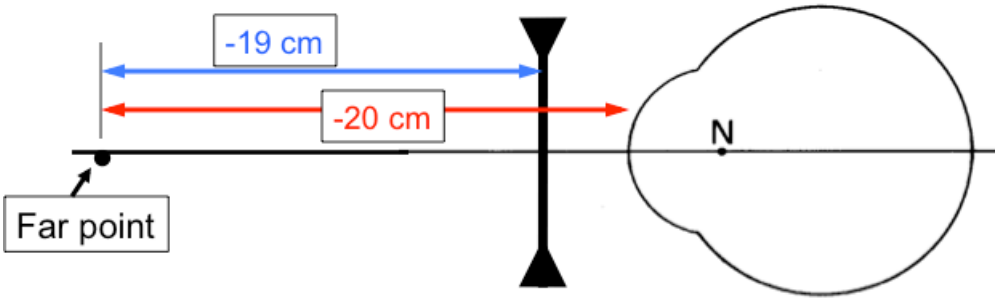
For this example,

SM = −19 cm / -20 cm
SM = 0.95

The size of the uncorrected retinal image (1.818 mm) was calculated above. The corrected image size can be found by multiplying the uncorrected image size by the SM.

$$SM = \frac{h'_c \text{ (corrected image)}}{h'_{un}\text{(uncorrected image)}}$$

$h'_c = SM\ (h'_{un})$
$h'_c = (0.95) \times (1.818 \text{ mm}) = 1.73 \text{ mm}$



$$SM = \frac{\text{distance between Spec. Plane \& Far point}}{\text{distance between Prin. Plane \& Far point}}$$

SM = -19 cm / -20 cm = 0.95

SM = h'(corrected) / h'(uncorrected)

h'(corrected) = (0.95)(1.818 mm) = 1.73 mm

Figure 4.23: *The spectacle magnification approach to calculating retinal image size*

EQUIVALENT POWER APPROACH

The corrected retinal image size can be determined by calculating RSM from the equivalent powers of the emmetropic eye and the ametropic eye-lens combination (see Figure 4.24). Then the corrected retinal image can be determined by multiplying the size of the image in the emmetropic eye by the RSM. The following relationship can be used to determine RSM:

$$RSM = \frac{F_{emm} \text{ (i.e. power of the emmetropic eye)}}{F_e + F_l - dF_eF_l \text{ (i.e.power of the eye+lens)}}$$

Note. To use this relationship you must know the effective power of the correcting lens -- not just the ocular refraction.

Effective correcting lens power (1cm vertex distance),

$F_l = 1 / -0.19m$

$F_l = -5.26D$

(Remember that the focal length of the correcting lens must be equal to the distance between the spectacle plane and the eye's far point)

By definition, the refracting power of an axial ametropia is

$F_e = +60.00$ D

Relative Spectacle Magnification,

$$\text{RSM} = \frac{+60.0\text{ D}}{60.0\text{ D} - 5.26\text{ D} - 0.01(60.0\text{ D})(-5.26\text{ D})}$$

$$\text{RSM} = \frac{+60.0\text{ D}}{+57.898\text{ D}}$$

Retinal Image Size,

$h'_{\text{corrected eye}} = \text{RSM}\ (h'_{\text{emmetropic eye}})$
$h'_c = (1.036) \times (1.67\text{ mm})$
$h'_c = 1.73\text{ mm}$

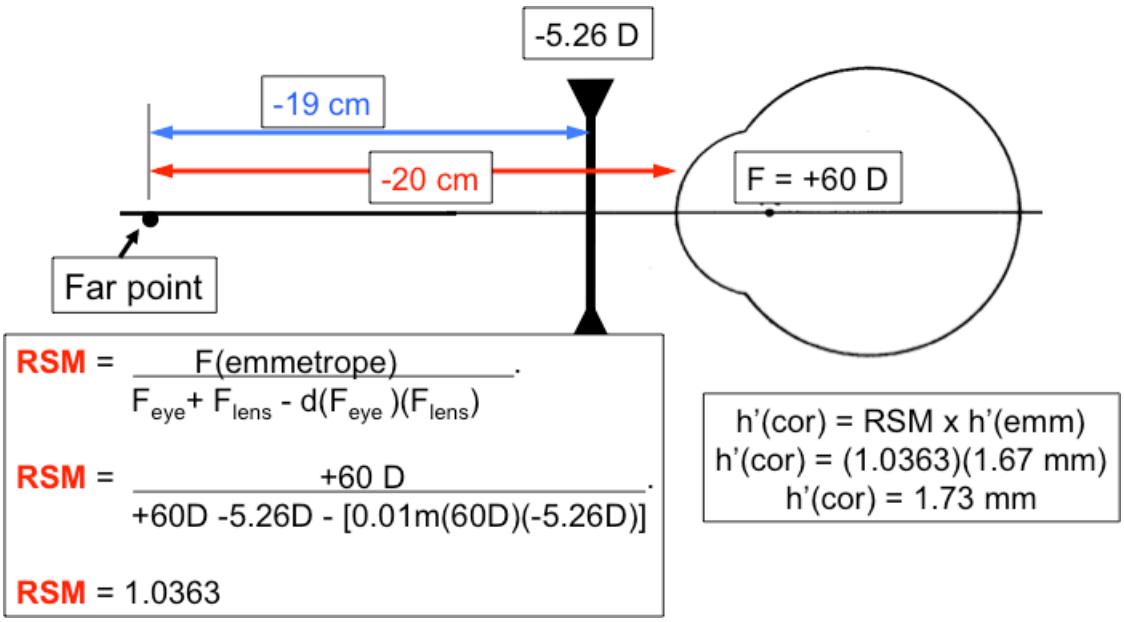


Figure 4.24: *Calculation of retinal image size using the equivalent power approach*