### Contact Lenses

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### Contact Lens/Eye System

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Types of contact lens

The generic term “contact lens” is used for all visual aids which come into direct contact with the anterior ocular segment. A contact lens without dioptic power is called a contact shell.

Contact lenses are classified:
1. depending on their position on the eye into corneal (Fig. 118), corneoscleral and scleral (Fig. 119);
2. depending on their surface form into spherical, toric, bitoric, peripheral toric and aspheric;
3. depending on their surface form into mono-curve, bi-curve, tri-curve, multi-curve and aspheric;
4. depending on their form stability into hard and soft;
5. depending on their effect on the appearance of the eye into cosmetic contact lenses and iris contact lenses.

Surfaces

The surface of a contact lens or contact shell facing the object is called the front surface; the surface facing the eye is known as the back surface. Spherical front surfaces or back surfaces are called mono-curve surfaces. If a front or back surface features two zones with different coaxial radii of curvature, it is called a bi-curve surface. Multi-curve surfaces have more than three coaxial radii of curvature. A rotationally symmetric front or back surface whose radii of curvature change continuously
from the centre to the periphery is a rotationally symmetric aspherical surface.
Table 45 contains the symbols used in contact optics.

Zones  The area of a contact lens displaying the required dioptric power for the correction is called the optic zone. Peripheral zones are zones in the outer area of the front or back surface; they may be spherical, aspherical or conical.
An aspherical zone is a curved area of the surface which is neither spherical nor conical; this zone can, for example, be ellipsoidal, paraboloidal or hyperboloidal.
A transition zone is an area between two zones.

Form stability  The form stability serves as a criterion for distinguishing between hard and soft contact lenses. It is essentially determined by the form of the lens and the material of which it is made.
Hard contact lenses are lenses which in normal conditions retain their shape without support.
Soft contact lenses change their shape if they are not supported.
Hydrogel lenses are soft contact lenses which are produced using hydrophilic materials.

Identification  Specification of the type of contact lens and the vertex power is necessary for identification purposes. As direct contact with the front outer ocular segment is necessary, the best possible back surface of the contact lens must be selected for the eye to be corrected. Specification of other dimensions relevant to fitting is therefore also required. These include the back central optic radius, the form of the peripheral zones and the total diameter of the contact lens.

Special contact lenses  Special contact lenses differ markedly in their construction or in their function from regular types of contact lens and are divided into two groups:
1. Special contact lenses with a profile corresponding to that of regular contact lenses; these include coloured and tinted contact lenses, cosmetic contact lenses, pinhole contact lenses and contact lenses with ventilations or “channels”.
2. Special contact lenses with profiles which clearly deviate
from standard profiles; these include contact lenses with stabilizing elements, lenticular contact lenses and underwater (diving) contact lenses.

**Contact lenses with a spherical power**

**Types of design**  
Contact lenses with a spherical power may be corneal, corneo-scleral or scleral contact lenses. They have an optic zone with a spherical dioptic power and a peripheral area with one or several spherical, aspherical or conical zones. Contact lenses with a spherical power may have different back surface profiles. The form of the peripheral zone or the number of the peripheral zones serves to identify the contact lens.

**Surfaces**  
If the back surface is mono-curve, the contact lens itself is described as mono-curve. In bi-curve contact lenses a spherical peripheral zone is also present (Fig. 120). Correspondingly, contact lenses with two or more spherical peripheral zones are called tri-curve or multi-curve contact lenses (Fig. 121). If the peripheral zone is aspherical, this is a contact lens with an aspherical marginal zone (Fig. 122).

The peripheral toric contact lens – a special form of contact lens with a spherical power – has a spherical optic zone and a peripheral toroidal area on the front or back surface. This group includes the front surface peripheral toroidal and the back surface peripheral toroidal contact lenses. Due to the peripheral toroidal area the optic zone exhibits an oval form; the smaller diameter of the oval coincides with the direction of the flattest part of the peripheral area (Fig. 123).

---

**Fig. 120**  
Bi-curve corneal contact lens  
(see Table 45 for symbols)
Contact lenses with an aspherical back surface occupy a special position amongst contact lenses with a spherical power. Contact lenses of this type have an optic zone which is not spherical. The back optic radius changes continuously from the vertex to the periphery of the contact lens. In the area around the vertex the rotationally symmetrical aspherical surface can be approximated by a spherical surface (vertex sphere) with a certain radius (vertex radius) (Fig. 124). In some lens types the profile of the aspherical back surface corresponds to a conical section (Fig. 125), i.e. to an ellipse, a parabola or a hyperbola. Either the shape factor $\rho$ or the numeric eccentricity $e$ (Fig. 126) are used to describe the conical section. Their relation is

$$(113) \quad \rho = 1 - e^2.$$  

Table 146 shows the values for the individual conic sections. Most contact lenses with an aspherical back surface have an elliptic profile which is described by an eccentricity of 0.4 to 0.6. The change in the dioptric power of the contact lens caused by the aspherical back surface does not have any practical significance in this range. Apart from conic back surface profiles, others are also used which can only be represented by higher-order functions.
Identification

A contact lens with a spherical power and a spherical optic zone is identified on its packing in the following way:

- **DIN marking**
- Manufacturer's symbol
- Back central optic radius \( r_0 \) in mm
- Vertex power \( F'_v \) in D
- Total diameter \( \varnothing_T \) in mm

It is not customary to specify the back peripheral radii, the form of the peripheral zone, the diameter of the optic zone or the widths of the peripheral zones. Specification of the type of contact lens involved, e.g. by the manufacturer's description, is sufficient.

For the identification of a contact lens with a spherical power and an aspherical back surface it is also necessary to specify the shape factor \( \rho \) or the numeric eccentricity \( e \) in a specific peripheral zone (usually 30° peripherally). The vertex radius corresponds to the back central optic radius.

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**Contact lenses with an astigmatic power**

**Types of design**

Contact lenses with an astigmatic power have at least one toroidal surface in the area of the optic zone and are therefore not rotationally symmetric. They are known as central toric contact lenses. The peripheral area may be spherical, aspherical or toroidal.
Surfaces  A distinction is made between front surface toric and back surface toric contact lenses depending on the position of the toroidal surface (Fig. 127). If the front surface is toroidal, the contact lens must then be provided with a stabilizing “element” in order to obtain the required cylinder axis of the astigmatic power of the contact lens. A centre of gravity displacement by means of a prism ballast and/or a truncation (Fig. 128) can result in axis stabilization. If the front surface and the back surface are toroidal, the contact lens is described as bi-toric (Fig. 129). The axis directions of the front surface torus and the back surface torus can be parallel, perpendicular or at an angle to each other. In the latter case the contact lens is described as oblique bi-toric.
Marking Two symbols defining one direction should be permanently applied to the front surface of the contact lens for a correlation of the back surface radii and the vertex power. This marking should run in the direction of the largest back surface radius. In hard toric contact lenses with an exclusively toroidal front surface the marking should be applied parallel to the truncation or 90° to the base position of the prismatic power of the prism ballast.

Identification A contact lens with an astigmatic power is identified on its packing in the following way:
- DIN marking
- Manufacturer's symbol
- Abbreviation of contact lens type
- Back central optic radius in mm
- Vertex powers in D
- Axis position (only in case of toroidal front surface)
- Total diameter $\varnothing_T$ in mm

Bifocal and multifocal contact lenses

Designations Contact lenses with two or three optic zones of different dioptric powers are known as bifocal or trifocal contact lenses. Contact lenses with more than three optic zones of different dioptric powers are known as multifocal contact lenses. Bifocal and more recently multifocal contact lenses are the most commonly used in practice.

Types of design Bifocal contact lenses are classified according to the arrangement of the two optic zones. A segment bifocal contact lens has two segment-shaped optic zones of different dioptric powers arranged one on top of the other (Fig. 130); the zones may be ground onto the surface or
they may be produced by fusing two separate parts made of materials with different refractive indices. The two optic zones may be arranged on the front or back surface. One of the two optic zones may also be positioned inside the other zone. Segment bifocal contact lenses must be provided with a stabilizing element (prism ballast or truncation) in order to ensure the correct position of the two optic zones.

A concentric bifocal contact lens exhibits two concentrically arranged optic zones of different dioptic powers (Fig. 131). The size of the two zones is dependent on the fitting principle applied. Concentric bifocal contact lenses are insensitive to rotation and do not therefore require a stabilizing element.

The contact lens with a progressive power is a special form of lens; the progressive power is generated by (usually rotationally symmetrical) aspherical surfaces on the front or back surface of the contact lens.
Fitting principle

Bifocal contact lenses can be fitted using the simultaneous (bivisual) or the alternating principle.

A simultaneous bifocal contact lens is designed in such a way that the two optic zones always lie simultaneously in front of the pupil. The two zones are usually arranged concentrically; their sizes must be selected in such a way that sufficiently large zone areas are positioned in front of the pupil at all times. In a contact lens of this type two retinal images of different sharpness are always produced of a viewed object (Fig. 132). The less sharp image must be suppressed by the visual centre of the brain in order to avoid any disturbance in vision.

An alternating bifocal contact lens is designed in such a way that by appropriate positioning of the eye, only the optic zone intended for the appertaining object distance lies in front of the pupil of the eye (Fig. 133). The two zones are usually arranged one on top of the other; a stabilizing element ensures the correct position on the eye.

Fig. 131
 Concentric bifocal contact lenses:
a) design principle
b) simultaneous type with distance portion ground onto back surface
c) simultaneous type with near portion fused onto back surface
CONTACT OPTICS: Contact lenses

Fig. 132
Principle of bifocal contact lenses of the simultaneous type:
a) the distance portion generates a sharp retinal image of a distant object point \( O \)
b) the near portion \( N \) generates a sharp retinal image of a near object point \( O \)

Fig. 133
Principle of bifocal contact lenses of the alternating type:
a) distance vision
b) near vision
Image-forming properties

Spherical aberration  The image-forming properties of contact lenses should always be considered in conjunction with the eye or more precisely with the film of tear fluid in front of it. The direct contact of a contact lens with the anterior outer segment of the eye effects a pronounced change in the dioptric power and therefore also in the spherical aberration of the front surface of the cornea. The greatest part of the dioptric power is provided by the front surface of the contact lens. This surface therefore plays a decisive role in image formation, with the result that it is its spherical aberration above all which determines image quality.

Transverse chromatism  Formula (92) shows the extent to which the chromatism is dependent on both the magnitude of the prismatic deviation and the Abbe number of the contact lens material. Even in contact lenses with a high vertex power, the prismatic power generated by decentration of the contact lens is so low that the threshold of visibility for colour fringes is not reached.

Decentration  A contact lens lying in a decentred position on the eye exhibits a prismatic power which can be estimated by Prentice's formula (83). For decentrations of no more than 2 mm as normally experienced, the amount of prismatic deviation is small. A disturbance in vision is only to be expected if a vertical binocular prismatic power is created due to decentration in the vertical direction.

Spherical and astigmatic deviation  The corrective power of a contact lens changes as a function of its decentration due to the spherical and astigmatic aberrations which result in a decentred contact lens. These aberrations are mainly influenced by the prismatic ray path and by the conditions of curvature present at the respective areas of the lens surface. The more the surface contours of the front surface of the cornea and the back surface of the contact lens approximate a spherical shape in the optical zone, the less pronounced the aberrations caused by decentration will be.

The magnitude of these deviations can be determined by performing a ray-tracing computation for the optical system comprising the decentred contact lens and the cornea. Fig. 134
Fig. 134
Tangential (T) and sagittal (S) components of spherical and astigmatic deviation as a function of the decentration of a contact lens with a vertex power $F_v = 5.0$ D (diameter 10.0 mm; centre thickness 0.3 mm) with a spherical front surface ($r_{a0} = 7.18$ mm; $e = 0$) and an aspherical back surface (vertex radius $r_s = 7.65$ mm; $e = 0.47$)

![Graph showing deviation vs. decentration](image)

shows an example. As the aberrations $\Delta S$ and $\Delta T$ are positive, they cannot be compensated by positive accommodation. A centred fit of the contact lens should be aimed at for optical reasons.

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**Light-transmission properties**

**Light attenuation**
Light-attenuating contact lenses (sun-protection contact lenses) have not yet gained any major importance. Only those contact lenses which absorb in the UV range have recently begun to be used to any great extent.

**Reflectance**
The reflection properties of contact lenses must be assessed in conjunction with the anterior outer segment of the eye. At the interfaces of optical media of different refractive indices reflections occur, the extent of which is dependent on the difference between the refractive indices as defined by formula (51). For the system contact lens/eye the sequence air ($n = 1$) – tear fluid ($n_{TL} = 1.336$) – contact lens ($n_{CL} = 1.39$ to 1.49) – tear fluid – front surface of cornea ($n_C = 1.376$) provides a reflectance of 2.15% to 2.67%. This value is only slightly greater than the reflectance of the eye itself which at 2.09% results from the interfaces air – tear fluid – front surface of cornea.
Contact lens fitting

The fitting of contact lenses involves the determination of the dioptric power of the contact lens, the selection of the optimum contact lens for the eye to be corrected and the after-care of the contact lens wearer.

Contact lens correction

Fundamental differences exist between the use of spectacle lenses and contact lenses and affect the optics of the two systems.

The different distance of the spectacle lens and the contact lens from the front surface of the cornea makes it necessary to convert the “spectacle lens correction” \( F'_{\text{SP}} \) applicable to a certain corneal vertex distance \( d \) into the correction referred to the front corneal vertex \( (d = 0) \) (Fig. 135). This power required for the optical system contact lens/tear lens shall be defined as the “contact lens correction” \( F'_{\text{CT}} \). The following relationship applies for the conversion of spectacle lens correction into the contact lens correction in accordance with formula (98):

\[
F'_{\text{CT}} = \frac{F'_{\text{SP}}}{1 - d \cdot F'_{\text{SP}}},
\]

where the corneal vertex distance \( d \) should be substituted in metres.

The evaluation of formula (114) provides the following information:

1. For a hyperopic eye, the contact lens correction is more positive than the vertex power of the corrective spectacle lens.
2. For a myopic eye, the contact lens correction is less negative than the vertex power of the corrective spectacle lens.
3. A conversion of the spectacle lens correction into the contact lens correction is only necessary for vertex powers greater than ± 3.0 D.

If we set \( F'_{\text{SP1}} = F'_{\text{CT}} \) and \( F'_{\text{SP2}} = F'_{\text{SP}} \) in Tables 38 and 39, the differences between \( F'_{\text{CT}} \) and \( F'_{\text{SP}} \) at the respective corneal vertex distance can be taken from Table 38 for negative vertex powers, and for positive vertex powers from Table 39.
Fig. 135
Transition from spectacle lens correction to contact lens correction:

a) in myopia
b) in hypermetropia
Hard contact lenses and spherical ametropia

The film of tear fluid found between the contact lens and the eye (Fig. 136) causes:
1. the refracting power of the contact lens back surface to be changed,
2. the tear film to display a certain vertex power due to its shape and thickness (tear lens) and
3. the refracting power of the front surface of the cornea to be changed.

The optical system comprising the contact lens, the tear fluid and the front surface of the cornea must compensate the ametropia of the eye. An optimum fit of the contact lens on the cornea is also required to avoid any discomfort for the wearer. This is achieved by using empirical values (as a function of the lens type) to determine the back surface of the contact lens in such a way that it approximates the profile of the cornea.

In the following text it will be assumed for the sake of simplicity that the contact lens and the front surface of the cornea are spherical, although this is not normally the case in the latter.

The back surface radius of the contact lens determines the shape of the tear film (tear lens) between the contact lens and the cornea.

If the back central optic radius \( r_0 \) of the contact lens and the radius \( r_C \) of the front surface of the cornea are concentric, the contact lens is then separated from the cornea by a very thin, even tear film ("parallel fitting", Fig. 137).

If the back central optic radius \( r_0 \) of the contact lens is smaller than the radius \( r_C \) of the front surface of the cornea, the contact lens bridges the corneal vertex and rests on the periphery of the cornea. The resultant pool of tears has the shape of a positive meniscus; it forms a positive tear lens ("steep fitting", Fig. 138).

If the back central optic radius of the contact lens is larger than the radius of the front surface of the cornea, the contact lens normally touches the corneal vertex. A space filled with tear fluid results at the corneal periphery. The pool of tears assumes the shape of a thin negative meniscus; it forms a negative tear lens ("flat fitting", Fig. 139).

The dioptric power of the tear lens is taken into account for the correction of the ametropic eye. To calculate this power, the
Tear lens is assumed to be isolated (Fig. 140). The radius of the front surface of the tear lens corresponds to the back central optic radius of the contact lens, and the radius of the back surface of the tear lens is equal to the radius of the front surface of the cornea. The centre thickness of the tear lens is dependent on the method of fitting used, but does not usually exceed 0.1 mm even with the steep fitting procedure. If the refractive index of the tear fluid is known, the vertex power of the tear lens in air can be calculated.

### Approximate formula

The use of an approximate formula is adequate for practical purposes. The evaluation of exact vertex power computations shows a clear dependence of the vertex power $F_{VTL}$ of the tear lens on the difference $\Delta r$ of the radii of the front surface of the cornea $r_c$ and the back surface of the contact lens $r_0$. For the range of normal fittings and for values of $r_0$ between 7.20 mm and 8.50 mm the following formula is sufficiently accurate:

$$F_{VTL} = 5 \frac{D}{\text{mm}} \cdot \Delta r \quad (\text{for } \Delta r \text{ to } \pm 0.15 \text{ mm}).$$

In the steep fitting method $\Delta r > 0$, therefore making the vertex power of the tear lens formed positive; in flat fitting $\Delta r < 0$, resulting in a negative vertex power.

The approximate formula (115) shows that a tear lens with a
vertex power of approximately ± 0.25 D is generated for every difference of ± 0.05 mm between the radii of the contact lens back surface and the front surface of the cornea. The approximate formula provides less exact results for positive tear lenses due to their greater centre thickness than for negative ones.

Contact lens and tear lens

The tear lens on the eye is in direct contact with both the contact lens and the cornea. The contact lens and the tear lens (both assumed to be infinitely thin) form an optical system whose vertex power \( F'_{\text{VCT}} \) is the sum of the vertex powers of the components, contact lens and tear lens, determined in air:

\[
F'_{\text{VCT}} = F'_{\text{VCL}} + F'_{\text{VTL}}.
\]

The same laws apply for the correction of an ametropic eye with the aid of a contact lens and a tear lens as for correction with a spectacle lens. The image-side focal point \( F'_{\text{CT}} \) of the corrective system comprising the contact lens and the tear lens must coincide with the far point of the eye to be corrected. The conversion of the spectacle lens correction into the correction referred to the front corneal vertex in accordance with formula (114) provides the vertex power \( F'_{\text{VCT}} \) (contact lens correction) which the contact lens/tear lens system must exhibit in air if it is to supply the required corrective power. The vertex power \( F'_{\text{VCL}} \) of the contact lens differs from the contact lens correction by the vertex power \( F'_{\text{VTL}} \) of the tear lens:

\[
F'_{\text{VCL}} = F'_{\text{VCT}} - F'_{\text{VTL}}.
\]

If the tear lens is reduced to a thin tear film (parallel fitting), the contact lens alone provides the corrective power. If an afocal contact lens \( (F'_{\text{VCL}} = 0) \) is used for the fitting, the tear lens must provide the corrective power. The contact lens provides the greater part of the corrective power in most fittings of hard contact lenses.

### Hard contact lenses and astigmatic ametropia

**Regular astigmatism**

The cause for an astigmatism is to be found on the cornea, the crystalline lens or (most commonly) on both (Fig. 141). As a regular astigmatism is characterized by two principal meridians perpendicular to each other, it can be corrected by an optical
system with an astigmatic power. Spectacle lens corrections for
astigmatic ametropia are therefore spherocylindrical combinations. With corresponding correction by a contact lens, the total
corrective power is distributed over the contact lens and the tear
lens as described for spherical ametropia.

The front surface of the majority of corneas is approximately
toroidal in the optically effective area in front of the pupil of
the eye. When this toroidal surface is combined with the
spherical back surface of a contact lens, a tear lens is formed
whose front surface bounded by the contact lens is spherical
and whose back surface bounded by the cornea is toroidal. The
result is a toroidal back surface tear lens with the front surface
radius \( r_{TLI} = r_0 \) and the two back surface radii \( r_{TLI} = r_{CI} \) and
\( r_{TLII} = r_{CII} \), where \( r_{CI} \) is the radius of the front surface of the
cornea in the flattest meridian and \( r_{CII} \) is the radius of the front
surface of the cornea in the steepest meridian. The imaginary
isolated tear lens bounded by air has an astigmatic power
whose astigmatic difference \( C_{TL} \) results from the corneal radii
in the two principal meridians:

\[
C_{TL} = (1 - n_{TL}) \cdot \left( \frac{1}{r_{CII}} - \frac{1}{r_{CI}} \right).
\]

The astigmatic difference \( C_c \) (the corneal astigmatism) for the
front surface of the cornea which borders on air and exhibits an
astigmatic power is:

\[
C_c = (n_c - 1) \cdot \left( \frac{1}{r_{CII}} - \frac{1}{r_{CI}} \right).
\]

With increasing thinness of the air space between the back
surface of the tear lens and the front surface of the cornea the
joint astigmatic power of these two surfaces yields the astig­
matic difference \( C_{CT} \):

\[
C_{CT} = C_{TL} + C_c = (n_c - n_{TL}) \cdot \left( \frac{1}{r_{CII}} - \frac{1}{r_{CI}} \right).
\]

As \( C_{CT} < C_c \), the toroidal back surface tear lens corrects a
considerable portion of the astigmatism of the front surface of
the cornea. With the refractive indices for the tear fluid \( n_{TL} =
1.336 \) and the cornea \( n_c = 1.376 \), formulae (120) and (119)
provide an important result for contact lens fitting:
Formula (121) shows that the back surface toric tear lens which forms between a contact lens with a spherical back surface and a cornea with a toroidal front surface corrects the astigmatism of the front surface of the cornea except for approximately 10.6%. If the astigmatism of an ametropic eye is a pure corneal astigmatism, correction by the back surface toric tear lens is therefore generally sufficient (up to approx. 2 D).

Irregular astigmatism

If poor visual acuity is caused by an irregular corneal surface, correction by spectacle lenses is generally not possible. An irregular astigmatism of this type may occur due to injury, corneal disease, surgery or keratoconus (conical protrusion of the cornea). An improvement in visual acuity can often be achieved with a hard contact lens due to the approximate equality of the refractive indices of the tear fluid and the cornea. The tear fluid "fills in" the irregularities of the front surface of the cornea (Fig. 142) and reduces their dioptric power to approximately 10.6% of the value present in air.

Fig. 142
Correction of an irregular astigmatism by the tear fluid under a hard contact lens
Soft contact lenses

Optical features  A soft contact lens usually has a larger diameter than the cornea and is generally fitted using the flat method. The back central optic radius of the contact lens is therefore larger than the radius of the front surface of the cornea. A soft contact lens actually rests against the front surface of the cornea. Only a very thin tear film is formed, but no optically effective tear lens. The back surface of the contact lens assumes the curvature of the front surface of the cornea. The front surface of the soft contact lens also experiences a corresponding curvature and is consequently also spherical or toroidal in the area of the optic zone. As no tear lens is created ($F'_{VTL} = 0$), the soft contact lens must provide the entire corrective power in accordance with formula (117) ($F'_{VCL} = F'_{VCT}$).

When determining the vertex power of a soft contact lens, a certain “bending effect” must be taken into consideration. As this bending causes the radii of the two contact lens surfaces to change, the vertex power inevitably changes at the same time. Practical experience points to a change of less than 0.5 D in the vertex power in the minus direction.

Astigmatism  The bending to which a soft contact lens with a spherical power is subjected on a cornea with a toroidal front surface is such that it also exhibits a toroidal front surface. Numerous investigations have shown that the difference between the radii in the flattest and steepest meridians of the front surface of the contact lens, the so-called toricity, barely differs on average from that of the front surface of the cornea. From this it can be derived mathematically that a soft contact lens with a spherical power does not exercise any major influence on an astigmatism caused by the front surface of the cornea; the total astigmatism of an eye system is therefore not changed to any considerable degree either.
Soft contact lenses

Optical features  A soft contact lens usually has a larger diameter than the cornea and is generally fitted using the flat method. The back central optic radius of the contact lens is therefore larger than the radius of the front surface of the cornea. A soft contact lens actually rests against the front surface of the cornea. Only a very thin tear film is formed, but no optically effective tear lens. The back surface of the contact lens assumes the curvature of the front surface of the cornea. The front surface of the soft contact lens also experiences a corresponding curvature and is consequently also spherical or toroidal in the area of the optic zone. As no tear lens is created (F'_{vTL} = 0), the soft contact lens must provide the entire corrective power in accordance with formula (117) \( F'_{vCL} = F'_{vCT} \).

When determining the vertex power of a soft contact lens, a certain “bending effect” must be taken into consideration. As this bending causes the radii of the two contact lens surfaces to change, the vertex power inevitably changes at the same time. Practical experience points to a change of less than 0.5 D in the vertex power in the minus direction.

Astigmatism  The bending to which a soft contact lens with a spherical power is subjected on a cornea with a toroidal front surface is such that it also exhibits a toroidal front surface. Numerous investigations have shown that the difference between the radii in the flattest and steepest meridians of the front surface of the contact lens, the so-called toricity, barely differs on average from that of the front surface of the cornea. From this it can be derived mathematically that a soft contact lens with a spherical power does not exercise any major influence on an astigmatism caused by the front surface of the cornea; the total astigmatism of an eye system is therefore not changed to any considerable degree either.
Optical differences from spectacle lens correction

**Causes**

An ametrope corrected with spectacle lenses does not have the same visual conditions as an emmetrope, since

1. the spectacle lenses are positioned a distance of approximately 12 to 20 mm in front of the object-side principal point of the eye,
2. the eyes can perform independent viewing movements behind the spectacle lenses and
3. prismatic effects are experienced when looking through peripheral areas of the lenses.

An ametrope corrected with contact lenses experiences virtually the same visual conditions as an emmetrope, since

1. the contact lenses lie directly on the tear fluid in front of the eyes at a distance of only approx. 1.5 mm from the object-side principal point of the eye,
2. the contact lenses follow every viewing movement of the eyes and
3. in general only a central area with a diameter of approximately 5 mm is used, with the result that the prismatic effects are usually negligible.

If an ametrope changes from spectacle lenses to contact lenses, he then experiences virtually the same optical conditions as an emmetrope with eyes of the same length. He perceives differences regarding the field of fixation and the field of view, the size of the retinal images, accommodation and convergence, which may be of special significance with the onset of presbyopia and in anisometropia. The optical differences are all the more noticeable, the more pronounced the ametropia present.

**Field of fixation and field of view**

Irrespective of the ametropia present, the change from spectacle lenses to contact lenses provides the ametrope with the field of view and the field of fixation of an emmetrope.

In the transition from spectacle lens correction to contact lens correction an ametrope experiences an increase in the field of view. This is all the more pronounced, the higher the ametropia. The differences are shown in Fig. 143. The same applies for the field of fixation and its changes.
Fig. 143
Fields of view in correction with a spectacle lens and a contact lens:
a) myopic eye with spectacle lens
b) hypermetropic eye with spectacle lens
c) eye with contact lens

Fig. 144
Approximate percentage change in the size of the retinal images in the transition from spectacle lens correction SP (d = 12 mm) to contact lens correction CT as a function of the far point refraction K (ignoring the shape magnification)
When a corrective device is brought close to the eye, the power magnification of formula (108) approaches the value 1, and the retinal images in the corrected eye are then as large as in an emmetropic eye of the same length, provided the shape magnification of the corrective device can be neglected. This is the case when contact lenses are used for correction. In the switchover from spectacle lens correction to contact lens correction a hypermetrope experiences a relative decrease in the size of the retinal image which in pronounced ametropia may be accompanied by a considerable deterioration in visual acuity. A myope, on the other hand, experiences a relative increase in the size of the retinal image which may lead to a considerable improvement in visual acuity.

The percentage difference in the size of the retinal images experienced by an ametropia in the transition from spectacle lenses to contact lenses is given in Fig. 144.

As the distance between contact lenses and the object-side principal point of the eye is considerably smaller (1 to 2 mm depending on the state of accommodation) than with spectacle lenses (12 mm and more), a hypermetrope corrected with contact lenses must accommodate less, and a myope more than in correction with spectacles at the same object distance. These differences between the accommodative effort \( \Delta F_{cc} \) necessary for a given position of a near object when corrected with spectacle lenses and contact lenses are shown in Fig. 145.
The differences in the required accommodative effort become more and more important with the onset of presbyopia. As correction with contact lenses creates approximately the same visual conditions with regard to accommodation as those experienced by an emmetrope, a hypermetrope with contact lenses requires a near addition at a later stage than with spectacle lenses. A myope with contact lenses, on the other hand, needs a near addition earlier than with spectacles.

**Convergence requirement**

As contact lenses when centred on the cornea follow the viewing movements of the two eyes, virtually the same conditions as those experienced by the emmetrope are also present with regard to the convergence requirement. Consequently, a hypermetropic pair of eyes with contact lenses has to converge less, and a myopic pair of eyes more than with spectacle lenses in order to obtain single binocular vision of an object at close range. Fig. 146 shows these differences which are caused by the prismatic effects of the spectacle lenses.

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**Fig. 146**

Difference between the convergence requirement experienced with contact lenses and spectacle lenses

a) in myopia
b) in hypermetropia
Anisometropia

If an anisometropic pair of eyes is corrected with spectacle lenses, the result is
1. a field of view and a field of fixation of different sizes for the two eyes,
2. strain on fusional vergence when viewing through areas outside the major reference points (due to the binocular prismatic power) and
3. different amplitudes of accommodation \( cc \) for the two eyes with the same accommodative effort.

Switching to contact lenses prevents these drawbacks of spectacle lens correction.

The size of the retinal images in the two eyes is especially important in anisometropia, as any difference between them can lead to optical aniseikonia.

Aniseikonia

If an aniseikonia \( P_{SP} \) (in %) measured in vision testing at the corneal vertex distance \( d \) (in cm) is positive (larger visual impression belongs to the stronger hypermetropic eye or to the weaker myopic eye), a reduction in the corneal vertex distance leads to a decrease in the aniseikonia. If we ignore the shape magnification of the corrective device, the aniseikonia \( P_{CT} \) (%) to be expected in the transition to contact lenses can be simply estimated using formula (111):

\[
P_{CT} = P_{SP} - d \cdot \Delta F_v,
\]

where \( \Delta F_v \) (in D) is the anisometropic difference. As, however, geometrical-optical considerations regarding the correction of anisometropia neglect anatomical factors (structure of the retinal elements) and physiological factors (processing of the visual stimuli in the visual cortex), exact information can only be obtained by actual measurement of the aniseikonia.

Unilateral aphakia is a special case of refractive anisometropia. Correction with a spectacle lens leads to optical aniseikonia of approximately 25% (if the other eye is emmetropic). A contact lens can reduce the difference in size between the retinal images to a few percent (about 4%). In numerous cases this permits adequate binocular vision.
Optical reasons

The fitting of contact lenses is recommended if contact lenses are more favourable from an optical viewpoint than spectacle lenses and if they lead to an improvement in visual performance. This group of applications includes cases in which contact lenses
1. "replace" an irregular cornea,
2. make binocular vision possible and
3. permit "better" vision.

Irregular deformations of the front surface of the cornea are levelled out almost completely by contact lenses, especially hard ones, in conjunction with the tear fluid. The irregular cornea is thus artificially given a regular form; optical image formation is determined by the front surface of the contact lens. It is, however, important that no opacity is present in the irregular areas.

In keratoconus the centre of the cornea loses its regular form and gradually assumes a more and more pronounced conical shape. This deformation makes the eye increasingly myopic and also causes an irregular astigmatism, leading to an extreme reduction in visual acuity. Hard contact lenses bridge the cone-shaped area (Fig. 147), and good image formation results due to the film of tear fluid between the contact lens and the cornea.

Apart from keratoconus and irregular healing of the front surface of the cornea after injury or corneal disease, another possible reason for the presence of an irregular astigmatism is a corneal transplant (keratoplasty) if the transplant does not grow evenly on the surface of the eye. An irregular astigmatism may also result from ophthalmic surgery (e.g. cataract surgery, squint operations, radial keratotomy).

In all these cases the contact lens and the tear fluid produce a "levelling" of the cornea and hence also an increase in visual performance.

In anisometropia contact lenses can make binocular vision possible and therefore lead to an improvement in visual performance.

Optical grounds for the use of contact lenses are also present if contact lenses constitute the better means of optical correction, even if other means of correction would be possible. In pronounced myopia contact lens correction causes a negligible reduction in the size of the retinal images compared with spectacle lens correction. Visual performance is therefore
usually higher. In pronounced hypermetropia contact lens correction offers the advantage of an increase in the field of fixation and the field of vision and a reduction in the accommodation and convergence requirements in near vision. In bilateral aphakia contact lenses provide virtually normal visual conditions compared with cataract lenses.

Aesthetic and psychological reasons

Contact lenses are often worn for aesthetic (cosmetic) reasons. For this group of wearers contact lenses do not provide any major optical improvement. A considerable number of people prefers contact lenses to spectacles for psychological reasons.

Medical-therapeutic reasons

Medical-therapeutic grounds for the use of contact lenses exist if the contact lenses result in
1. a healing of the cornea in the event of disease or injury,
2. protection of the cornea against contact with the lids or eyelashes,
3. an easing of pain in corneal disease or injury and
4. an improvement in the appearance of the outer front segment of the eye.

It is advantageous if a good optical corrective power is provided at the same time; it is not, however, the main objective of the fitting procedure. Hydrogel contact lenses are normally used for medical-therapeutic purposes.

Work and leisure

Contact lenses can make it possible for ametropes to take up or to continue in occupations from which they would otherwise be excluded or only able to practise to a limited extent. Moreover, contact lenses are now being used increasingly for leisure activities. It is frequently the case that they are only worn for a limited amount of time, i.e. only at work or only for leisure activities, and are then replaced by spectacles.

The following properties of contact lenses make their use attractive:
1. invisibility (important for actors, singers and in show business, for example),
2. virtually break-proof during wear (important for athletes, nursery school and other teachers, for example),
3. mist-proof (important for surgeons, cooks, sailors, for example) and
4. they require little room (favourable for use under protective eyewear and diving goggles, for example).