CONTACT LENS OPTICS

Introduction

In what follows we'll talk briefly about the **optical** aspects of contact lens fitting, ignoring most of the mechanical, physiological, psychological, and economic aspects of the art.

Contact Lens Materials

In the beginning was PMMA, the material of the hard corneal contact lens which came out in 1957. The material didn't transmit oxygen and was really tough to fit. Until the early 70's, PMMA was the **only** contact lens material.

At that time the various "soft" or "hydrogel" materials started coming out. By 1980 these latter materials dominated the market--to the extent that some young doctors forgot how to fit hard lenses. The newer materials "breathed", were much more comfortable, and were much easier to fit but they wore out, got coated, were indicted in a number of long term corneal problems, and the optics was not as good as rigid lenses.

In the late 70's various RGP materials came out. These materials are hard, but not quite as rigid as PMMA. They transmit oxygen and have better optics than hydrogel materials. They are much easier to fit than PMMA lenses but share many of the advantages and fitting characterists. The comfort of RGP lenses with modern designs is greater than PMMA but much poorer than hydrogel.

The Optics of Rigid Contact Lenses

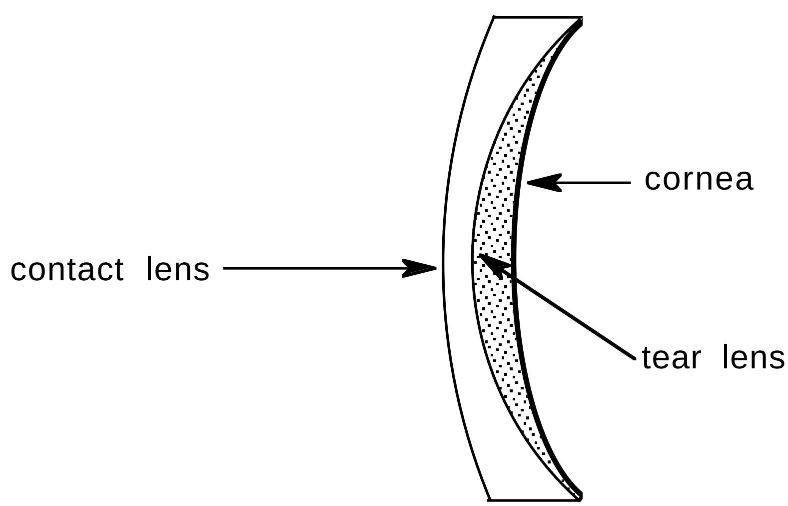
General Considerations

Rigid lenses are relatively small, typically about 9.0mm diameter. Even RGP lenses must move a bit to transfer O_2 through tears to the cornea. Movement or "lag" usually is around 2-3mm. The discomfort of the lenses is primarily due to lid feel, especially the upper lid going over the lens. As a consequence, patients often stop blinking normally, and 3-9 staining results from drying of the horizontal cornea. Nowadays, lenses are often fit so they tuck under and move with the upper lid, thus minimizing lid feel. The lenses are paper thin, <0.1mm, and somewhat brittle and scratchable.

The Tear Lens, Sarver's Equation and All That

To account for the effect of a rigid contact lens we must take into account the power of the contact lens **and** the power of the tear lens formed between the back of the lens and the cornea. Let R_X be the power of the contact lens-tear lens system. If the power of the contact lens in air is F_C and the power of the tear lens in air is F_T, then

$$F_C + F_T = R_X$$



Generally, the value of R_X is the back vertex power of the spectacle lens, vertexed down to compensate for the distance t to the cornea,

$$R_X = F_V'/[1-(t/n)F_V'].$$

In the usual clinical situation, one knows the keratometer reading of the patient, K, and the radius of the back surface of the contact lens, r_2. The power of the tear lens is just

$$F_T = (n-1)/r_2 + (1-n)/r_C$$

where r_C is the radius of curvature of the cornea, and n the index of the tears. But the index of tears is very close to the index of calibration of the keratometer, 1.3375, so

$$K \cong (n-1)/r_C$$

$$K_2 \cong (n-1)/r_2$$

where $K_2 = 0.3375/r_2$ is the keratometer reading taken from the back surface of the contact lens. Thus we may write for the power of the tear lens

$$F_T = K_2 - K.$$

Hence, finally,

$$R_X = F_C + K_2 - K.$$

This is Sarver's equation. Let's add one further complication to Sarver's equation. Suppose the contact lens power is **not** the appropriately vertexed spectacle lens. Then when the patient is refracted, there will be an over-refraction F_{OR} which we'll measure in the contact lens plane. The over-refraction is that lens power which must be added algebraically to the contact lens power to completely correct the patient's ametropia. If F_{TL} is the power of the trial lens,

$$F_C = F_{OR} + F_{TL}$$

Hence

$$R_X = F_{TL} + F_{OR} + K_2 - K$$

and

$$F_{OR} = -F_{TL} - K_2 + K + R_X$$

A bit of terminology: an "on K fit" is one in which the back surface of the contact lens parallels the flattest meridian of the corneal surface. In such a case $K_2 = K$ and $F_T = K_2 - K = 0$, hence the tear lens is plano. This is about the most common kind of rigid lens fit.

Example: A lens is fit 0.50 steeper than K on an eight diopter myope. What power contact lens should be used? Assume the spectacle lens has its back vertex 15mm from the cornea.

Solution: For a lens fit 0.5 steeper than K, $K_2=K+0.5$ or $K_2-K=0.5$D. Vertexing down the spectacle prescription,

$$R_X=-8D/[1-(0.015m)(-8D)]=-7.14D$$

From Sarver's equation, the contact lens power is

$$F_C=R_X-(K_2-K)=-7.14D-(0.5D)=-7.64D\cong-7.75D.$$

Example: A patient's keratometer readings are 42.50@020/43.75@110 and his Rx is -1.00-1.25x020. When a contact lens with K_2=43.00 and power -2.50DS is placed on the cornea, what will the over-refraction be?

Solution: From Sarver's equation, $F_{OR}=R_X-F_{TL}-K_2+K$. Applying it meridian by meridian,

$$F_{OR,20}=(-1.00)-(-2.50)-(43.00)+(42.50)=+1.00$$
$$F_{OR,110}=(-2.50)-(-2.50)-(43.00)+(43.75)=+1.00$$

So the result is +1.00DS, a spherical rigid contact lens.

Example: A patient with keratometer readings 44.50@030/46.00@120 is to be fit "on K" with a rigid contact lens. What is the radius of the base curve of the contact lens?

Solution: The base curve used is K_2=44.50 which corresponds to a radius of curvature of r_2=0.3375/44.50=0.00758m=7.58mm.

Example: A patient is fit with a -5.00DS trial lens. The over-refraction is +1.25DS. What lens should be prescribed?

Solution: The contact lens power is the sum of the trial lens power plus the over refraction or

$$F_C=F_{TL}+F_{OR}=-5.00D+1.25D=-3.75D.$$

Note that we need to know nothing about the patient's refraction or K's or the base curve of the contact lens to do the calculation. We can use a -3.75 lens with the same base curve as the trial lens, be that base curve spherical or toric, so long as the trial lens seems to perform satisfactorily on the eye, e.g. move, cover the pupil, seem comfortable.

Example: A patient sees well with a rigid lens of power -4.75DS, but experiences discomfort at the end of the day. The doctor discovers that the lens is moving very little and decides to refit with a lens of 0.50D flatter base curve. What will the power of the new lens be?

Solution: From the Sarver equation, $R_X=F_C+K_2-K$. Since R_X and K remain constant and $0=\Delta F_C+\Delta K_2$ so since $\Delta K_2=-0.50D$, $\Delta F_C=+0.50D$ and the new contact lens power would be
-4.75D+0.50D=-4.25D. This could also be reasoned out by noting that the flatter back surface curve diminishes the tear lens power by 0.50D so 0.50D less minus power is required of the contact lens.

Example: A contact lens patient's initial spectacle prescription was -3.00DS. After wearing the lenses two months the patient's cornea steepens one diopter and the new spectacle prescriptions is -4.00DS. What change is necessary in the contact lens for the patient to see well?

Solution: In this problem ΔK=+1.00D and ΔR_X=-1.00D. Since the same contact lens is in place, ΔK_2=0 and the change in contact lens Rx is given by the Sarver equation as

$$-(\Delta K_2-\Delta K)\Delta R_X=\Delta F_C=-(0-1)+(-1)=0.$$

Surprise!! the spectacle prescription doesn't change at all! Another way of looking at this is that the back of the tear lens cancels out any contribution of the cornea to the refraction of the eye, so corneal changes aren't apparent through rigid contact lenses.

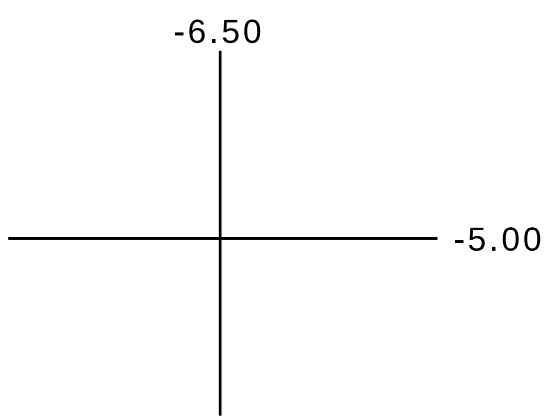
The Sarver equation is versatile enough to apply even to toric contact lens fits, although the calculations become very tedious. Consider the following example.

Example: A patient presents these findings:

Rx: -5.00/-1.50x180, vertex 13mm
K: 45.00@090/43.00@180

Find front and back toric lenses which will fully correct the patient.

Solution: First find the prescription in the spectacle plane, R_X. In the spectacle plane, the power cross is

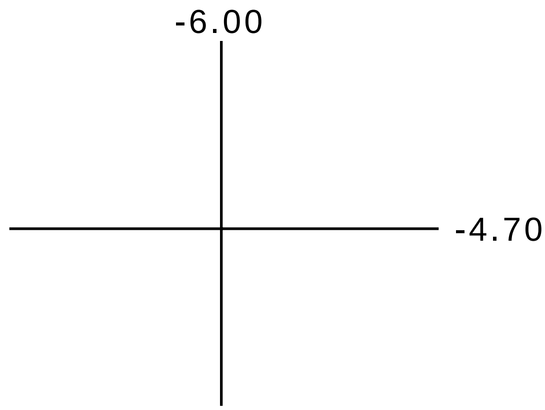


Vertexing down gives

$$R_{X180}=-5.00D/[1-(0.013m)(-5.00D)]=-4.70D$$

$$R_{X90}=-6.50D/[1-(0.013m)(-6.50D)]=-6.00D$$

The power cross for this is

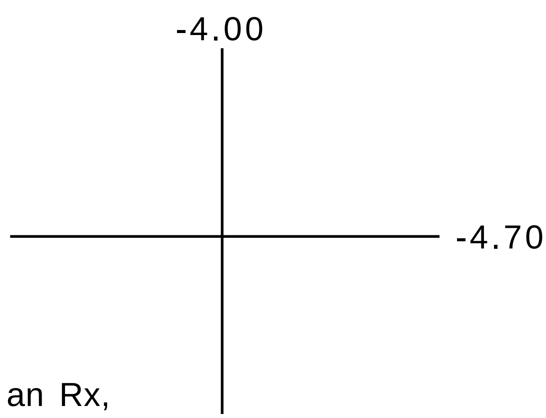


Try a front surface toric fit on "K". In this case the back surface of the lens is chosen parallel to the flattest corneal meridian so K_2 = 43.00. From the keratometer readings, K_{90}=45.00 and K_{180}=43.00 so applying Sarver's equation, $F_C=R_X-K_2+K$,

$$F_{C180}=-4.70D-43.00D+43.00D=-4.70D,$$

$$F_{C90}=-6.00D-43.00D+45.00D=-4.00D.$$

From this, the power cross of the contact lens is



or written as an Rx,

$$F_C=-4.00-0.70x090\cong-4.00-0.75x090.$$

Now one is confronted with the problem of getting a -0.75x090 cylinder on the contact lens and stabilizing it. Various tactics exist, prism ballast being the usual. Alternatively, just forget it and let patient suffer through with equivalent sphere of power -4.50DS.

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An alternative kind of fit would be a back surface toric fit with the flattest back surface curve on K. Presumably the lens is stabilized by the back surface cylinder so that principal meridians of the lens and cornea stay alligned. In this case,

$$R_{X90} = -6.00\text{D}$$
$$R_{X180} = -4.70\text{D}$$
$$K_{2,90} = ?$$
$$K_{2,180} = 43.00\text{D}$$
$$K_{90} = 45.00\text{D}$$
$$K_{180} = 43.00\text{D}$$

In this case note that the contact lens power is given by the sum of its front and back powers,

$$F_C=F_1+F_2$$

the back surface power being given by the familiar equation

$$F_2=(1-1.49)/r_2=-0.49/r_2,$$

where 1.49 is the index of the rigid lens material. From Sarver's equation,

$$R_X=F_1+F_2+K_2-K= F_1-0.49/r_2+0.3375/r_2-K \text{ or}$$

$$R_X=F_1-0.1525/r_2-K.$$

We know that $F_{1,180}=F_{1,90}=F_1$ since we specified that the contact lens have spherical front surface curve. We may solve for r_2 and F_1 between the 180° and 90° meridian equations. Writing Sarver's equation for these meridians,

$$F_{V',90}=-6.00D=F_1-0.1525/r_{2,90}-45.00D,$$
$$F_{V',180}=-4.70D=F_1-0.1525/r_{2,180}-43.00D.$$

But the fit is on K so $r_{2,180}$ =0.3375/43.00=0.007849m, hence

$$F_1=-4.70D+0.1525/r_2+43.00D$$
$$=-4.70+0.1525/(0.007849)+43.00=+57.73D.$$

Solving for $r_{2,90}$,

$$0.1525/r_{2,90}=F_1+6.00D-45.00D=57.l73+6.00-45.00=18.73D$$

hence

$$r_{2,90}=0.1525/18.73=8.14mm.$$

Now solve for the posterior contact lens surface powers.

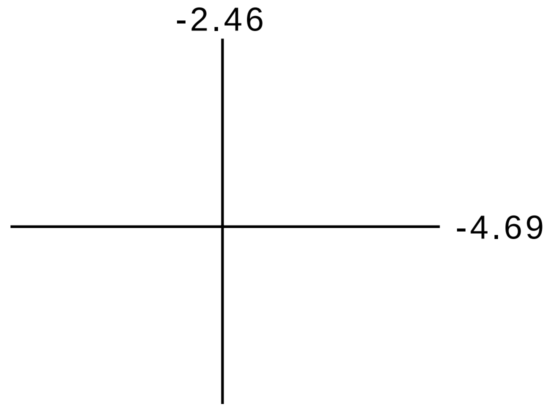
$$F_{2,180}=(1-1.49)/(0.00785m)=-62.42D,$$

$$F_{2,90}=(1-1.49)/(0.00814m)=-60.19D.$$

Add front and back surface powers to get the total contact lens prescription.

$$F_{180}=F_1+F_{2,180}=57.73D-62.42D=-4.69D$$
$$F_{90}=F_1+F_{2,90}=57.73D-60.19D=-2.46D$$

On a power cross this becomes



with the final contact lens prescription

$$F_C = -2.46 - 2.23\text{x}090 \cong -2.50 - 2.25\text{x}090.$$

Remember that the spectacle Rx was -5.00-1.50x180. The contact lens Rx and contact lens cylinder is quite different from spectacle Rx and cylinder in this case.

The above sorts of calculations work out fine on paper, but in practice there are a couple of factors which may make things work out wrong. They are:

☞ Experimental error. Measurement of K's and refraction carry with them errors on the order of +0.25D, maybe more.

☞ Lens flexing. A thin lens, and most are nowadays, may bend when placed on the cornea, thus leaving a spherical lens with spherical power, but a toric back curve. Check for this by measuring the K's over the lens while it rests on the eye. Lens flexing often makes the performance of rigid gas permeable lenses quite unpredictable. In particular, it is almost impossible to know the exact amount of cylinder which will be masked without using a trial lens and even then the lens delivered for the patient may behave differently than expected.

Optics of Soft Lenses

Soft lenses cling to the eye like a wet leaf. Unlike hard lenses, they move very little, typically 0.5mm or less. The tear film has zero power and calculations are, therefore, extremely simple. The only complication is if a lens is fit too far off K (whatever that means). In that case he lens may wrinkle up and have lousy optics.

Practical Fitting of Contact Lenses

Most contact lens practitioners now fit rigid lenses on the basis of a trial fit. A lens close to the parameters of the lens the practitioner guesses will work is placed on the cornea. The Dr. examines movement, optical quality, and refraction. If the lens is satisfactory he uses his over-refraction to arrive at the exact Rx he wants, and then orders it. Ideally he monitors the lens' performance for several weeks, making changes if necessary. When all seems well, he dismisses the patient.

Soft spherical contact lens fitting is sufficiently routine nowadays that one can skip the trial fitting most of the time. Instead guess at the best parameters, order the lenses (they're cheap) and let the patient wear them a while. If all is well, dismiss. If not, add the lenses to the trial set and try a different approach.

Prescription for cylinder presents a number of practical problems. Toric lenses, hard **and** soft, are very expensive, often available with only a limited selection of parameters, and risky to fit since they have either no warranties or limited warranties. At best they use up a lot of chair time. As a practical matter small residual astigmatism is tolerated, e.g. -1.00DC with the rule or -0.50 against the rule, especially if acuities are good in the dominant eye.

Verification of Contact Lenses

Soft contact lenses are easy to verify since you can't really verify anything. Check the parameters on the bottle against your own specifications. If they're O.K., the patient is comfortable and sees well, and if the lens performs all right, everything is probably fine.

With rigid contact lenses many parameters can be measured. They are, with the appropriate instrumentation, as follows:

- ☞ Edge quality. Check with a loupe, microscope (including biomicroscope), or shadowscope.
- ☞ Lens power. Check with a lensometer.
- ☞ Lens base curve. Check with a keratometer or radiuscope.
- ☞ Lens and optical zone diameter. Check with a loupe.

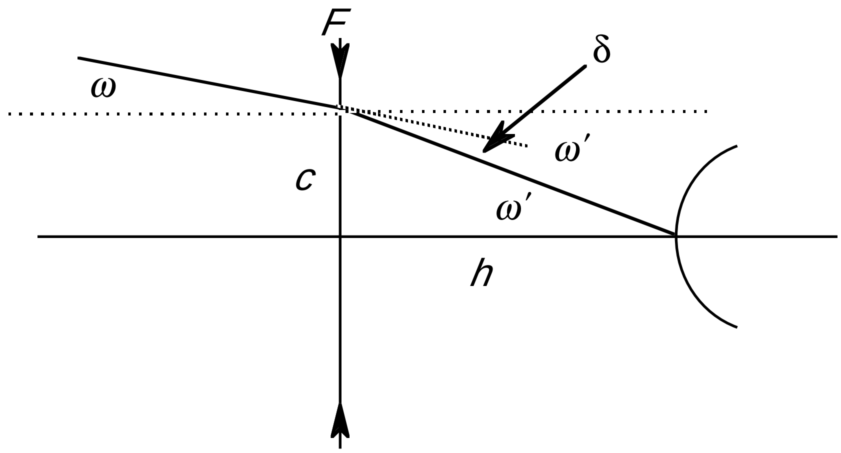
A radiuscope is a device in which a real image is used as the object for the back surface of the contact lens behaving like a mirror. The observer finds the two positions where this object and its image formed by the mirror coincide. These are at the mirror itself (erect image) and at the center of curvature (inverted image). The distance between these points is the radius of curvature.

Inexpensive reticles--loupes with a millimeter scale for measurement--are available from any contact lens supplier.

Image Magnification with Contact Lenses

The image size with spectacles and contact lenses will be different, enough so to affect visual acuity with very high corrections.

The diagram shows a ray from a remote object incident on the spectacle lens at height c which then hits the center of the cornea.



From Prentice's rule, the deviation δ of the rays is $\delta=Fc$. But $\delta=\omega'-\omega$ so $\omega'-\omega=cF$. The angular magnification $M=\omega'/\omega$. This is the ratio of the retinal image size with spectacles to that with contact lenses. Using this to eliminate ω, $\omega'-\omega'/M=Fc$. But from the diagram, $\omega'=c/h$, so $(-1/M)(c/h)=Fc$ and eliminating the c's and solving gives $M=1/(1-hF)$, a familiar result. Since the contact lens power is $F_c=F_g/(1-hF_g)$, this may be written $M=F_c/F_g$. Thus the elegant result is that the relative magnification of the retinal image is given by

$$M = \frac{\text{image size with spectacles}}{\text{image size with contact lenses}} = F_c/F_g$$

Example: A patient has 20/25 visual acuity when wearing her best correction, -10.00DS spectacle lenses fit 12mm from her cornea. What will her acuity be when she wears her best correction in soft contact lenses? Assume glasses and contact lenses are thin lenses with perfect optics.

Solution: The contact lens power is F_{cl}=-10/[1-(0.012)(-10)]=-8.93 so that M=-8.93/(-10.000)=+0.893.

The ratio of the decimal acuities the glasses and contacts, V_g and V_{cl} is V_{cl}/V_g=1/M. Hence V_{cl}=(20/25)x1.12=20/22.

