CHAPTER 18

BASIC PRINCIPLES OF CONTACT LENS OPTICS
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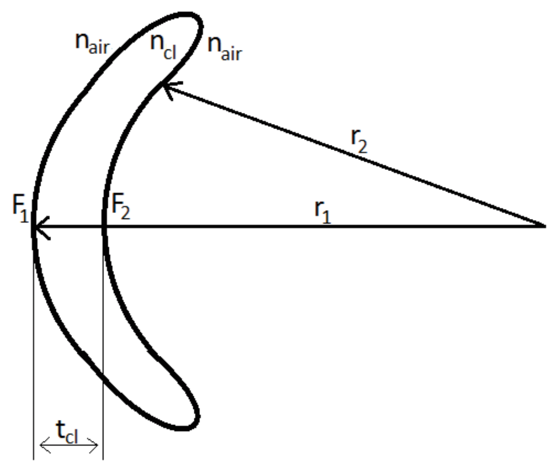
A few basic principles of contact lens optics will be reviewed in this chapter, the aim is to provide a better understanding and practical application of contact lens optics. Throughout the chapter a few assumptions are made and kept constant. This includes the assumption that the refractive index (n) of air is 1.0, the refractive index of a contact lens is 1.490 and the refractive index of tears are standardised to that used in Keratometers - 1.3375. The vertex distance used is 14 mm [487], and Finally, general derivations for equations are not covered in this chapter.

POWER OF A CONTACT LENS AND TEAR FILM

In lens optics, there are generally two systems used, the thin lens system and the thick lens system. The thin lens system is more often used and easier, but less accurate than the thick lens system. Using the thin lens system, the power of a contact lens in air (F_{cl}) can be determined by adding the power of the front surface (F_1) and the power of the back surface (F_2) of the lens.

$$F_{cl} = F_1 + F_2$$



The power of each surface is determined by using the principles of refraction. To determine the power of a refractive surface, you divide the difference between the refractive indices (n) by the radius of curvature (r) of the lens giving you the power of that surface [488]:

$$F_2 = \frac{n_{air} - n_{cl}}{r_2} \qquad F_2 = \frac{n_{air} - n_{cl}}{r_2}$$

These formulae do not account for the thickness of the lens, which could provide a significant error in calculations. By making use of the thick lens system, such errors can be avoided. The equivalent power of a thick lens, as first explained by Gullstrand, can be determined by using the following formula [140, 489]:

$$F_T = F_1 + F_2 - \frac{t}{n_{cl}} \times F_1 F_2$$

Once the contact lens is placed onto the eye, another refractive surface is created, known as the tear film, which is formed between the contact lens and the cornea. The front surface of the tear lens adheres to the back surface of the contact lens. It therefore has the same radius of curvature as the back surface of the contact lens. The back surface of the tear lens adheres to the front surface of the cornea, and therefore has the same radius as the front surface of the cornea. This is illustrated below:

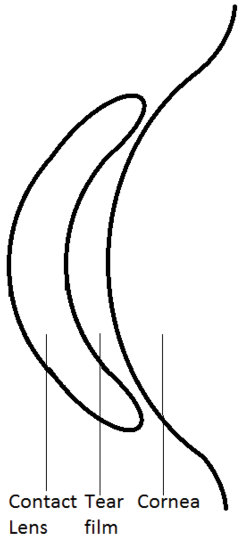


Figure 115: Illustration of a contact lens on the cornea

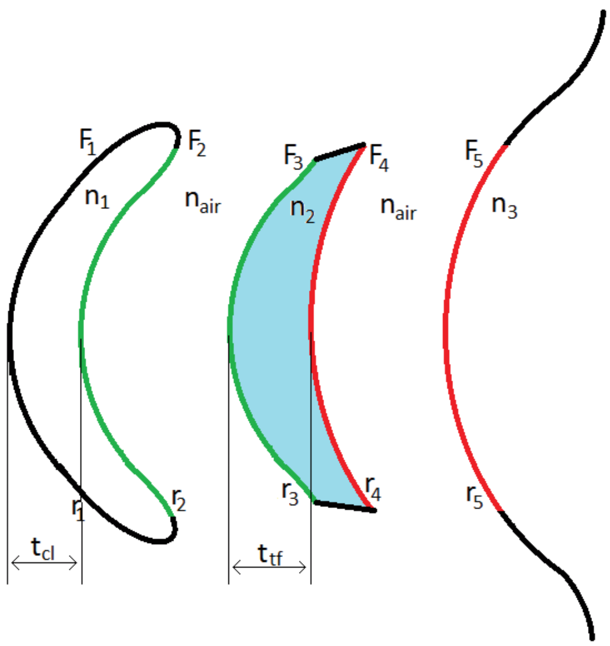


Figure 116: Exploded illustration of Figure 115

Figure 116 shows the contact lens, tear film and the cornea. Labels are as follow: F_1 & F_2 are the powers of the front surface and back surface of the contact lens respectively. F_3 & F_4 are the powers of the front surface and back surface of the tear film respectively. F_5 refers to the power of the front surface of the cornea. r_1 and r_2 are the radii of curvature for the front surface and back surface of the contact lens respectively. r_3 and r_4 are the radii of curvature for the front surface and back surface of the tear film respectively. r_5 refers to the radius off curvature for the cornea. n_1 is the refractive index of the contact lens. n_2 is the refractive index of the tear film. n_3 is the refractive index of the cornea. n_{air} is the refractive index of the surfaces inserted in the exploded diagram, these surfaces are inserted as air and has a refractive index of 1. t_{cl} refers to the thickness of the contact lens and t_{tf} refers to the thickness of the tear film.

It is important to note:

$r_2 = r_3$
$r_4 = r_5$

However:

$F_2 \neq F_3$
$F_4 \neq F_5$

The power of the entire system can be determined by adding the power of each refractive surface in the system.

From the diagram it can be observed that the isolated power of the contact lens and tear lens can be determined.

The following figures (Figures 117–119) illustrate how the fit of a contact lens affects the power of the tear layer:

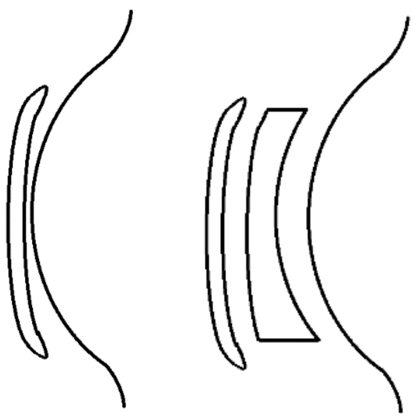


Figure 117: Flat fitting lens

Figure 117 illustrates a flat fitting contact lens. The right illustration shows the shape of the tear film, which can be compared with a negative powered lens. A positive over refraction can be expected as the tear film acts as a negative powered lens.

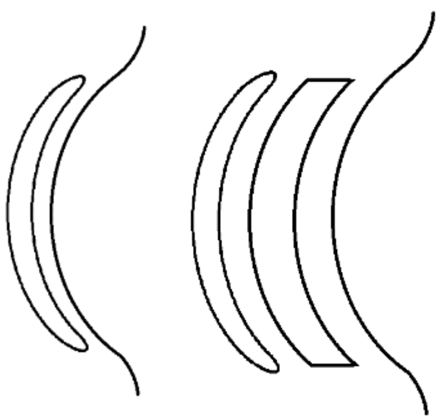


Figure 118: Alignment fit

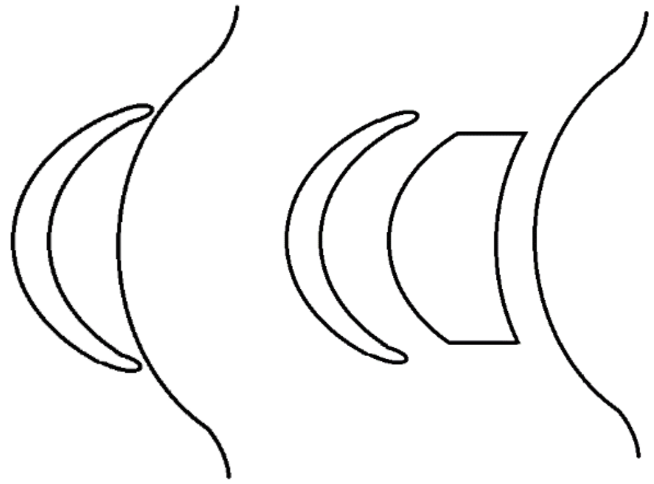
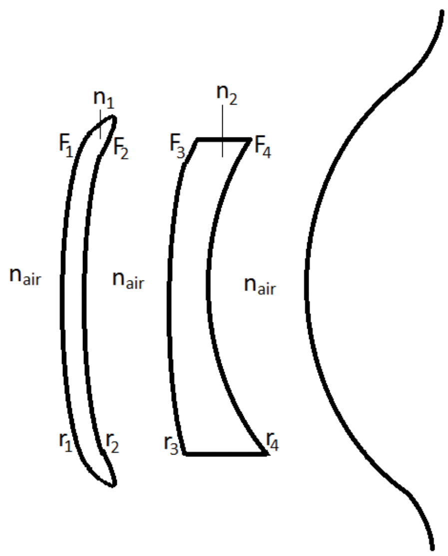


Figure 119: Steep fitting lens

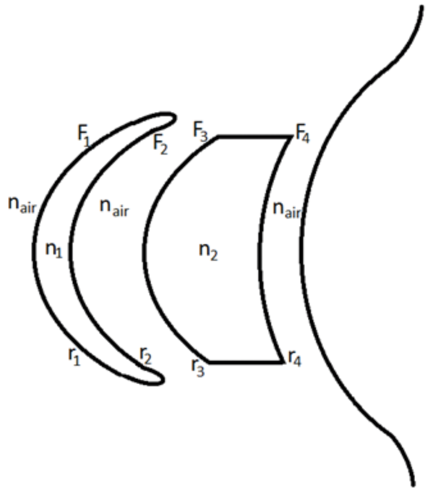
Figure 119 illustrates a steep fitting lens, showing the shape of the tear film, which can be compared with a positive powered lens. A negative over refraction can be expected as the tear film acts as a positive powered lens. For example, a contact lens of power -10.00D in air is fitted 1 mm flatter than the corneal curvature. The cornea is spherical and has a radius of 8 mm. Calculate the power of the tear lens:



$$F_{cl} = -10.00D$$
$$r_3 = r_2 = (8mm + 1mm) = 9mm$$
$$r_4 = 8mm$$
$$F_{tf} = ?$$

$$\begin{aligned} F_{tf} &= F_3 + F_4 \\ &= \frac{n_{tf} - n_{air}}{r_3} + \frac{n_{air} - n_{tl}}{r_4} \\ &= \frac{1.3375 - 1}{0.009} + \frac{1 - 1.3375}{0.008} \\ &= +37.50\ D + (-42.1875\ D) \\ &= -4.6875\ D \end{aligned}$$

Fitting the lens 1 mm steeper than the cornea, it can be shown that the tear film has a positive power:



$$F_{cl} = -10.00\ D$$
$$r_3 = r_2 = (8mm - 1mm) = 7mm$$
$$r_4 = 8mm$$
$$F_{tf} = ?$$

$$\begin{aligned} F_{tf} &= F_3 + F_4 \\ &= \frac{n_{tf} - n_{air}}{r_3} + \frac{n_{air} - n_{tl}}{r_4} \\ &= \frac{1.3375 - 1}{0.007} + \frac{1 - 1.3375}{0.008} \\ &= +48.214\ D + (-42.1875\ D) \\ &= +6.0265D \end{aligned}$$

COMPENSATION FOR VERTEX DISTANCE

It is well known that spectacle correction above 4.00D, should be converted into contact lens prescription to compensate for vertex distance. As parallel light rays enter the eye vergence is zero. If a surface with refractive power is introduced at a certain distance before the eye, vergence is no longer zero.

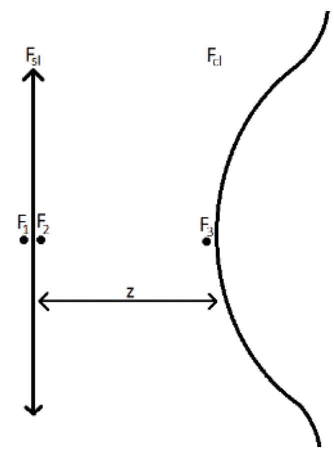


Figure 120: Vertex correction

By assuming that spectacles are thin lenses, the vergence can be determined just before light enters the eye using equations to determine vergence across a homogenous gap.

$F_{cl} = \frac{1}{\frac{1}{F_2} - \frac{z}{n}}$ or $F_{cl} = \frac{F_{sl}}{1 - zF_{sl}}$

These formulae can be used to determine the power of the needed contact lens, from the spectacle prescription and is known as the effectivity equation [1]. If a patient has a distance spectacle refraction of -8.00D and wishes to be fitted with contact lenses, what would the corrected power at the corneal plane be for a vertex distance of 14 mm? (Figure 120).

$F_1 = 0$

$F_{sl} = F_1 + F_2$

$F_{sl} = 0 + F_2$

$F_{sl} = -8.00$ D

$F_3 = F_{cl} = \frac{1}{\frac{1}{F_2} - \frac{z}{n}}$

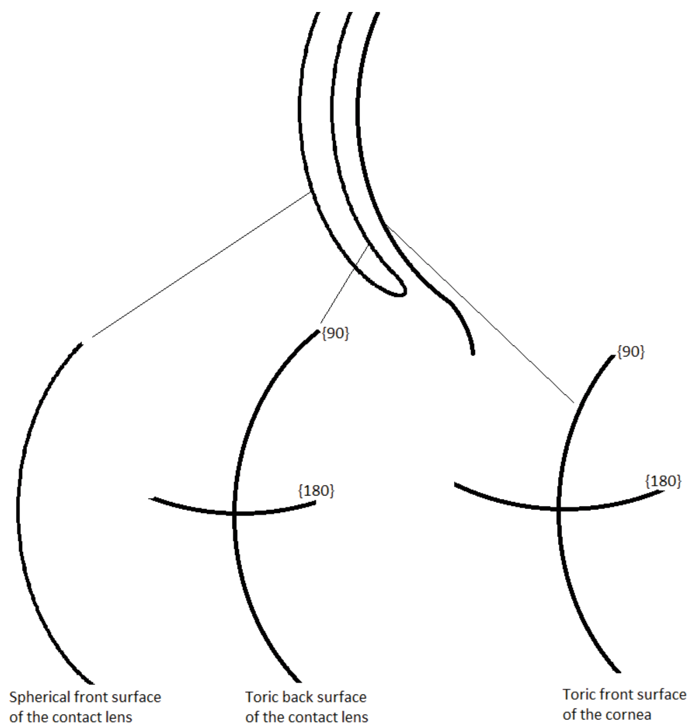
$F_{cl} = \frac{1}{\frac{1}{-8.00} - \frac{0.014}{1}}$

$F_{cl} = -7.19\ D$

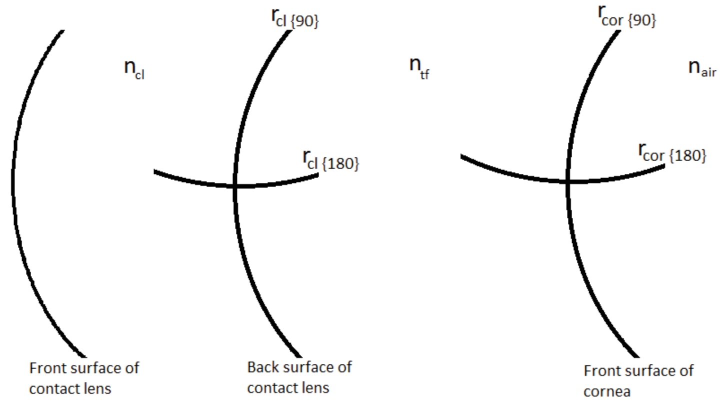
The above calculations apply to spherical lenses only. For cylindrical lenses, the power should first be converted to principal meridian format after which the calculation should be applied to each meridian independently

RESIDUAL ASTIGMATISM

By placing a spherical RGP on the eye the corneal astigmatism should theoretically be neutralised. If a patient has a prescription of Plano/-10.00 x 180 and K-readings are 41.00/51.00, it is easy to see the corneal astigmatism is equal to the refractive astigmatism.

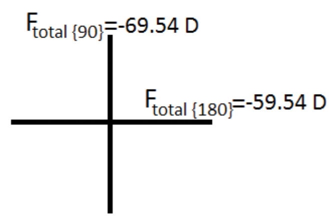


By determining the power along the two principal meridians:



$$F_{total\{180\}} = F_{cl\{180\}} + F_{cornea\{180\}}$$
$$= \frac{n_{tf} - n_{cl}}{r_{cl\{180\}}} + \frac{n_{air} - n_{tf}}{r_{cor\{180\}}}$$
$$= \frac{1.336 - 1.49}{0.00823} + \frac{1 - 1.336}{0.00823}$$
$$= (-18.71) + (-40.83)$$
$$= -59.54D$$

$$F_{total\{90\}} = F_{cl\{90\}} + F_{cornea\{90\}}$$
$$= \frac{n_{tf} - n_{cl}}{r_{cl\{90\}}} + \frac{n_{air} - n_{tf}}{r_{cor\{90\}}}$$
$$= \frac{1.336 - 1.49}{0.00823} + \frac{1 - 1.336}{0.00661}$$
$$= (-18.71) + (-50.83)$$
$$= -69.54D$$

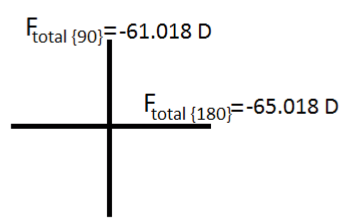


From the power cross, one can see -10.00D x 90 was created, and therefore the entire corneal cylindrical component (astigmatism) is neutralised.

Using the following example: Prescription of Plano /-4.00 x 90 and K- readings 46.00/42.00. It is evident that corneal astigmatism is equal to the refractive astigmatism.

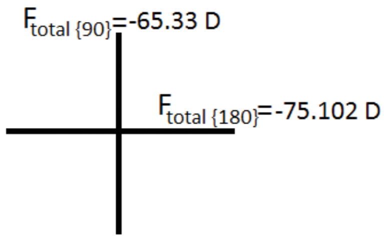
$$F_{total\{180\}} = F_{cl\{180\}} + F_{cornea\{180\}}$$
$$= \frac{n_{tf} - n_{cl}}{r_{cl\{180\}}} + \frac{n_{air} - n_{tf}}{r_{cor\{180\}}}$$
$$= \frac{1.336 - 1.49}{0.0066} + \frac{1 - 1.336}{0.00649}$$
$$= (-23.33) + (-51.772)$$
$$= -75.102D$$

$$F_{total\{90\}} = F_{cl\{90\}} + F_{cornea\{90\}}$$
$$= \frac{n_{tf} - n_{cl}}{r_{cl\{90\}}} + \frac{n_{air} - n_{tf}}{r_{cor\{90\}}}$$
$$= \frac{1.336 - 1.49}{0.0075} + \frac{1 - 1.336}{0.0075}$$
$$= (-20.53) + (-44.80)$$
$$= -65.33D$$



The difference between these two powers proves that the amount of cylinder created by the tear film neutralises the corneal astigmatism. Theoretically this is correct, but the fit of a spherical RGP might not be optimal and a back surface toric design may be a more effective solution. However, this may not neutralise the corneal astigmatism, as illustrated in the next example:

Patient prescription is Plano/-7.00 x 90 and K readings 52.00/45.00. Fitting a back surface toric design we find the following:



The difference between these two values show that we created -9.772D x 180. However, we only need -7.00D x 90. Therefore, -2.772D x 180 should be corrected by adding it to the front surface of the contact lens, creating a bi-toric lens.

Tear lens changes with Base Curve Changes

- For every 0.05 mm that the Base curve is steeper than K, add -0.25D to the lens power
- For every 0.05 mm that the Base curve is flatter than K, add +0.25D to the lens power
- Therefore, for every 0.1 mm change in base curve, causes a 0.50D of change in lens power

Vertex Formula

- $F_{cl} = \dfrac{F_{sl}}{1 - zF_{sl}}$

Residual Astigmatism

- Total Astigmatism = Corneal astigmatism + Residual astigmatism