THIRD EDITION

The CONTACT LENS MANUAL

A PRACTICAL GUIDE TO FITTING

Andrew Gasson
Judith Morris

BUTTERWORTH HEINEMANN

The Contact Lens Manual

A practical guide to fitting

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Preface to the third edition

This new revision of *The Contact Lens Manual* brings it up to date with the numerous changes which have occurred in the contact lens field since the second edition was published in 1998. The basic format of the text remains the same with a deliberately concise, pragmatic approach to fitting and aftercare. This is assisted by the newly designed layout and the contents summaries for each chapter. The use of colour also more effectively highlights key practical points.

Disposable lenses now dominate current contact lens practice and Chapter 19 has been considerably enlarged to indicate the extensive range now available in the UK for both simple and complex lens forms. Perhaps the most important clinical development during the last five years is explored in the new chapter on silicone hydrogels. Lenses made from these materials are already used widely for both daily and continuous wear and Chapter 22 now reflects their preferred use as the first choice in many circumstances. The chapter on orthokeratology has also been greatly enlarged since there are now several different fitting approaches for corneal reshaping. For simplicity, the previous sections on therapeutic fitting have now been combined into a single new Chapter 32. The Glossary has been expanded and another addition is the list of commonly used abbreviations in contact lens practice. Terminology has been brought into line with accepted practice in respect of the classification of ocular infections and inflammatory responses. Lenses continue to be described in accordance with European and international standards and advice is offered on the current thinking for the use of trial and diagnostic lenses.

The content of CD-ROM which accompanies *The Manual* has also been enlarged to give a wider variety of interactive lens types with which to work and the tear layer thickness diagrams have been enhanced in full colour. There are also more than 100 photographic images in colour. These show a variety of contact lens fluorescein fittings and complement the text by illustrating numerous conditions and aftercare problems encountered in routine clinical practice.

There are many people who have helped us with the production of this new edition. Our thanks are due in particular to Tony Hough whose digital expertise and passion for lens design make the CD-ROM such a valuable working tool and for permission to use his work on European standards. We are also grateful to Ken Pullum for his help with updating the chapter on scleral lens fitting. As ever, it proves impossible to give examples of every contact lens and related product but we are indebted to all the laboratories which have been so helpful in providing current and in many cases advance information on their products.

Preface to the first edition

The Manual is designed as an essentially practical guide to all aspects of contact lens fitting. It follows the authors' own approach to patient management, initial assessment and lens selection as well as giving detailed fitting procedures for both basic and complex lenses. Significant space is allocated to aftercare as this is considered an inextricably linked continuation of fitting, whereas theoretical aspects have been kept deliberately concise, supplemented by detailed references and suggestions for further reading.

The introductory chapters and basic fitting are directed mainly at the student or practitioner without recent experience. The Manual, however, also covers advanced fitting techniques for the more experienced and the specialist sections on therapeutic lenses and the management of children requiring contact lenses should be of interest both to hospital fitters and to those who encounter the occasional medical case.

Terminology is based on the relatively new British and International Standards. The most common lens types are referred to as either 'hard' or 'soft'. The term 'hard' has been used throughout to indicate specifically modern materials which have been described elsewhere as 'gas-permeable'. PMMA is now considered a little-fitted sub-group.

Inevitably, it is impossible to include details of every lens or solution currently available and the authors have been forced to select representative examples. Mention of a particular product is not intended as an endorsement and any omission, however obvious, should not be construed as an implied criticism.

Finally, the authors would like to acknowledge all of the contact lens companies which have kindly made available detailed information concerning their products; the ACLM for the use of their materials classification system; Allergan-Hydron, Bausch & Lomb and Igel International for their permission to reproduce tables and illustrations; Tony Hough of Microturn for his assistance in producing tear lens thickness diagrams; Ken Pullum for providing the basis of the section on scleral lenses and for his diagrams; and to the publishers for their constant help and encouragement.

How to use this book

Please note that for accuracy some of the composite illustrations have been reproduced from the CD-ROM. These illustrations have been generated using mathematical values and are thus not as neat as the figures drawn by our artist. However, they are very accurate.

Every time that the CD-ROM icon appears in the text, it indicates that there is an illustration available for viewing on the CD-ROM. Most of these are in full colour.

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Common abbreviations in contact lens practice

AEL	Axial edge lift
AI	Asymptomatic infiltrates
AIK	Asymptomatic infiltrative keratitis
BOZD	Back optic zone diameter
BOZR	Back optic zone radius
BSR	Back scleral radius
BSS	Back scleral size
BUT	Break up time
BVD	Back vertex distance
BVP	Back vertex power
CAB	Cellulose acetate butyrate
CAEL	Constant axial edge lift
CD	Centre distance
CLAPC	Contact lens associated papillary conjunctivitis
CLARE	Contact lens acute red eye
CLIPC	Contact lens induced papillary conjunctivitis
CLPU	Contact lens peripheral ulcer
CLSLK	Contact lens induced superior limbic keratoconjunctivitis
CN	Centre near
CRT	Corneal refractive therapy
D	Displacement
Dk	Oxygen permeability
Dk/t	Oxygen transmissibility
e	Eccentricity
Ec	Edge clearance

EOP	Equivalent oxygen percentage
EW	Extended wear
FDA	Food and Drugs Authority
ff	Flattening factor
FLOM	Fenestrated lens for optic measurement
FOZD	Front optic zone diameter
FVP	Front vertex power
GPC	Giant papillary conjunctivitis
HEMA	Hydroxyethyl methacrylate
HGP	Hard gas-permeable
HVID	Horizontal visible iris diameter
IK	Infiltrative keratitus
MDD	Medical Devices Directive
MK	Microbial keratitis
MPS	Multipurpose solution
MRDT	Minimum recommended disinfection time
NIBUT	Non-invasive break-up time
OK	Orthokeratology
p	Corneal shape factor
PMMA	Polymethyl methacrylate
POD	Primary optic diameter
PRK	Photorefractive keratectomy
PVP	Polyvinyl pyrrolidone
REL	Radial edge lift
RGP	Rigid gas-permeable
RK	Radial keratotomy
SEAL	Superficial epithelial arcuate lesion
Si-Hy	Silicone hydrogel
TBUT	Tear break-up time
tc	Centre thickness
TD	Total diameter
te	Edge thickness
TLT	Tear layer thickness
TR	Tear reservoir
USAN	United States Adopted Name

Colour plates

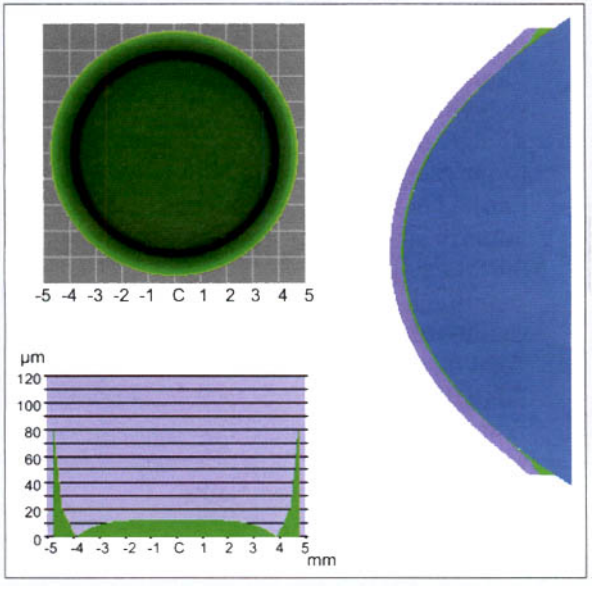


Plate 1 Tear layer profile

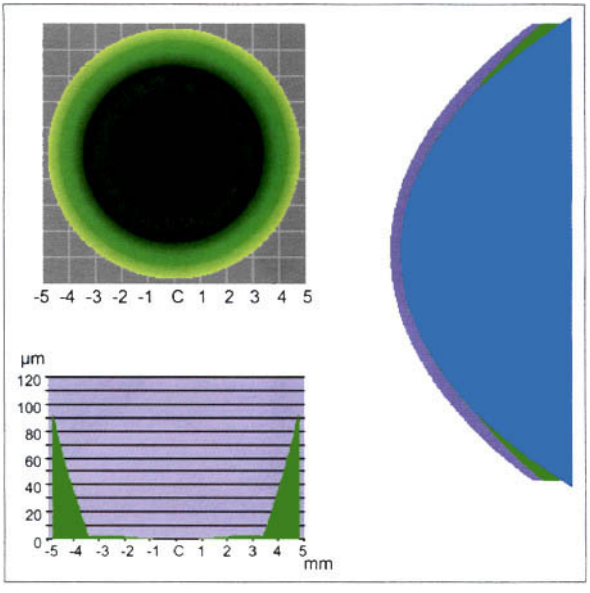


Plate 2 Tear layer profile/Bier contour technique

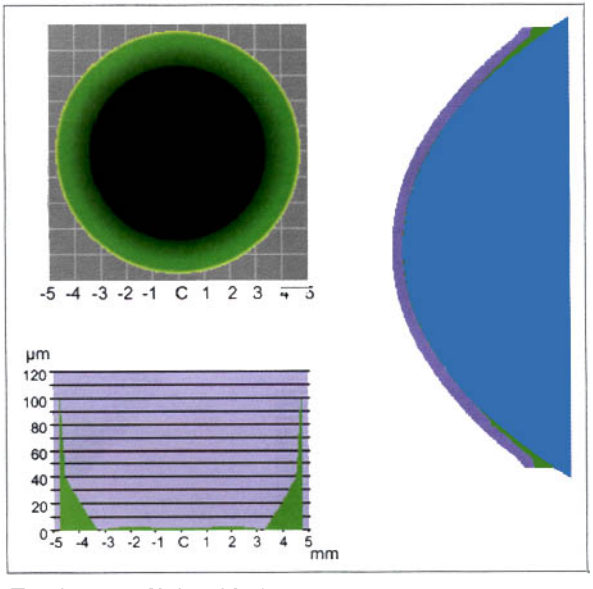
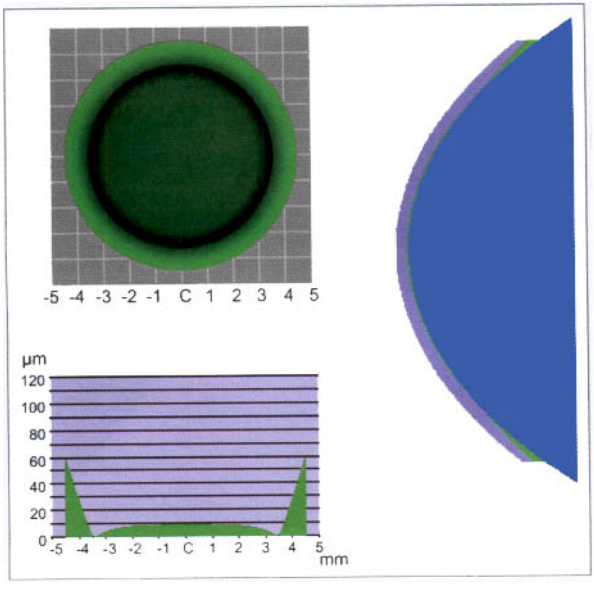


Plate 3 Tear layer profile/modified contour technique



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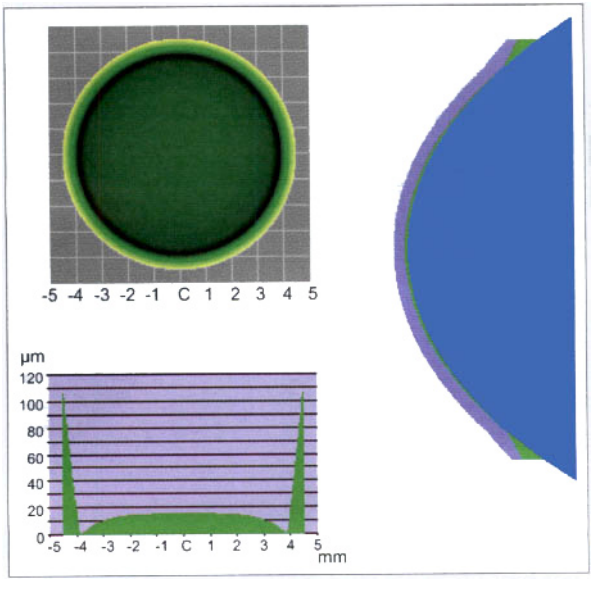
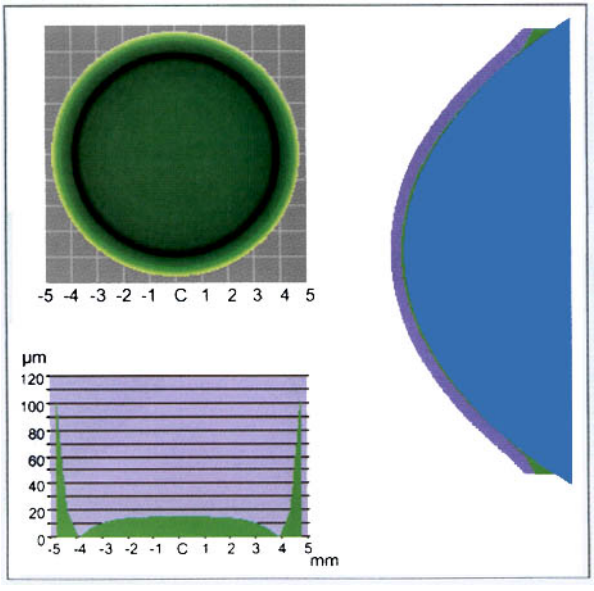


Plate 5 Tear layer profile/bicurve (C2)



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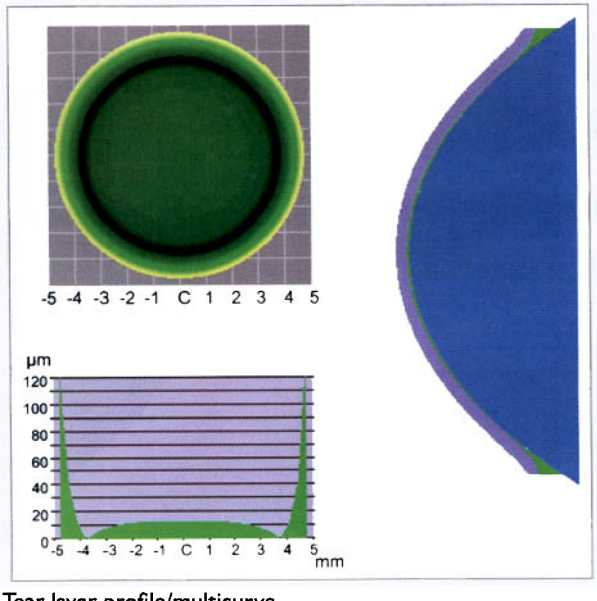


Plate 7 Tear layer profile/multicurve

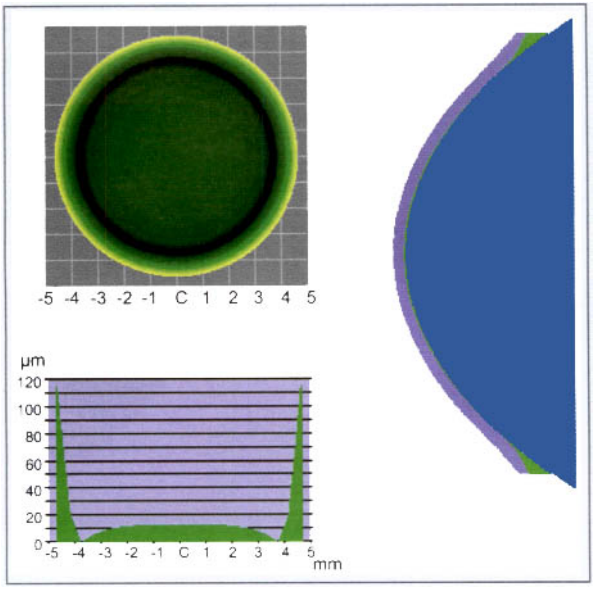


Plate 8 Tear layer profile/BOZD

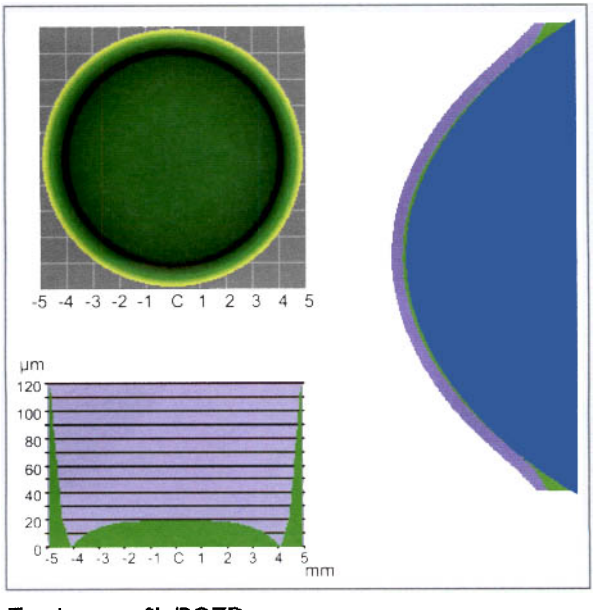


Plate 9 Tear layer profile/BOZD

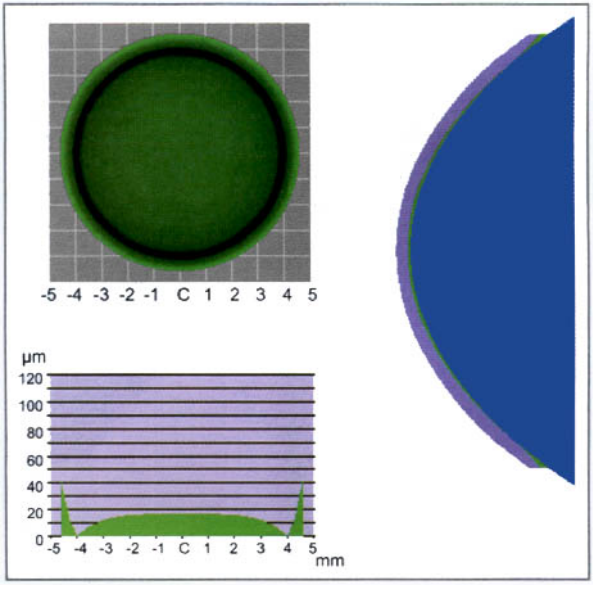


Plate 10 Tear layer profile/tight periphery

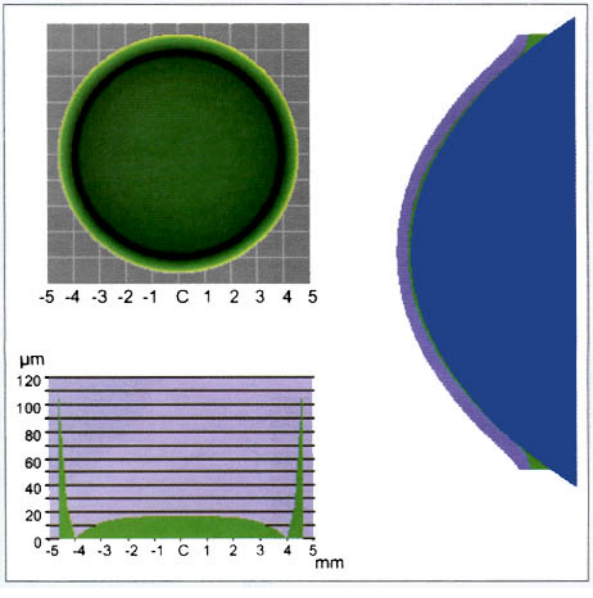
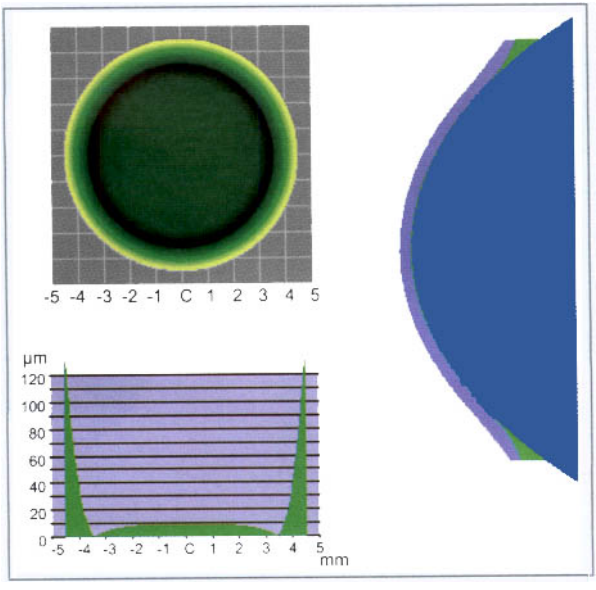


Plate 11 Tear layer profile/average periphery



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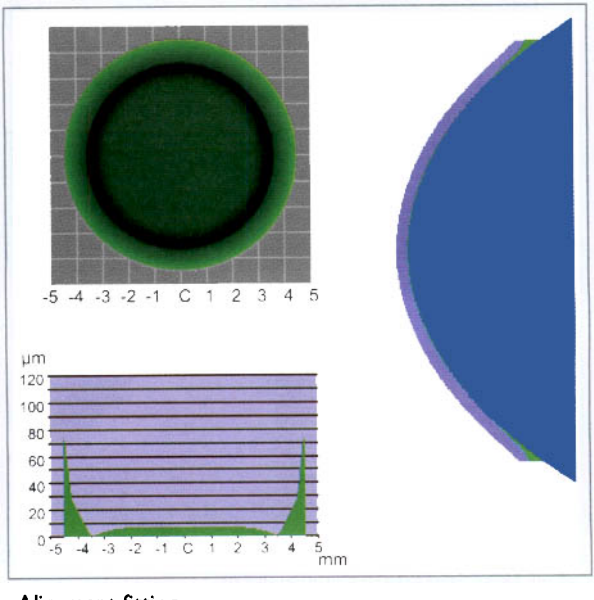

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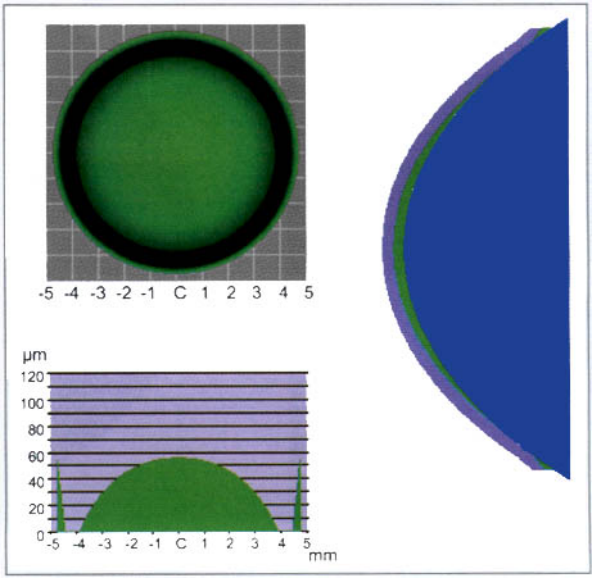

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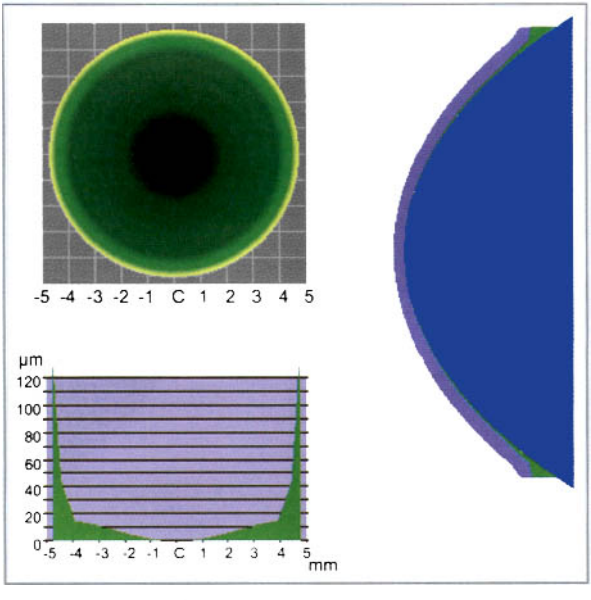

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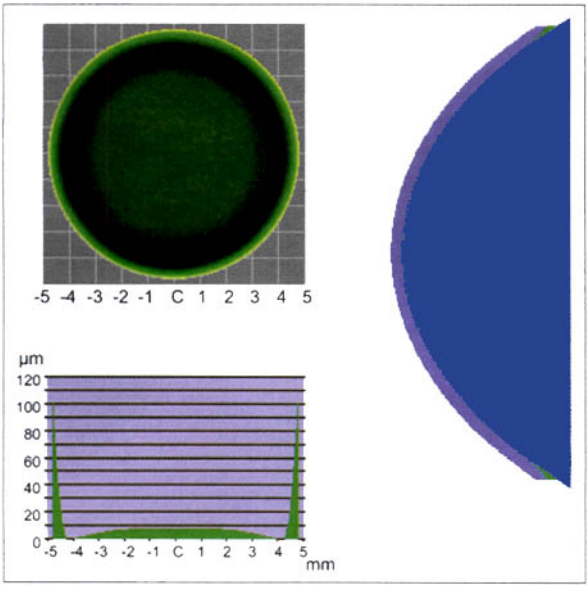

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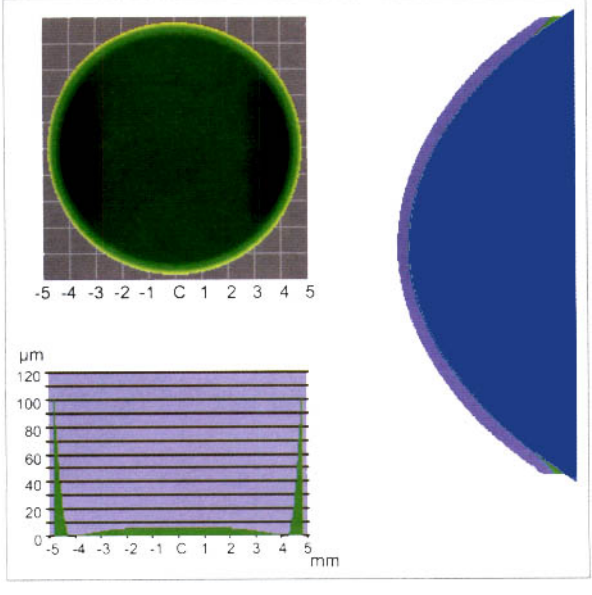

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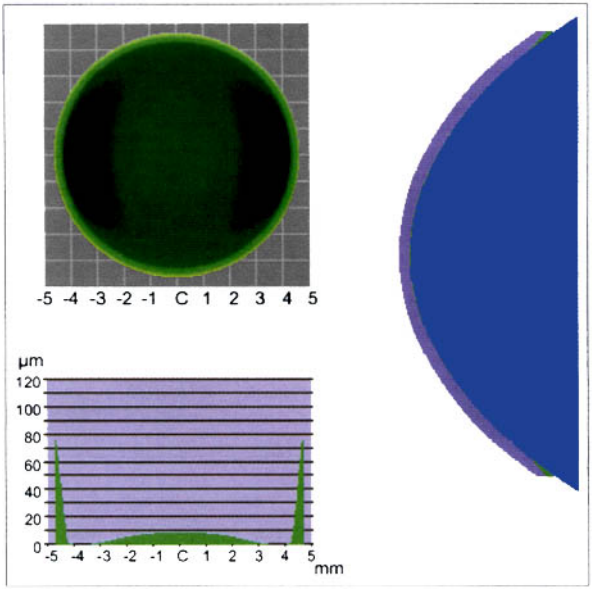

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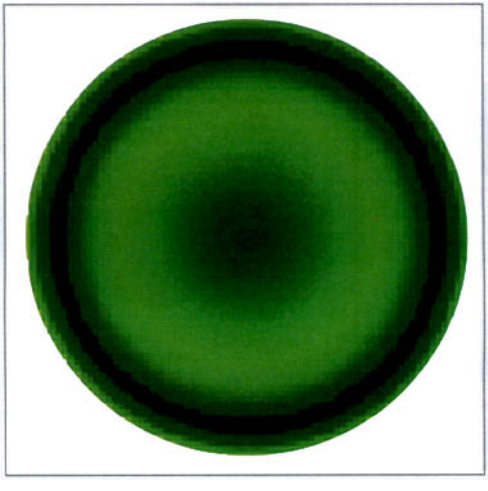

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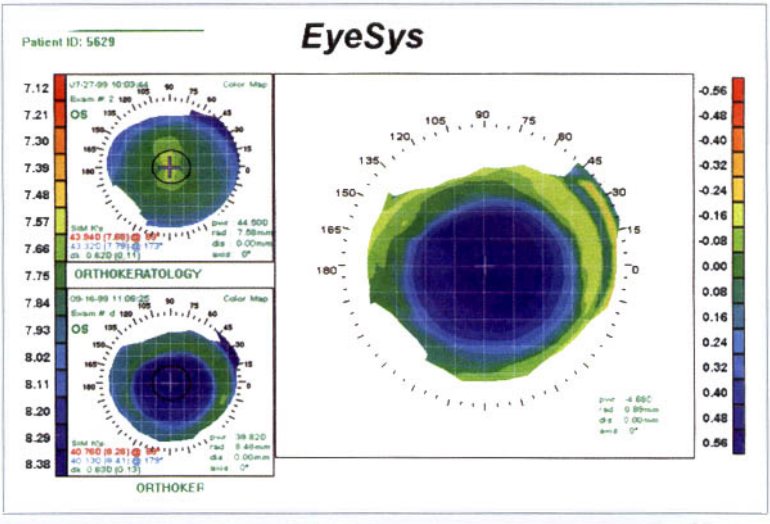

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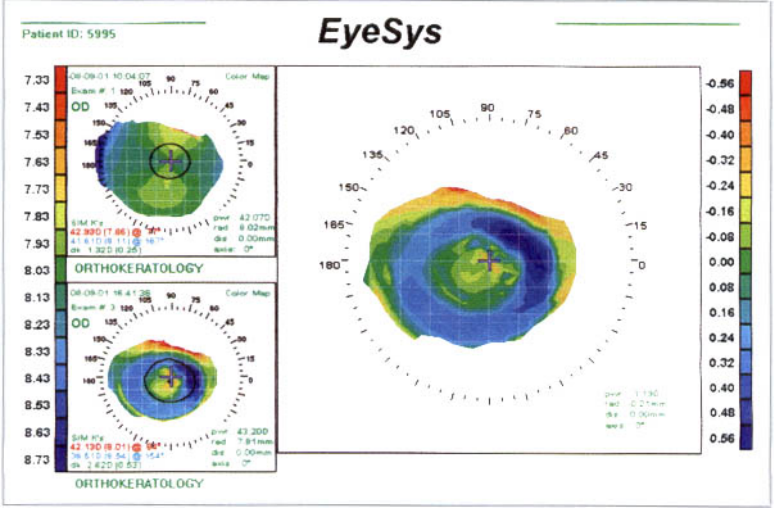

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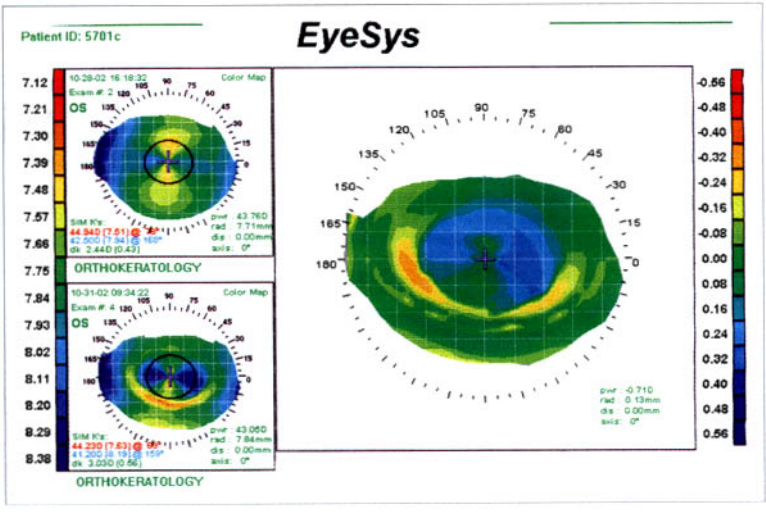

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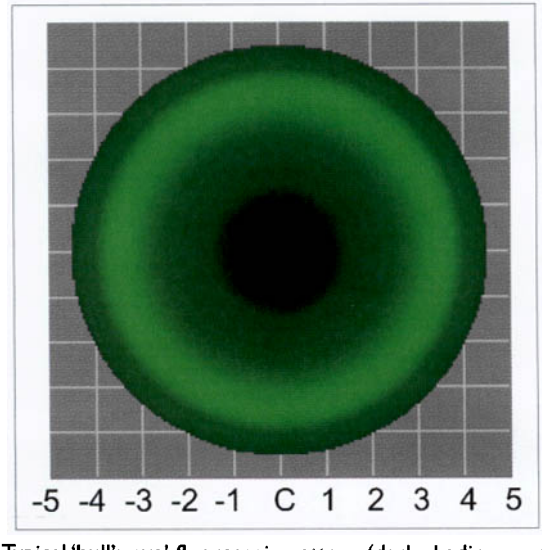

Plate 23 Typical 'bull's-eye' fluorescein pattern (dark shading represents corneal touch)

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CHAPTER 1

Background

1.1 Applied anatomy

1.1.1 The cornea

Corneal tissue is transparent and avascular, consisting of three layers and two membranes. It protects the interior ocular structures and contributes 70% of the refractive power of the eye. It has the following average dimensions:

Radius of front surface	7.86 mm
Horizontal diameter	11.8 mm
Centre thickness	0.52 mm
Peripheral thickness	1.00 mm

Epithelium

Provides a layer of protective cells. It is enhanced by microvilli, which are prominent irregularities increasing the surface area and providing a roughened surface to assist the adherence of the precorneal tear film.

Very minor corneal insult is covered in about 3 hours by neighbouring cells. Larger areas of damage are covered by the migration of cells from all layers of the surrounding epithelium. Lesions close to the limbus show conjunctival cells taking part in the cell migration.

Practical advice

Newly regenerated epithelium is very susceptible to damage. Lens wear should be suspended for a few days following any significant degree of corneal trauma such as overwear or severe abrasion.

Bowman's membrane

The relatively tough anterior limiting layer of the cornea. It consists of a very fine non-orientated fibrillar meshwork. If Bowman's membrane is damaged, fibrous scar tissue is laid down, resulting in a permanent opacity.

Stroma

An avascular, regular structure which ensures both the mechanical strength and optical transparency of the cornea. Approximately 78% water, it represents about 90% of the corneal thickness.

Descemet's membrane

The posterior limiting layer of the cornea. It is the basement layer of the endothelium and is elastic in nature.

Endothelium

A single layer of cells in direct contact with the aqueous humour. Its pump mechanism maintains the cornea's fluid balance, which is in turn responsible for transparency. No mitosis occurs, but enlargement and spreading of existing cells take place. Irregularity in the size of endothelial cells is termed *polymegathism*.

Corneal sensitivity

Innervation is by 70–80 sensory nerves entering the epithelium and usually losing their myelin sheaths within 0.5 mm of the limbus. The sensitivity of the cornea is greatest centrally and in the horizontal meridian. It reduces towards the vertical and is least at the periphery. Conjunctival sensitivity increases from a minimum at the limbus towards a maximum at the fornix and lid margins.

Sensitivity reduces with age and with contact lens wear. The first indication of reduced oxygen is a drop in corneal sensitivity, although clinically this may not be evident until there is a significant

and measurable decrease. Sensitivity varies in women during the menstrual cycle and there is also a diurnal variation, sensitivity being greatest in the evening.

1.1.2 The conjunctiva

A mucous membrane, continuous with the corneal epithelium. It is divided into a bulbar portion which covers the anterior sclera and a palpebral portion which lines the tarsal plate of the eyelids. The conjunctival glands or goblet cells secrete the mucoproteins found in the tears.

1.1.3 The eyelids

The orbicularis oculi muscle makes up almost one-third of the eyelid thickness. Behind lies the tarsal plate, which consists of dense fibrous tissue. The openings to the sebaceous meibomian glands lie in a single row along the lid margins. There are about 25 in the upper lid and 20 in the lower, and they are best observed by eversion.

1.1.4 The tear film

Functions

- Maintains a smooth optical surface over the cornea.
- Keeps the surface of the cornea moist.
- Acts as a lubricant for eyes and lids on blinking.
- Provides bactericidal action to protect corneal epithelium.
- Removes foreign bodies.

Practical advice

- Several contact lens problems relate to the eyelids so that lid eversion and thorough examination are essential prior to fitting.
- Lid eversion is an indispensable skill which the practitioner needs to develop.
- Meibomian gland dysfunction and blockage can contribute to dry-eye symptoms. These glands should always be investigated if patients report symptoms of dryness.
- Infection of meibomian glands causes styes or cysts.
- The average blink rate is about once every 5 seconds.

Composition

- An outermost oily, lipid layer secreted by the meibomian glands. Helps prevent evaporation.
- A central aqueous phase produced by the lacrimal gland and accessory glands of Krause and Wolfring.
- A mucoid layer, covering the epithelium, secreted by the conjunctival goblet cells.

The tear film is approximately 0.7 μm in thickness and about 90% of its volume is contained in the tear prism along the lid margin. The preocular tear film is adversely affected by the presence of a contact lens.

1.2 Applied physiology

A contact lens effectively occludes the cornea from its normal environment of oxygen, tears and ocular secretions. The effect depends upon lens thickness, size, method of fitting and material.

In this context, the following definitions are used:

- Anoxia occurs where no oxygen is present.
- Hypoxia occurs where there is reduced oxygen supply to the ocular tissues.
- Hypercapnia is the accumulation of CO_2.

1.2.1 Corneal metabolism

Constant metabolic activity in the cornea maintains transparency, temperature, cell reproduction and the transport of tissue materials. The main nutrients needed for these functions are glucose, amino acids and oxygen. Glucose and amino acids are provided by the aqueous humour, whereas oxygen is mainly derived from the atmosphere via the tears.

Each layer of the cornea consumes oxygen at its own rate.

Epithelium	40%
Stroma	39%
Endothelium	21%

Oxygen enters the cornea from both surfaces so that there is minimal tension in the stroma. *Oxygen tension* is the driving force that moves oxygen into the cornea. At sea level, it is 155 mmHg for the

open eye. Oxygen is supplied to the closed eye mainly by the palpebral conjunctiva, where the tension is about 55 mmHg.[1]

Corneal swelling as a result of anoxia can be explained by biochemical theory.[1] In simple terms, there is not enough oxygen available to convert the glucose by means of glycolysis into sufficient energy and allow the waste product, lactic acid, to diffuse quickly out of the tissue. Less energy is therefore available for cellular activity, more lactic acid is produced and this builds up in the stroma. Sufficient osmotic pressure is created to allow water to be drawn into the stroma faster than the endothelial pump can remove it, and so corneal swelling occurs.

1.2.2 Oxygen consumption

The rate of oxygen consumption appears to vary. The range is 1 to 10 ml/h/cm^2, with different patients having varying oxygen needs.

1.2.3 Corneal temperature

The normal corneal temperature of 33–36°C may alter during contact lens wear. The effect becomes more significant under closed eye conditions. The change in temperature may be only 3°C, but the rate of metabolic activity is so dependent on ambient temperature that the fine balance between available oxygen and corneal demands under the closed lid may be stressed by such a small temperature change. Corneal temperature can be measured by thermography (*see* Section 2.6).

1.2.4 Stromal acidosis

A drop in stromal pH induces a state of acidosis in contact lens wearers as a result of corneal hypoxia and hypercapnia. It appears that hypercapnia accounts for about 30% of the total pH drop, which can occur even without a change in corneal thickness.[2] Chronic acidosis may explain some of the alterations seen in both corneal structure and function following contact lens wear.

1.2.5 Tear osmolarity

Corneal thickness is also affected by the osmolarity of the tears. In the normal, open eye, the salt content of the tear film is about 10% greater than that of freshly produced tears due to evaporation. When the eye is closed during sleep, there is a shift in tear tonicity from the open eye value of about 0.97% NaCl to 0.89% NaCl following

6 hours sleep. This overnight hypotonic shift may be explained by reduced tear evaporation. The cornea responds to the less concentrated solution by drawing water into the stroma faster than it can be pumped out by the endothelium. Hence, on wakening, the cornea is found to have increased in thickness by about 5%.[3] Deswelling occurs rapidly during the first 2 hours the eyes are open.

1.2.6 Tissue fragility

Reduced epithelial adhesion is found following contact lens wear. It appears to be directly related to the reduced numbers of hemidesmosomes[4] due to loss of basal cell shape and chronic corneal hypoxia following contact lens wear. The hypoxia causes a decrease in the level of metabolic activity including the rate of cell mitosis. Cell life span increases and those at the anterior surface of the epithelium may not retain normal functional resistance. As a result of these changes, the overall resistance of the epithelium is lowered and the risk of infection increased. The thickness of the epithelium is found to reduce as cell production rate and wastage reach a new equilibrium. Such thinning has been observed in long-term extended wear patients.

1.2.7 Corneal sensitivity

One of the first, important effects of hypoxia, of which the patient is unaware, is a drop in corneal sensitivity.[5] Reduced corneal sensitivity is most obvious when a long-term wearer of PMMA is refitted with a hard gas-permeable material. One of the side effects is a period of lens and foreign body awareness that has not been present before. This indicates a rise in corneal sensitivity which eventually settles to the expected norm with an increase in available oxygen.

1.2.8 Closed eyelid conditions during sleep

The following changes are induced:

- Increase in temperature.
- Hypotonic shift in tear osmolarity as a result of increased evaporation.
- Slight acidic shift in tear pH as a result of retardation of carbon dioxide efflux from the cornea.
- Corneal oxygenation reduced from 155 mmHg (open eye) to 55 mmHg (closed eye).

1.3 Physical properties of materials

1.3.1 Oxygen permeability, oxygen transmissibility and equivalent oxygen percentage

Oxygen permeability

The oxygen permeability of a material is generally referred to as the *Dk*. In this nomenclature, *D* is the diffusion coefficient – a measure of how fast dissolved molecules of oxygen move within the material – and *k* is a constant representing the solubility coefficient or the number of oxygen molecules dissolved in the material.

The *Dk* value is a physical property of a contact lens material and describes its intrinsic ability to transport oxygen. It is defined as 'the rate of oxygen flow under specified conditions through unit area of contact lens material of unit thickness when subjected to unit pressure differences'.[6] It is not a function of the shape or thickness of the material sample, but varies with temperature. The higher the temperature, the greater the *Dk*.[7] The traditional units are 10^{-11} cm^2/s ml O_2/ml × mmHg (usually referred to as Fatt units), now also known as barrers. They are often omitted for convenience. When the international standard (ISO) unit of pressure, the hectopascal, is used instead of mmHg, the units of *Dk* are 10^{-11} cm^2/s ml O_2/ml hPa. To convert to ISO units, multiply by 0.75[8] (*see* Table 1.1): to convert from hPa to mmHg, multiply by 1.33322.

Table 1.1 Comparison of *Dk* and *Dk/t* for Fatt and ISO units (after Hough[8])

Material	*Dk*		t	*Dk/t*	
	Fatt units	ISO units	mm	Fatt units	ISO units
38% WC	9.5	7.13	0.06	15.83	11.88
55% WC	20	15	0.08	25.00	18.75
70% WC	35	26.25	0.15	23.33	17.50
Generic HGP	60	45	0.15	40.00	30.00

WC = water content

Oxygen transmissibility

Oxygen transmissibility is referred to as *Dk/t*, with Fatt units of 10^{-9} cm/s ml O_2/ml × mmHg and ISO units of cm/s ml O_2/ml hPa (see Table 1.1). Here, *t* is the thickness of the lens or sample of material, and *D* and *k* are as defined above.

The *Dk/t* for a particular lens under specified conditions defines the ability of the lens to allow oxygen to move from anterior to posterior surface. The value of *t* is generally an average lens thickness for powers between ±3.00 dioptres (D). Outside of this range it is necessary to apply a nomogram.[9] Oxygen transmissibility is not a physical property of a contact lens material, but is a specific characteristic related to the sample thickness.

The methods employed to undertake measurement of oxygen permeability are:

The polarographic method. Developed by Fatt during the 1970s for rigid and hydrogel materials – ISO 9913-1 (1996).

The coulometric method. Developed by ISO during the 1990s for use with highly permeable non-hydrogel materials – ISO 9913-2 (2000).

Surface effects

High *Dk* materials do not always give the oxygen performance on the eye that would be expected from laboratory results. The corneal swelling is equivalent to that of a lens with a *Dk* only 55% of the measured value.[10] This barrier effect is due to an intermediate water layer used in measurement (Table 1.2).

Edge effect

There is also an edge effect due to oxygen flow around the periphery of the sample, since in the laboratory flat as opposed to curved test pieces are generally used.[11]

Table 1.2 Corrected *Dk* values after surface, edge and boundary effects are taken into account (after Benjamin and Capelli[12])

Lens name	Corrected *Dk* value (Fatt units)	Previous uncorrected values
Boston IV	20.8	26.7
Boston 7	60.4	73
Boston ES	27.3	31
Fluoroperm 30	30.3	30
Fluoroperm 60	42.7	65
Fluoroperm 90	64.0	95

Boundary effects

The boundary effect (or boundary layer effect) is important for hard gas-permeable materials as there is resistance to oxygen permeation at the boundary between the tears and polymer surface when measurement is made under water/water conditions. For a clean lens, the boundary effect is constant whether the lens is thick or very thin. The effect therefore has a relatively greater influence on a thin lens. This means that a particular *Dk/t* value with a lens, for example, of thickness 0.35 mm will not be significantly improved compared with a thin 0.10 mm lens. For thin lenses, the boundary effect becomes more important in determining the dissolved oxygen permeability as the *Dk* of the material increases. There are virtually no boundary effect implications for polymethyl methacrylate (PMMA) and low *Dk* materials.

Equivalent oxygen percentage

The equivalent oxygen percentage (EOP) refers to the level of oxygen at the surface of the cornea under a contact lens. For the uncovered cornea exposed to the atmosphere at sea level, the amount of oxygen available is 20.9%, whereas with the eye closed the cornea receives 8%. The EOP obviously varies with altitude. A particular value for a material is that oxygen percentage on a scale of 0 to 21 which in a goggle experiment produces an 'oxygen thirst' after steady state has been reached, equivalent to that produced by a test contact lens worn for the same period of time. With lens wear, to avoid oedema, the EOP should be over 10%[13] (*Dk/t* = 24.1), and for no overnight swelling it needs to be as high as 18% (*Dk/t* = 87). All EOPs are dependent on lens thickness. An EOP profile (Figure 1.1) for a lens of known material and thickness shows whether it can provide enough oxygen to avoid corneal oedema.

Oxygen flux

- Is a measure of the actual amount of oxygen available to the corneal epithelium.
- Is expressed in $\mu l\ O_2/cm^2/h$.
- Decreases with contact lens thickness and hydration.
- The tear pump mechanism is needed to make up any deficiencies.

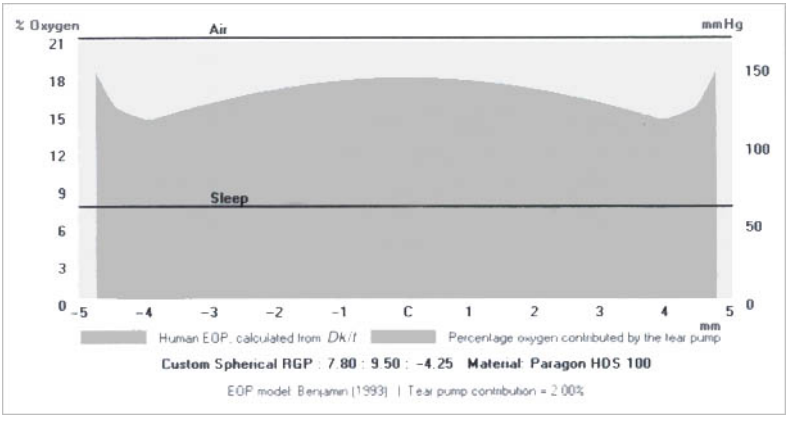

Figure 1.1 Equivalent oxygen percentage profile

Practical advice

Consistently reliable comparisons of various materials can be made only by the same person using the same instrument under identical conditions. Care is therefore required when comparing *Dk* measurements from different sources.[14]

1.3.2 Water content and water uptake

The water content is the amount of fluid taken up by a lens material as a percentage of the whole under specified conditions:

$$\text{Water content (\%)} = \frac{\text{Wt of fully hydrated lens} - \text{Wt of fully dehydrated lens}}{\text{Wt of fully hydrated lens}} \times 100$$

$$\text{Water uptake (\%)} = \frac{\text{Wt of fully hydrated lens} - \text{Wt of fully dehydrated lens}}{\text{Wt of fully dehydrated lens}} \times 100$$

Water is lost by evaporation when a hydrogel lens is worn on the eye. This is in part caused by a rise in temperature and is accompanied by a tightening of the fit (*see* Section 17.3).

Water balance ratio

This represents the water retention capability of the lens material.

$$\text{Water balance ratio} = \frac{\text{Time to dehydrate 10\%}}{\text{Time to re-hydrate from 90\% saturation}}$$

A high ratio indicates a material with stable hydration characteristics (Table 1.3).

Table 1.3 Comparison of water balance ratios (data supplied by Mark'ennovy)

Material	Water content	Water balance ratio
Polymacon p-hema	38	1.0
Crofilcon PMMA/CMA	38	0.9
Omnafilcon p-hema/PC	58	1.5
Hioxifilcon A	59	5.5

1.3.3 Wettability

Wettability is the ability of a drop of liquid to adhere to a solid surface. The lower the cohesive forces within a liquid, the greater the attraction between the fluid and surface. Thus, superior wettability enhances the spread of liquid over a surface.

Contact angle is a measure of the hydrophilicity of a surface. The contact angle may be measured in a variety of ways:

- Sessile drop method: measures the tangent to a drop of liquid placed on a sample surface (Figure 1.2).

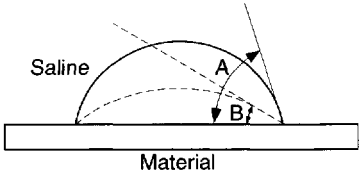

Figure 1.2 Sessile drop method (A, advancing angle; B, receding angle)

- Captive bubble method: measures the tangent to an air bubble formed on the surface of an immersed sample.
- Wilhelmy balance method. A sample is immersed or withdrawn vertically from a liquid.[15]
- Direct meniscus method.[15]

Both the advancing and receding angles are measured. These are formed when liquid is added to or removed from the controlled liquid drop used for measurement (Figure 1.2).

The lower the contact angle, the more wettable the surface (Figure 1.3). Typical values are given in Table 1.4, which demonstrates the great inconsistency between different methods. Comparisons can therefore only be made when the same method has been employed.

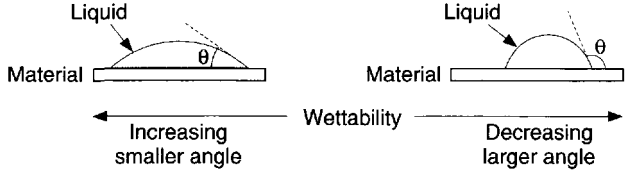

Figure 1.3 Surface wettability

1.4 Methods of manufacture

The current trend is for soft lenses to be made cheaper and more reproducible by means of mass production since the raw materials are relatively inexpensive. With hard lenses, however, the emphasis is on careful, stress-free manufacture, because the raw materials are costly and the laboratory is concerned to avoid waste.

Regulation

One of the most important influences on contact lens manufacture during the 1990s has been CE marking. Under the European Medical Device Directive (MDD), contact lenses are treated as medical devices and care products are treated as their accessories. Devices conforming to the directive should show the European standard CE marking, and from June 1998 it has been illegal to buy or sell a contact lens which does not have affixed the CE mark from a 'Notified Body', which would require the manufacturer to have some form of quality system. Manufacturers are required to have a formal quality control system such as ISO 9001/2000 and ISO 13485, the European equivalent.

1.4.1 Hard lens manufacture

- Conventional lathes to cut the back and front lens surfaces from buttons.

Table 1.4 Wetting angles

Material	Captive bubble[a]	Captive bubble[b]	Sessile[b]	Wilhelmy[b]		Direct[c]	
				Adv.	Rec.	Adv.	Rec.
PMMA	–	59.3	67.3	76.2	34.0	20	11
CAB	20	–	–	–	–	–	–
Boston II	21.5	36.5	82.7	74.0	27.4	46	14
Paraperm O_2	23.1	44.4	83.3	77.4	30.6	–	–
Polycon II	15	–	–	–	–	–	–
	receding	–	–	–	–	–	–
Boston Equalens	30	–	–	–	–	–	–
Fluoromethacrylate (Quantum)	24	–	–	–	–	–	–

[a]From manufacturers' details.
[b]After Sarver *et al.*[16]
[c]After Madigan, Holden and Fonn.[17]
PMMA, polymethyl methacrylate; CAB, cellulose acetate butyrate.

- Computer numerically controlled (CNC) lathes. Four types are available with different types of automation, so that both spherical and aspheric surfaces can be cut.[18]

Polishing

The time and speed of polishing, together with the wetness and composition of the polish, are all very important. Frictional heating and over-polishing of the lens surface cause poor lens wettability.

1.4.2 Soft lens manufacture

- Lathing as with hard lenses, using buttons cut from rods. The finished lens is then hydrated.
- Spin-casting, in which polymerization of the monomer and solvent takes place in open, spinning moulds (*see* Section 17.6).
- Cast moulding, which uses closed, disposable moulds with two components. Polymerization is by means of heat. The two methods are dry moulding, where the lens is moulded in the dry state and the edges finished by buffing; and wet moulding, in which the material is already hydrated (e.g. for disposable lenses).

- Liquid edge moulding, in which lenses are cast in polypropylene moulds in the dry state. The contact lens edge is formed by accurate control of pressure on the mould and the volume of polymer employed, leaving the edge intact when the excess polymer (termed *flash*) has been squeezed out.[19] There is no need to polish the edge with this process.
- Lightstream Technology which eliminates the need for solvents and extraction of toxic residues, e.g. with CIBA Vision's PVA based nelfilcon A. Rigid quartz moulds are used but the front curve and base curve moulds never actually touch. A mechanical system holds them microns apart. A circular mask blocks the UV light stream at the edge of the mould, preventing light interaction with the liquid material at the lens edge. This liquid is washed away whilst the photo-lithographic process forms the edge.

1.4.3 Toric lens manufacture

Soft lenses

- For conventional (non-disposable) torics, the method of choice is lathing using CNC lenticular back surface lathes and purposeful crimps to form the toric back surface under pressure. For the front surface, manual lenticular lathes with prism ballast capability are needed. The finished lens is polished before hydration.
- Disposable torics, which have a rather simpler design, are moulded.
- Recent developments are lathe waveform generators capable of generating complex, non-symmetrical geometries on surfaces that can be rotated off axis.

Hard gas-permeable lenses

- Conventional lathes in conjunction with crimping devices can be used to manufacture toric peripheries, back surface torics, bitorics and front surface torics.[20] The lens is lathed in the conventional manner, with a radius halfway between the required steeper and flatter meridians. It is then lathed a second time while held under a specified tension within the crimping device. The peripheral curves are then cut and the lens polished.
- Toric lathes that can generate a specified toric back surface.

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CHAPTER 2

Instrumentation

2.1 Slit lamp

The slit lamp provides the best method of observing ocular tissue in section under high magnification.

2.1.1 Instrument controls and focus

Instrument controls allow for variation in height, lateral movement and focusing. The illumination and observation systems are focused at a common point unless they are uncoupled to allow independent movement.

The optical system contains an *objective*, typically with ×3 to ×3.5 magnification, and an *eyepiece* with variable or interchangeable power. The normal range of total magnification gives ×6, ×10, ×16, ×25 and ×40, but with optional eyepieces up to ×70 is possible. Zoom optics give a smoother change of magnification.

The illumination system provides a slit width and height of up to 14 mm and contains a variety of filters depending on the slit

lamp model. The range available includes:

- White light.
- Neutral density or heat absorption filters – to reduce the light intensity.
- Cobalt blue filter – for use with fluorescein.
- Yellow filter (Wratten 12) – a barrier filter placed in front of the viewing system. This is used in conjunction with the cobalt blue filter to enhance the contrast of fluorescein. It allows the transmission of the green fluorescent light while at the same time blocking the blue light reflected from the corneal surface.
- Green 'red-free' filter – to enhance contrast when looking for corneal vascularization. This also increases the visibility of rose bengal staining.
- Diffusion filter (usually external).
- Polarizing filter – to reduce unwanted specular reflections and enhance the visibility of subtle changes.

The lamp housing can be rotated so that the slit beam may be used in a range of meridians. This is a useful technique for measurement (e.g. tear prism height) or axis location if associated with a graticule (e.g. for soft toric markings).

Focus is achieved by rotating the slit beam about its fulcrum[1] (Figure 2.1).

- If the illuminated area moves with the direction of the arm, the projected slit is in front of the focus position.
- If the illuminated area moves against the direction of the arm, the projected slit is beyond the focus position.

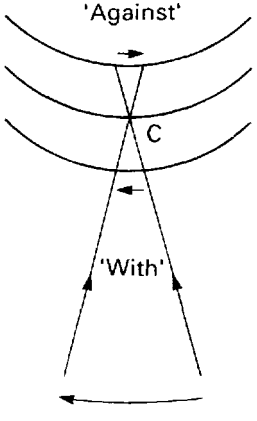

Figure 2.1 Focusing the slit beam (C, focus point)

- If the illuminated area remains stationary as the arm moves, the slit is exactly in focus.

2.1.2 Methods of illumination

Direct methods

The slit beam and microscope are focused at the same point to give:

- Diffuse illumination.
- Direct focal illumination.
- Indirect illumination.
- Specular reflection.
- Sclerotic scatter.

Indirect methods

The beam and microscope are uncoupled so that they are no longer focused at the same point to give:

- Indirect proper illumination.
- Sclerotic scatter.
- Retro-illumination.

2.1.3 Recommended slit lamp routine

- The instrument height is set for a halfway point in its travel range. The eyepieces are adjusted for the observer's prescription and pupillary distance (PD).
- The patient is made comfortable in relation to the height of the headrest and the instrument table.
- The patient closes the eyes and a slit beam is focused onto the eyelids. The beam is moved to the outer canthus without moving the instrument out of its range of focus, and the patient asked to open the eyes.
- Diffuse illumination is used for a general look at the ocular tissues under low magnification.
- In a darkened room, the cornea is examined with sclerotic scatter using either the microscope or the unaided eye for signs of opacities or oedema (Figure 2.2).
- Starting at the temporal limbus, the corneal tissue is scanned using direct focal illumination and a parallelepiped at least 2 mm wide. The slit beam is set between 40° and 60° to the temporal

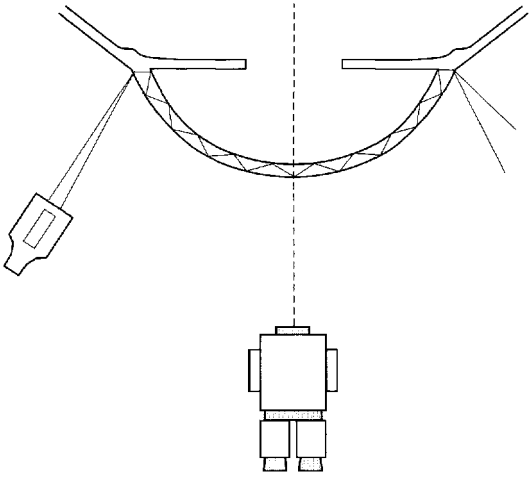

Figure 2.2 Sclerotic scatter by indirect method

side of the centrally placed microscope. Magnification should be about ×20. From the corneal apex to the nasal limbus, the illumination system can be swung to the nasal side of the microscope (Figure 2.3).

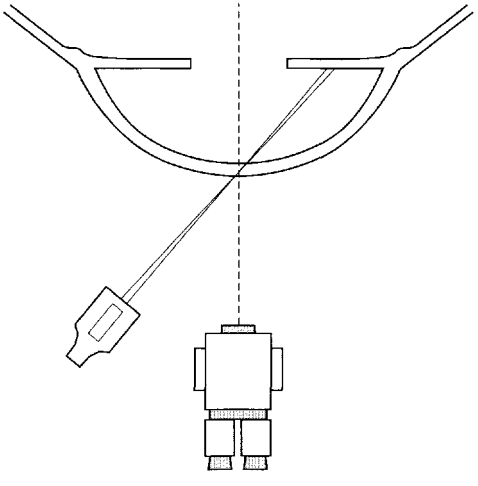

Figure 2.3 Direct focal illumination

- The beam is reduced to an optic section and the cornea examined in the same manner, localizing any abnormality discovered with the wide beam.
- The patient looks up and down, to take in the superior and inferior limbal areas.

- The direct slit beam is oscillated as the cornea is traversed. Any abnormality changes the scattering of light in the tissues and aids identification. The whole field of view contained by the beam and its surrounds is continuously observed with a combination of direct and indirect illumination.
- As the direct beam is moved across the cornea, specular reflection of the tear film occurs. Examination of this bright area, looking for any debris or oiliness, gives a qualitative assessment of the tear film. Changing focus to the rear of the beam section brings an area of endothelium into view (Figure 2.4). A general idea of endothelial regularity is obtained, rather than specific cell details. Each zone appears double, as the reflected light using this method enters only one eyepiece at a time.

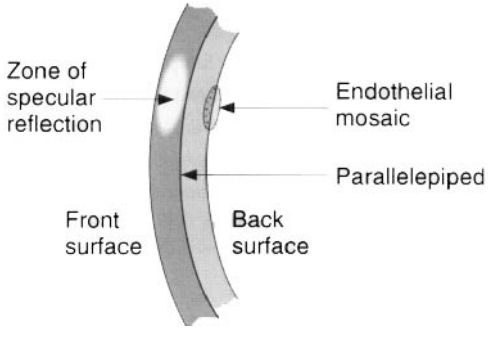

Figure 2.4 Specular reflection showing the endothelium

N.B. The endothelium looks like a patch of beaten gold to the side of the much brighter specular zone.

- The slit lamp is uncoupled to examine the cornea by means of retro-illumination. Direct, marginal and indirect retro-illumination ascertain whether any abnormality is more or less dense than the surrounding tissue. This is revealed by the way the light converges or diverges around the abnormality, and aids in its identification (Figure 2.5).[2]
- A small drop of fluorescein is instilled into each eye.
- Both the cornea and conjunctiva are then examined for evidence of epithelial staining using a broad scanning beam and the cobalt blue filter. A yellow barrier filter (Kodak Wratten 12) in the observation system gives enhanced contrast and assists examination of any staining present. Other stains used are rose bengal and, less commonly, alcian blue.

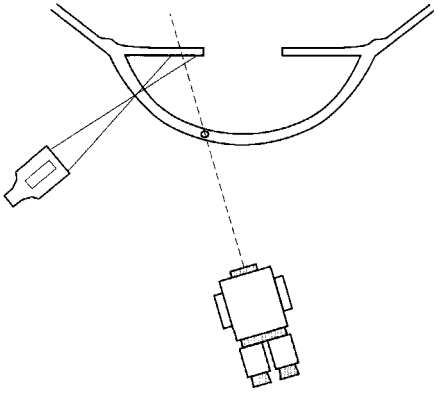

Figure 2.5 Retroillumination

Practical advice

- Correct use of the slit lamp requires the co-ordinated use of both hands – one to control the joystick and the other the slit beam.
- The slit lamp routine at an aftercare visit may be carried out in a different order. If the patient wears hard gas-permeable lenses and fluorescein has already been instilled to check the fitting, the blue light assessment can be done first, followed by white light and lid eversion.

2.2 Specialist instruments for higher magnification

Specular microscope

The specular microscope is used to give a highly magnified image (e.g. Tomey, ×200) of the corneal epithelium and more particularly the endothelium. Both of these structures would otherwise be difficult to observe because of their normal transparency. Light is focused near to the focal plane of the objective close to a point of reflection. This gives a specular image to permit an assessment of features such as cell density, polymegathism and corneal thickness.

Confocal microscope

The confocal microscope focuses the illumination system at exactly the same point as the focal plane of the microscope objective. Scanning through the structure under examination at different depths allows the instrument to reconstruct the image to give three dimensional observation, sacrificing field of view and depth of

field for resolution and magnification. Instruments typically give a magnification of 680× with a field of view of 300 μg × 220 μg, a depth of field of 10 μg and lateral resolution of 1 μg.

2.3 Keratometers and autokeratometers

Keratometers measure the curvature of the central cornea over an area of approximately 3–6 mm to determine:

- The radii of curvature.
- The directions of the principal meridians.
- The degree of corneal astigmatism.
- The presence of any corneal distortion.

2.3.1 Types of keratometer

There are two types of instrument, depending on the system of doubling employed to measure the separation of the mire images. Doubling helps in taking the reading, since rapid eye movements would otherwise make the measurement extremely difficult.

Practical advice

The same cornea measured with more than one instrument can result in a variety of readings because different keratometers employ:

- Different mire separations, so that the area of cornea used for reflection varies.
- Different refractive indices for calibration, so that the same radius could give a variety of surface powers.

Variable doubling

The mires have a fixed separation. The separation of the mire images is found by varying the doubling power. The Bausch & Lomb keratometer has two variable doubling devices and two sets of fixed mires (Figure 2.6). Both principal meridians can therefore be measured simultaneously, and it is called a *one position* instrument.

Fixed doubling

The doubling is fixed for a particular separation of the mire images. It is only by altering the separation of the mires themselves that a

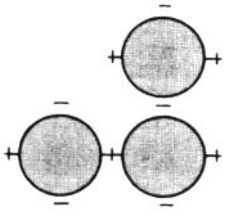

Figure 2.6 Bausch & Lomb mires

reading can be taken. These keratometers are called *two position* instruments and are based on the Javal–Shiötz design (Figure 2.7).

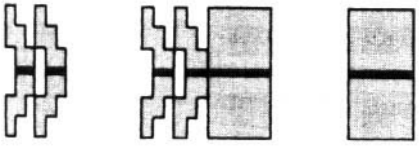

Figure 2.7 Javal–Schiötz mires

2.3.2 Focusing the eyepiece

Most keratometers have a graticule incorporated in the eyepiece. This should be focused prior to taking a reading to prevent accommodation giving an inaccurate result.

2.3.3 Taking a measurement

The patient should be comfortably seated, with the forehead positioned firmly against the headrest. Fixation should be accurate, with the other eye occluded. To help line up the optical system and locate the patient's cornea use:

- The sights attached to the instrument.
- The light from a pen torch directed through the eyepiece, looking for the corneal reflection.

The instrument is positioned initially at a greater distance from the cornea than necessary and slowly moved forward until the mire images come into view and are sharply focused. There should be four images, two of each mire either side of the centre. The middle pair are brought together until lined up in the correct position to take a reading (Figure 2.7).

Similar images need to be superimposed (Figure 2.8), whereas dissimilar mires are required to touch (Figure 2.7). In each case, the

instrument is rotated to orientate with the first principal meridian. The measurement is recorded and the second principal meridian found by rotating the instrument through 90°.

Figure 2.8 Superimposed images – Zeiss (Oberkochen) mires

Practical advice

- The principal meridians are not at 90° with an irregular cornea.
- Instruments usually show the corneal radius in both millimetres and dioptres.
- The power and radius scales have their maximum and minimum values at opposite ends.
- The axis of the meridian is usually obtained from an external protractor scale.
- Keratometry readings are expressed as *along* a particular meridian.
- Patients fitted in the USA generally have their keratometry and lenses specified in dioptres.

2.3.4 Extending the range

Radii steeper than the range of the instrument (e.g. keratoconus) can be obtained by placing a +1.25 D trial lens in front of the keratometer objective. At the flatter end, the range can be similarly extended with a −1.00 D lens. Prior calibration is necessary using steel balls of known radius.[3]

Practical advice

- For keratoconus, the Javal–Schiötz instrument is particularly useful, because the range at the steep end extends as far as 5.50 mm.
- Keratometers with circular mires (e.g. Bausch & Lomb) give a qualitative assessment of corneal distortion.
- Keratometers with circular mires can be used for measurement of NIBUT (see Section 5.6.2).

2.3.5 Topographical keratometer

The keratometer can also be used to explore the paracentral and peripheral areas of the cornea by means of a graduated fixation attachment.[4]

2.3.6 Autokeratometers

Autokeratometers determine the radii and principal meridians along the visual axis.[5] They can also measure peripheral radii at predetermined positions away from the corneal apex (e.g. at 23° and 30° with the Nikon Speedy K). Some instruments use computerized image processing to determine the flattest and steepest corneal radii with corresponding meridians and powers.

Autokeratometers achieve the measurement by calculating the distance between the reflected images from light-emitting diodes. The mires are usually circular and designed to reveal any corneal distortion. They also include distance indicators which enable the reading to take place. Despite the speed of measurement, steady fixation by the patient is essential. This is often assisted by a light-emitting diode, but the practitioner should carefully observe the eye during measurement as well as ensuring that the patient maintains a wide palpebral aperture.

Hand-held models (e.g. Nidek KM-500, Alcon Renaissance) allow single-handed operation and offer benefits in dealing with infants and young children.[6] They can also be employed in the operating theatre and where disabilities make conventional instruments impossible to use. The practitioner must be at the same height as the patient, although some models have a levelling device that automatically corrects the measured axis even if the instrument is held up to 15° off axis.

2.4 Corneal topographers

Videokeratoscopy

Videokeratoscopy (e.g. EyeSys, Tomey Technology, Zeiss Humphrey Systems) gives a more detailed assessment of overall corneal topography by means of modern computer analysis. These instruments are now in more general use and are mainly Placido disc based computerized corneal topography systems. The tear film reflects the image of the rings, which is captured by a digital video camera.

An algorithm process detects and identifies the position of the rings. The detection of the border of the keratographic axis, which differs depending on the system, is applied to the digital image, which then reconstructs the corneal curvature.[7] The results are presented as a topographic contour map of the cornea with colour used to indicate the curvature and power distribution for the area under analysis.

Curvature map options vary but the most common for contact lens practice are the tangential radius of curvature and the axial representation as these tend to differ more in the mid to outer corneal periphery to show up clinically significant differences. The colour scale normally runs from red at the steep end to blue at the flat end. The options are an 'absolute' scale which is consistent and allows direct comparison between each eye and on different occasions, or the 'normalized' scale which automatically adjusts the map into smaller colour intervals for greater detail but can vary depending on the particular cornea. Elevation maps depict relative height differences, useful for hard lens fluorescein patterns. High red areas indicate where fluorescein is displaced and the low blue areas where fluorescein pools. Difference maps are specifically helpful for monitoring corneal change or distortion as they represent a mathematical subtraction of two selected maps.

Topographers also provide a value for the apical radius of the cornea, r_o. It is important to note that this differs from any reading for the same eye obtained by keratometry because these instruments measure the cornea over an area approximately 3 mm around the apex (Figure 2.9).

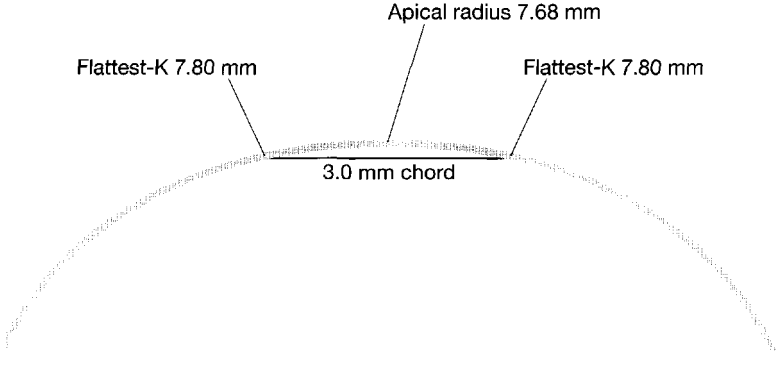

Figure 2.9 Topographical apical radius compared with keratometry

In contact lens practice, videokeratoscopy is particularly useful for assessing corneal eccentricity (*e*-value, *see* Section 8.4), surface

irregularity and irregular astigmatism. Subtractive plots are used to monitor corneal changes with orthokeratology (*see* Chapter 14) or when ceasing PMMA wear. Some instruments include a programme for designing the optimal contact lens based on the corneal map (*see* Section 8.5), together with simulated fluorescein patterns. Misalignment of the visual axis during measurement can give misleading results.

Extreme asymmetry or distortion is frequently seen with:

- Irregular astigmatism, distinguished from regular astigmatism in the corneal map by the lack of a symmetrical 'bow tie' pattern. Residual astigmatism, however, is not necessarily revealed by videokeratoscopy.
- Keratoconus.
- Penetrating keratoplasty.
- Contact lens-induced corneal warpage.
- Refractive surgery.
- Trauma.

A more recent version of corneal topographer is based on slit lamp technology using diffusely reflected light from the corneal surfaces, iris and lens (e.g. Orbscan). The images are acquired by video camera. The slit beam scans with over 7000 independently and directly measured data points. Ray trace triangulation determines elevations of the anterior and posterior corneal surface, giving limbus to limbus data. The corneal mapping produced gives a full analysis of the cornea under view, including a variety of refractive power maps; central (optical axis identification) and peripheral measurement data for contact lens fitting; full corneal pachometry (e.g. Pacscan module); and three-dimensional virtual reality models.

Photo-electric keratoscope

In the past, the original photo-electric keratoscope (PEK) produced a photographic record of corneal topography and explored the paracentral and peripheral areas of the cornea. The information was used to provide a computer-designed contact lens (e.g. the Wesley–Jessen system).

2.5 Image capture

Video and digital photography are the two methods currently employed to capture images related to contact lens practice. The

slit lamp, for optimal recording, should have continuous zoom optics and variable illumination.

Video images are captured using a CCD (charge coupled device) camera attached to the slit lamp, possibly via a beam splitter, and connection to a video recorder or computer. Cameras are either *one-chip* or *three-chip*, with the latter giving considerably better optical resolution.

Digital photography permits true digital imaging where the result is captured through pixels. The images are easy to store, can be copied without degradation and can be manipulated by means of computer technology. High-quality screen and colour resolution, however, requires large computer storage capacity, so CD-ROM or other archiving technology is often used to deal with this problem.[8]

2.5.1 Advantages of image capture over conventional photography

- Images are captured in real time, ensuring that the desired picture is recorded.
- Unsatisfactory images can be deleted and retaken.
- Where necessary, results can be demonstrated immediately to the patient.
- Digital images can be transmitted to other locations via a modem.
- There is no degradation of digital images over time.
- Images can be time or date stamped to provide an audit trail for legal protection.

2.6 Other instruments

Burton lamp

The Burton lamp uses ultraviolet light at a safe wavelength of about 400 nm. The lamp is also referred to as a *blue light* or *black light* and is used in conjunction with fluorescein (*see* Section 10.2.1).

Most Burton lamps are combined with a low-power magnifier, large enough to permit binocular viewing. Many models combine white light tubes and some incorporate a yellow filter to intensify the fluorescence.

Placido disc

The Placido disc is a flat, circular disc with alternate black and white concentric rings. The width and separation of the rings increase towards the periphery and are designed so that the reflections appear the same width when reflected from an average cornea. It gives a qualitative assessment of the regularity of the cornea itself. The eye is viewed through a convex lens in the centre of the disc. The Klein keratoscope is an internally illuminated version of the Placido disc.

Pachometer

The pachometer measures corneal thickness. It is used as a slit lamp attachment, fitted on the instrument post with a seperate image splitting eyepiece.

Thermography

Corneal temperature can be measured by a wide-field colour coded infrared imaging device, a thermography–visual system. Thermography has shown a pattern of ellipsoidal isotherms approximately concentric about a temperature apex (the coldest point) which is found to be slightly inferior to the geometric centre of the cornea.

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CHAPTER 3

Record keeping

The information in this chapter represents the authors' interpretation of the obligations laid on practitioners by existing regulations: it is not intended as a substitute for legal advice.

Since the NHS Act 1948, optometrists (opticians) have had a common law Duty of Care that 'records should be adequate'. Against the background of increasingly litigious patients and the possibly serious consequences of the misuse of contact lenses or solutions, it is essential for practitioners to maintain comprehensive written notes. Complete and proper records, as a matter of legal precedent, are now the first line of defence in most complaints of a clinical nature.

3.1 Legal implications

Practitioners, for their own protection, must take a full history of both ophthalmic and general medical factors. Negative findings should also be noted and a second opinion sought in case of doubt.

Informed consent

The doctrine of informed consent, which is pertinent to the preliminary discussion with all potential contact lens wearers, acknowledges that:

- 'The patient has a right to know and understand the risks as well as the benefits before agreeing to undergo a procedure as well as knowing if examinations revealed any abnormal findings.'
- Patients should also have an opportunity to ask questions and discontinue at any stage of fitting or treatment. Many practitioners prefer to avoid discussing possible negative consequences, but there could be serious legal problems if a patient claims lack of informed consent.
- In the UK, the Department of Health (DoH) has issued a leaflet called *Contact Lenses and You* which practitioners may use for their patients. It summarizes firstly the questions that patients should be asked by the practitioner at the preliminary visit and, secondly, the topics about which they should receive information when contact lenses are dispensed. The final page consists of a form to be signed by patients to acknowledge that they have been given full information and instructions on the type of lens selected, the care of those lenses, and advice should problems arise. The DoH recommends providing an out-of-hours telephone number in case of serious emergency.
- To avoid any misunderstandings, it is important to tell patients the possible adverse consequences of not following directions – i.e. non-compliance. The practitioner should never guarantee success, and at the dispensing visit patients should be given adequate instructions reinforced by written information. An acknowledgement or consent form may be used if appropriate, particularly in the case of a new or experimental technique.

Record keeping

When obtaining details of history, signs and symptoms, *open questions* should be used. This means that patients are given the opportunity to explain symptoms or describe their compliance with the instructions. The technique of open questions at aftercare examinations may prove less confrontational and give much more information than a simple 'yes' or 'no' answer. In addition, the use of *closed questions* often allows patients to provide the answer that they feel is expected by the practitioner.

Example:

When asking about the use of solutions at night:

Closed question:	Do you use the surfactant cleaner each night?
Open question:	What do you do each night?

The open question is much more likely to obtain the truth; the closed question may not.

Record all patients' comments that reveal non-compliance, followed by advice and warnings given. It is both useful and necessary to describe fully the fit and surface condition of the lenses. It is important to record corneal and other changes by means of grading (*see* Section 3.3) and a drawing, but also note negative findings. Thus, 'no staining' indicates that fluorescein has been used during the examination. Do not forget to note down the final advice given to the patient for resolving any problem as well as a suggested date for the next appointment.

In general terms, it is not a legal defence to say:

'I always do that...'
'I didn't write it down because it was normal.'
'I remember telling the patient that...'
'We always tell patients that...'

Legal action could occur several years after an alleged event, and memory alone, unsupported by the written evidence of the record card, will potentially leave the practitioner in a perilous position. Records should be kept for at least 10 years and professional indemnity insurance maintained for a minimum of 5 years after retirement.

If something is incorrectly recorded, cross it out but do not erase it. Never add to a record at a later date, intending to show that it was written at the time of the visit. Untruthful records will always automatically condemn, whatever the true circumstances of the case.

Telephone conversations

Always make a careful record of telephone conversations, particularly in respect of problems. The notes should be dated on the patient's card with details of advice given. The practitioner bears ultimate responsibility for advice given by unqualified staff and their comments should be similarly recorded.

Complaints

Details of any complaint and the response given must be carefully documented and dated. The details should include what was said by both the practitioner and the patient during the conversation.

Patient access to records

The 1990 Access to Health Records Act allows patients access to a copy of their records on written request. It is now important, therefore, not to write any derogatory or other comments that are not intended to be read by patients. They are also entitled to know the meaning of any coded abbreviations. The practitioner is able to charge a fee for the copy of the records.

There is also a duty to keep records in a secure place and to maintain patient confidentiality. If a request for the records is made when patients transfer to another practice, a copy or summary should be sent. The records are the property of the practitioner and the original should remain in the practice for reference and in case of future litigation.

Specification and replication

The General Optical Council has ruled that opticians have a duty to provide patients with details of their contact lens specification, stating 'An optician who fits a person with a contact lens shall on completing the fitting give to him a written statement of the particulars necessary to enable the lens to be replicated' (The Contact Lens (Specification) Rules 1989). The practitioner must make a decision based on clinical judgement when the fitting is complete. Up to this point, followed by an adequate period of time for checking, no contact lens prescription can be said to exist. The specification should be dated and is current for up to 1 year.

If a patient asks for the prescription to obtain contact lenses elsewhere and, in the practitioner's opinion, the fitting has not been completed, this fact should be clearly indicated on the written specification.

If replacement lenses are requested and it is over 1 year since the last examination, the patient should be advised of the need for continuing aftercare before lenses are ordered. In the event of refusal, it is advisable for this to be noted on the patient's record.

The prescription should enable the lens to be replicated accurately. Conversely, a practitioner should decline to order lenses from another practitioner's prescription if it is unclear, incomplete,

ambiguous or no longer current. Any modification to the prescription incurs a liability for the practitioner issuing the lenses.

Care should be exercised in repolishing or cleaning lenses fitted elsewhere. Without a full history, including visual acuities, the practitioner will be left in an invidious position if subsequently a complaint is made by the patient about either ocular problems or lens performance.

Responsibility

Implicit in the acceptance of a patient are responsibilities towards that patient. The examination should not be limited only to those aspects that concern contact lenses but must also include standard techniques to determine the patient's ocular health, consistent with the common law Duty of Care. In the event, for example, of a retinal problem which should have been apparent at the time of examination, the practitioner would be considered negligent if the problem had not been detected.

The College of Optometrists and the Association of British Dispensing Opticians each has its own set of guidelines relating to contact lens practice. These are intended to guide practitioners and fitters in their responsibilities for all aspects of contact lens practice. Such guidelines could well be used as the peer view in any legal case, and are currently used in this manner by the General Optical Council for complaint procedures. By virtue of their training, optometrists and medical practitioners have a greater duty of care in general than dispensing opticians.

Out-of-hours cover

Reference is made to out-of-hours contact in the guidelines of both professions to address potential complications with extended wear or overwear. Even though there is no legal requirement to give a contact telephone number, many practitioners either have an answerphone message explaining possible procedures in an emergency or give an appropriate home or emergency telephone number.[1]

Committee on the Safety of Medicines

In dealing with contact lens patients, any adverse reaction with a known cause should be reported using a Yellow Card provided by the Committee on the Safety of Medicines. The scheme, however, relates only to adverse reactions to contact lenses, medicaments or preparations that optometrists have themselves provided.

The value of these reports enables the statistical monitoring of adverse reactions to materials and solutions.

Product liability

Practitioners incur product liability for all products dispensed, including their accuracy and sterility. All materials must be safe, properly tested, and comply with any licensing regulations from the Committee on the Safety of Medicines, European directives and the Food and Drugs Administration (FDA) in the USA.

General advice

- The golden rule for patient records is *write it down.*
- If it wasn't recorded in writing, it wasn't seen, done or said.
- Always maintain comprehensive cover for professional indemnity.
- Do not treat conditions outside the scope of the practice or professional responsibility.

Medical Device Directive

The Medical Device Directive requires manufacturers of contact lenses and contact lens care products to issue information with all devices or packaging so that they may be used safely. Contact lenses are purchased and prescribed by eye-care practitioners but then issued to patients. The information provided by the manufacturer must therefore take into account the backgrounds of both groups.

- The glass vial, blister pack or mailer should include information on the lens material and lens parameters, including power.
- Soft contact lenses must indicate sterility and method used, batch code, and intended use of lenses (e.g. daily wear, extended wear or single use).
- Custom-made lenses should be labelled as such.
- Lens details should also include the manufacturer's expiry date and CE marking.
- The manufacturer's name and address together with the recommended use of the lens should be included with the packaging.

Manufacturers' leaflets should contain warnings in respect of: bacterial contamination; ocular side effects; circumstances under which contact lens wear should cease (e.g. red eye or pain); not using tap

water; washing hands before use; and that tamper-proof seals should be unbroken.

Written instructions from the practitioner should include: correct procedures for hand washing; how to insert and remove contact lenses; how to clean and maintain lenses; wearing schedules; arrangements for aftercare; signs and symptoms of adverse effects and how to deal with them; and advice when participating in water sports (*see* Section 28.4).

Despite the potential risks, plano tinted contact lenses with the function only of changing the eye colour were not until recently considered to be medical devices.

3.2 Record cards

The use of a standard designed record card helps to ensure that all procedures are completed and documented. The card is also used as a prompt during the consultation to avoid missing out routine procedures and questions. The use of diagrams aids description and is an ideal method of monitoring any changes. Photographs or image capture, however, are superior (*see* Section 2.5).

The visits that require full documentation are: Initial, Fitting, Dispensing and Aftercare plus adequate space to record order information and subsequent changes to the lens specification.

3.3 Clinical grading

A simple definition of clinical grading is 'putting numbers instead of words'. An important aspect of record keeping is to record findings in a reproducible way that can be easily understood by professional colleagues and provide a comparison between patient visits. Various scales are currently in use, while some practitioners have devised their own systems.[2] Successful grading needs to be simple, consistent and derived from an understanding of the clinical judgement necessary to discriminate between findings.[3]

Scales are either numeric, usually from 0 to 4, or based on identifying symbols. Definitions are helped by photographic or line illustration.

Published grading scales

There are two main published scales currently in use:

The CCLRU grading scale

Devised by the Cornea and Contact Lens Research Unit (CCLRU) in Australia and produced by Johnson & Johnson VisionCare. The grading scales are photographically illustrated and include: corneal staining, depth and extent; conjunctival staining; bulbar and limbal redness; lid redness and roughness; and endothelial polymegathism. The CCLRU scheme uses five grades:

0 = normal
1 = very slight
2 = slight
3 = moderate
4 = severe.

The Efron grading scale for contact lens complications

Devised by Professor Efron of University of Manchester Institute of Science and Technology (UMIST) and produced by CooperVision.[4]

The scale is illustrated with drawings by Tarrant on the basis that the desired level of change can be precisely represented whilst all other factors are kept constant. Eight complications are included, two from each of the conjunctiva, corneal epithelium, stroma and endothelium. The UMIST scheme also uses five grades from 0 to 4:

0 = normal
1 = trace
2 = mild
3 = moderate
4 = severe.

The Institute of Optometry grading scale

Instead of numbers it is possible to introduce + and − signs to be used with a scheme of consistent abbreviations. In this way, several other features can be graded. Such a system has been devised for use at the Institute of Optometry and includes the following items:

Fitting:	Hard and soft lenses
Lens surface spoilation:	Deposits, drying, greasiness and scratches
Tears:	Debris, grease, tear prism and break up
Cornea and conjunctiva:	Staining, oedema, vessels, abnormalities and endothelium
Lids:	Hyperaemia, follicles, papillae, cobblestone and roughness

The combination of scalar grades and measurements in millimetres enables the quantification of most problems. Corneal changes are in addition illustrated with scale diagrams. The location, depth and extent can all be recorded with careful drawing.

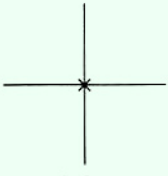
Fitting

Hard lenses

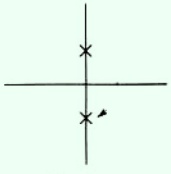
Central pattern:	Apical clearance	− Al +, Al + +, Al + + +
	Alignment	= Al
	Apical touch	− Al −, Al − −, Al − − −
Peripheral pattern:	No edge clearance	= Ec − −
	Minimum edge clearance	= Ec −
	Optimal edge clearance	= Ec
	Excessive edge clearance	= Ec +

Soft lenses

Centration:



Soft



Hard

Movement:	None	= Mov − −
	Only on upwards gaze	= Mov −
	Optimal	− Mov
	Mobile	− Mov +
	Excessively mobile	= Mov + +

Surface spoilation

Deposits:	None	− 0
	1 or 2 small deposits	= +
	Moderate deposits	= + +
	Heavy deposits	= + + +
Drying:	None	= 0
	Small area	= +
	Moderate area	= + +
	Complete dryness	= + + +

continued

Greasiness:	None	= 0
	Light greasiness	= +
	Moderate greasiness	= ++
	Heavy greasiness	= +++
Scratches:	None	= 0
	Light	= +
	Moderate	= ++
	Deep	= +++

Tears

Debris:	None	= 0
	Minimal	= +
	Moderate	= ++
	Severe	= +++
Greasiness:	None	= 0
	Minimal	= +
	Moderate	= ++
	Severe	= +++
Tear prism:	Minimal	= +
	Moderate, ≤0.50 mm	= ++
	Full, >0.50 mm	= +++

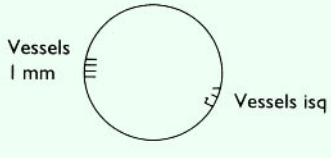
Cornea and conjunctiva

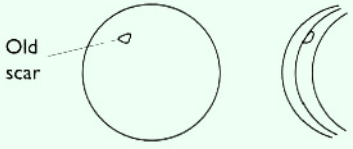
Staining:	No stain	= 0
	Superficial	= +
	Moderate	= ++
	Dense	= +++

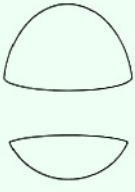
(extent and depth by drawing and comment)

Oedema:	Possible	= –
	None	= 0
	Definite	= +
	Unacceptable	= ++

Vessels:



Abnormalities:		
Endothelium:	Regular	= 0
		= +
		= ++
	Irregular	= +++
Lids		
Hyperaemia	Absent	= H0
	Minimal	= H+
	Moderate	= H++
	Severe	= H+++
Papillae:	Absent	= P0
	Micro, <0.3 mm	= P+
	Macro, 0.3–1.0 mm	= P++
	Giant, >1.0 mm	= P+++
Cobblestone	= C	
Follicles	= F	



The simple 0 to 4 scale can be easily and rapidly recorded on the record card for the most important features of the examination using a mnemonic such as ONIST, where:

O = Oedema
N = Neovascularization
I = Injection
S = Staining
T = Tarsal plate anomalies

R	0	1	0	1	2
	O	**N**	**I**	**S**	**T**
L	0	0	1	0	0

This would record trace neovascularization and staining plus slight CLIPC in the right eye together with trace conjunctival injection in the left. However, some sort of pictorial interpretation should always accompany any positive finding for medico-legal reasons.

3.4 Computerization of patient records

Data Protection Act

Practitioners are increasingly using computers for both practice management and storage of patients' clinical records. It is essential to comply with the provisions of the Data Protection Act in respect of continued registration and the duty to maintain confidentiality of patient information. Safeguards are therefore necessary to prevent unauthorized access to the records.

The registered entry for a practice must contain particulars of the data held and declare the intended purposes of those data. These are numerically classified into some 200 options and the appropriate category numbers must be declared. On average, there are six options that relate purely to patients.

There are eight data protection principles that data users must observe:

1 Data should be obtained and processed fairly and lawfully.
2 Data may be held only for registered uses.
3 Data may not be disclosed contrary to their registered purposes.
4 Only the minimum amount of information required should be kept for each patient.
5 Data must be accurate and, where necessary, kept up-to-date.
6 Data should be held for no longer than required and regularly deleted where necessary.
7 Proper security is essential. All reasonable steps should be taken to ensure that there is no accidental loss of data or improper access.
8 Individuals are entitled to know what personal data may be held on them, and are entitled to a copy of those data. If appropriate, inaccurate data may need to be corrected or erased.

With certain provisos, computer-generated records are admissible as evidence in a court of law. The system must be tamper-proof and needs to incorporate an audit trail that dates, times and records every change to the files as well as identifying the author.

Compared with written notes, there is a greater risk of accidental loss to computer records, so full back-ups must be taken regularly and stored securely. Patient records should be kept for at least 10 years, so any upgrading of the computer system must allow transference of data. To avoid mistakes, the practitioner must maintain supervision over the input of data, although this is frequently delegated to unqualified personnel.

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CHAPTER 4

Consulting room procedures and equipment

4.1 Hygienic procedures to avoid cross-infection

Hygienic procedures within the consulting room are extremely important to avoid any risk of cross-infection between patients as well as between patient and practitioner.[1] Standard practice should include the following:

Hand washing between patients

- For routine washing, use an antiseptic hand cleaner such as 4% chlorhexidine gluconate (e.g. Hibiscrub).
- After known contact with a source of infection, use an antibacterial hand cleaner such as 5% chlorhexidine in 70% isopropyl alcohol (e.g. Hibisol).

Decontamination and disinfection of trial lenses

All diagnostic lenses, which in effect means only hard lenses, must be routinely decontaminated and disinfected after use (*see* Section 4.3).

Disinfection of instrumentation

Surfaces of ophthalmic instruments that come into direct contact with the patient, such as chin rests, forehead supports and trial

frames, should be routinely disinfected (e.g. with wipes containing 70% isopropyl alcohol). Worktops should be similarly treated.

Temporary lens containers

Containers for temporary storage of patients' lenses during examination should be clean and sterile. With the advent of disposable lenses, the plastic blister containers in which they are supplied can be kept by the practitioner for single use with future patients. Glass vials can be autoclaved for repeated use.

4.2 Solutions and drugs

Water

Sterile water may be used for rinsing hard lenses, and prior to their insertion with a suitable wetting solution. It should not be used with soft lenses because of the likelihood of hypotonic adhesion to the cornea (*see* Section 17.8).

Tap water should not be used with soft lenses because of the risk of contamination by micro-organisms, particularly *Pseudomonas* and *Acanthamoeba*[2] (*see* Section 30.1.1). For the same reason, it should not be used for rinsing lens cases, although the use of boiled water followed by air drying is acceptable.

Saline (0.9% sodium chloride BP)

Normal saline is extensively used in contact lens practice for a variety of applications:

- Ocular irrigation.
- Rinsing lenses prior to insertion.
- Rinsing and cleaning lenses after fitting.
- Heat disinfection of soft lenses and subsequent storage.
- Wet cells of instruments for soft lens verification.
- Wetting fluorescein strips.
- Rewetting soft lenses.

Practical advice

- For soft lenses, use unpreserved saline.
- For hard lenses, use either preserved or unpreserved. Avoid aerosols for insertion because of air bubbles trapped under the lens.

Proprietary solutions

A range of proprietary wetting, soaking and cleaning solutions is required for both hard and soft lenses (*see* Chapter 27).

Staining agents

Fluorescein sodium BP

Used in 1% or 2% solution or, more usually, as impregnated paper strips which can be stored indefinitely if kept dry. Cross-infection is avoided by using a different strip for each patient and, in some cases, for each eye.

Fluorescein is the main method of checking hard lens fitting. It makes the tear pattern visible either by means of ultraviolet fluorescence with a Burton lamp or with the cobalt filter of the slit lamp. Fluorescein is almost entirely washed out of the eye within an hour, but a saline rinse is recommended before soft lens reinsertion to avoid any risk of discolouration. It is an important diagnostic aid because it stains damaged living corneal tissue green and the conjunctiva yellow. Contrast with the slit lamp can be enhanced by a combination of filters. A Wratten yellow (6 or 12) is used for observation in conjunction with either the standard cobalt filter or a Wratten 47A blue placed in front of the light source.

Fluorescein is also used to assess dry eyes by evaluating the break-up time and prism height of the tears (*see* Section 5.6).

High molecular weight fluorescein (e.g. Fluoresoft and Fluorexon)

The molecular weight is sufficiently great to prevent immediate penetration into most soft lens materials, although care is still required with high water content lenses as there may be some uptake and discolouration. (N.B. Do not subsequently disinfect with hydrogen peroxide since oxidation may well bind molecules of dye to the lens.) The degree of fluorescence is less than with standard fluorescein so that a yellow filter is recommended for observation. High molecular weight fluorescein can be used to:

- Assess corneal integrity.
- Evaluate the fitting of soft lenses, or hard/soft combination lenses (*see* Section 32.8).
- Assess break-up time (BUT) and tear prism immediately prior to soft lens fitting.
- Assess BUT and tear prism with soft lenses in situ.
- Locate axis markings of toric soft lenses.

Rose bengal 1%

Devitalized epithelial cells of the cornea and conjunctiva are stained bright red, indicating abnormal ocular conditions or skin disease. Rose bengal also stains mucus. It can cause mild discomfort if instilled directly into the eye, and takes several hours to absorb. A better technique is to use a cotton wool bud or impregnated paper strip.

Lissamine green

Equivalent to rose bengal but causing far less stinging. It is a diagnostic agent for evaluating corneal and conjunctival abnormalities.

Alcian blue

Stains mucus blue. Not generally used in contact lens practice as traces remain in the eye for too long, and rose bengal can be used for the same purpose.

Topical anaesthetics

Benoxinate (oxybuprocaine) 0.4%; amethocaine (tetracaine) 0.5% and 1.0%

Primarily employed with scleral lenses prior to taking eye impressions. Occasionally used with hard lenses when fitting very sensitive eyes (e.g. keratoconus), where lid spasm prevents lens removal, and for special techniques such as orthokeratology (*see* Chapter 14). Anaesthetics tend to retard healing of the corneal epithelium, and in cases of trauma and overwear are used only in the presence of extreme pain.

Antimicrobial agents

Chloramphenicol BP 0.5%

A prescription-only broad-spectrum antibiotic normally used as a prophylactic, ophthalmic anti-infective.

Brolene (0.1% propamidine isetionate)

Antibiotic with some efficacy against *Acanthamoeba*.[3] Available over the counter.

Other drugs

Sodium cromoglicate 2% (e.g. Opticrom, Broleze, Vividrin)

An anti-allergic, antihistaminic, over-the-counter preparation to reduce inflammation and mucus secretion. Used generally for a

period of 28 days in the treatment of CLIPC to stop irritation, mucus production and growth of papillae. Generally effective in reducing symptoms but not always the size of papillae. Technically a hay fever remedy and not strictly available for optometric treatment. Gives better results in reducing papillae with atopic patients.

Adrenaline (epinephrine) 1%

A conjunctival decongestant, often used after taking eye impressions.

Sodium bicarbonate 2%

Used to fill sealed scleral lenses on insertion and for ocular irrigation.

4.3 Decontamination and disinfection of trial lenses

General advice used to be simply that all trial lenses, hard and soft, must be thoroughly cleaned before use and properly disinfected after being worn. In 1999 the Spongiform Encephalopathy Advisory Committee (SEAC) advised the UK Department of Health (DoH) of a *remote theoretical risk* that abnormal prion proteins could be transmitted from one patient to another by means of a contact lens. Since this time, the DoH and professional bodies have effectively banned the reuse of trial lenses except in special complex cases.[4]

The following definitions are currently used to distinguish between trial lenses and special complex diagnostic lenses:

A *trial contact lens* is used to assess fitting, following which it is either disposed of or dispensed to the patient. Such lenses may not be reused.

A *special complex diagnostic contact lens* is used to assess the performance of the design on the eye. Although it may be of any type it is nearly always hard. The reuse of such lenses is permitted only under the following stringent conditions:

- The lenses should be used solely within the practitioner's premises and under the control of the practitioner at all times.
- The practitioner should ensure that decontamination is carried out to the highest possible standards.
- The practitioner should keep full records to show the usage of each lens.
- The practitioner should inform the patient of all the relevant risks and benefits associated with contact lens fitting.

In effect, this means that soft trial lenses are now almost never used, their place being taken by disposable lenses. With hard lenses, several laboratories have introduced simplified designs for so-called 'empirical fitting' where the lens is supplied on the basis of 'K' readings and refraction. This has never really been a satisfactory substitute, however, for assessing a diagnostic lens on the eye, and the fitting of complex cases such as keratoconus, grafts, irregular astigmatism, corneal distortion and post refractive surgery is not feasible without the use of diagnostic lenses. Hard lenses are therefore still used to a limited extent. As an alternative to the complete prohibition of diagnostic lenses, some form of safe decontamination and disinfection is required. The following represent current guidelines:

Decontamination and disinfection of hard gas-permeable and PMMA lenses

- After removal from the eye, a hard lens must not be allowed to dry prior to decontamination.
- It is cleaned in the usual way and then soaked in sodium hypochlorite 2% solution for one hour.
- It is then removed from the solution and shaken to remove excess.
- The lens must be rinsed very thoroughly with sterile normal saline solution or freshly boiled water at room temperature.
- It is then disinfected in the normal way by storing in a proprietary soaking solution since sodium hypochlorite is ineffective against spores and cysts of some micro-organisms.
- Low-powered PMMA lenses can be stored dry but require careful cleaning and rewetting before insertion.

Practical advice on lens decontamination

- Set aside a 'quarantine' area for lenses to be decontaminated.
- 2% Sodium hypochlorite solution should be stored safely with restricted access.
- 2% Sodium hypochlorite can be obtained as the proprietary solution, Menilab, from Menicon who also supply a solution for patient cleaning and disinfection. This consists of a mixture of Progent A (0.4% sodium hypochlorite) and Progent B (potassium bromide).
- Sodium hypochlorite is also available as Milton from pharmacies.

General advice

- It is no longer permitted in cases of loss or damage to loan old or obsolete trial lenses to patients while replacements are obtained.
- Avoid very viscous solutions for storage. A lens left for any length of time can be extremely difficult to remove from the vial.

Soft lenses

Following the above advice, it is essential that straightforward soft lenses are either dispensed to the patient or disposed of. Where a special complex diagnostic lens is used, it must be decontaminated first and then disinfected before use with another patient.

Various **disinfection** methods are possible:

- Heat. Autoclaving in 0.9% saline in sealed vials is the safest method, but high temperature can adversely affect the life span of some high water content lenses.
- Preserved solutions are the most convenient method but may be unreliable against *Acanthamoeba*, fungi and yeasts. A minimum of 4–6 hours is required before lenses can be reused, and some patients are sensitive to the preservatives.
- Most two-step hydrogen peroxide systems are more efficient and require less time. The procedures, however, are complicated for routine trial lens storage.

Historically, other methods such as chlorine tablets and microwave radiation have been used but these are no longer feasible.[5,6]

Warning

2% Sodium hypochlorite is extremely toxic and even concentrations much lower than this can cause severe damage to ocular tissues. Extremely thorough rinsing is absolutely essential after decontamination to ensure that no traces remain on the lens and for this reason it must not be used with soft lenses.

In case of accident

- The eye should immediately be irrigated with normal saline.
- Check the ocular surface with fluorescein for signs of epithelial damage.

- Arrange to re-examine the patient after 24 hours even if only minor signs are seen.
- Refer for medical examination if any serious signs are seen.
- Record details in the practice accident book.

4.4 Other procedures

4.4.1 Professional cleaning and rejuvenation

Hard gas-permeable and PMMA lenses

A modification unit is used to repolish hard lenses, recondition the lens surface and make other adjustments (*see* Section 30.6). There is also a Boston professional cleaner for laboratory or practitioner use.

Soft lenses

Magnetic stirrers incorporating a hotplate efficiently clean most soft lenses using oxidizing chemicals such as sodium perborate (*see* Section 27.4.5). Professional cleaning is now less often required with the advent of disposable lenses and frequent replacement schemes.

Ultrasonic devices are claimed to have a cleaning and disinfecting action with both soft and hard lenses, but have not achieved routine use. The same applies to methods employing ultraviolet irradiation.

4.4.2 Lens verification

The instruments for hard and soft lens verification are covered respectively in Sections 12.3 and 21.3.

4.4.3 Ancillary items

The following ancillary items are frequently required during fitting:

- Soft-ended tweezers, a lens lift or a glass rod for removing soft lenses from their vials.
- A glass rod or muscle hook is also useful for removing a dislodged lens from the upper fornix.
- Suction holders for use with hard lenses.
- Clean lens mailers or disposable lens trays for temporary storage when lenses are removed from the eye during examination.

- Glass vials or lens cases for storage when lenses are retained for professional cleaning.
- A crimping device for resealing pharmaceutical lens vials.
- Small self-adhesive labels for identifying lenses temporarily stored in unmarked bottles.
- Miscellaneous items including facial rule, grease pencil, pupil gauge and pen torch.

Practical advice

- Use a projection magnifier in the consulting room both for lens checking and for demonstrating lens condition to the patient.
- Regularly clean and disinfect wet cells filled with saline since they are a potential source of contamination. Hydrogen peroxide is generally the best method, but for any particular instrument seek the manufacturer's advice to ensure that there is no risk of damage.

4.5 Insertion and removal by the practitioner

4.5.1 Hard gas-permeable and PMMA lenses

Practical advice

- Ensure that the patient is as relaxed as possible.
- Avoid the patient actually seeing the lens approach.
- Ensure that both eyes remain open because of Bell's phenomenon.
- Keep the eyes still and slightly depressed by using a fixation target below eye level.
- The head and neck should lean firmly against a carefully positioned headrest.
- Stand to the side of the patient.
- Establish whether the lids are tight or loose, as this may influence the choice of method.
- With hard lenses, have a suction holder readily available for speedy removal in case of a bad reaction.
- For the same reason, have available local anaesthetic for emergency use.

Insertion

- The patient looks with both eyes either at a fixation target just below the horizontal or down at the floor.
- The upper lid is retracted.
- The lens is placed onto the cornea from above using either the forefinger or a suction holder.

With very tight-lidded patients and where fixation cannot be controlled:

- The patient looks to the extreme nasal position.
- The lens is placed onto the temporal sclera and slid gently across to the cornea.

Once the lens is in position, the patient is advised not to look up, but to half-close the eyes, looking down to minimize lid sensation.

Removal

- The head is leaned firmly back into the headrest.
- The patient fixates straight ahead.
- The lens is ejected with pressure applied either at the top and bottom lid margins or at the outer canthus.
- Alternatively, the lens is removed from the cornea with a moistened suction holder.

4.5.2 Soft lenses

Insertion

Soft lenses may be inserted either onto the temporal sclera and slid across or in the same way as hard lenses and placed directly onto the cornea.

Once the lens is correctly centred, the patient should notice only slight lid sensation. Any significant discomfort is probably due to a foreign body, either carried in with the lens or already present in the tear film and subsequently trapped. The lens should be removed, rinsed and reinserted. Mild discomfort, which patients may describe as stinging, is frequently cured by sliding the lens onto the temporal sclera with a circular motion and allowing it to recentre. Other, slightly more efficient, techniques are: (1) to slide the lens in the opposite direction to the discomfort; and (2) to displace the lens first temporally and then nasally to give complete excursion over the cornea.[7]

Practical advice

- If placed on the cornea with an air bubble, lenses are unstable at the moment of insertion and can be expelled by an involuntary blink.
- Most lenses (except some ultrathin) self-centre onto the cornea.
- Where necessary, place ultrathin designs, including some of the daily disposables, directly onto the cornea as these lenses are more difficult to recentre from the sclera.
- In difficult cases, allow the lens to dry on the finger for 15–30 seconds to prevent it from turning inside out and to make it easier for the tear film to attract it onto the cornea.
- Partially fold lenses to cope with very small palpebral apertures.
- With high plus or aphakic lenses, because of the effect of gravity, it may be easier to insert the lenses over a flat mirror with the patient's head in a horizontal position.
- With difficult, tight-lidded patients, it is sometimes much easier to insert the left lens first, since the angle of approach is better for a right-handed practitioner.

Removal

Removal is effected by pinching from the eye after moving the lens onto the temporal or inferior sclera, or by applying lid pressure in a way similar to that for hard lenses.

Practical advice

- Hard lens 'scissors methods', using the lids, can be tried with soft lenses but do not always prove effective because of their softness and size, particularly if ultrathin.
- Because of osmotic imbalance, a lens may sometimes appear to stick to the cornea. The eye should be irrigated with 0.9% normal saline, and after a short while the lens may be drawn gently onto the sclera and removed.

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Further reading

College of Optometrists Guidelines – *Cross-Infection Control in Optometric Practice*

CHAPTER 5

Preliminary considerations and examination

5.1 Discussion with the patient

It is important to discuss the various aspects of contact lenses at the first examination and assess potential suitability in relation to patient expectations, spectacle refraction, 'K' readings and slit lamp examination. The discussion, reinforced by introductory patient leaflets, should cover many other related aspects of lens wear and fitting:

- General health, including allergies, hay fever and systemic drugs.
- Ocular health, previous infections or surgery, and family history.
- Vision, nature of *Rx*, amblyopia.
- Previous contact lens history, success or failure.
- Reasons for contact lens wear.
- Types of lens currently available.
- Preconceived ideas and misconceptions.
- Outline of fitting procedures.

- What is required of the patient in terms of aftercare examinations, hygiene and proper use of solutions.
- Fees for both initial fitting and future aftercare.

5.2 Indications and contraindications

5.2.1 Advantages and disadvantages of contact lenses compared with spectacles

Advantages

- Wider field of view.
- Better for refractive anisometropia.
- Retinal image size almost normal with refractive ametropia (e.g. with aphakia, high minus).
- No unwanted prismatic effects with eye movements.
- Less convergence required by hyperopes for near vision.
- Avoid surface reflections.
- Minimal oblique or other aberrations.
- Cosmetically superior.
- More practical for sports.
- Avoid weather problems (rain, snow, fogging up).
- Provide good acuity for irregular corneas (keratoconus, trauma, and subsequent to refractive surgery).
- Therapeutic uses.
- Vocational uses.

Disadvantages

- Time required for fitting and adaptation.
- Handling skills required by patient.
- Hygienic procedures and lens disinfection necessary.
- Wearing time may be limited.
- Range of useful tints limited, especially with complex lenses.
- For binocular problems, only limited vertical prism possible.
- Greater convergence required by myopes for near vision.
- Lenses can be lost or broken.
- Problems with foreign bodies.
- Peripheral flare (especially at night).
- Deteriorate with use and age.
- Retinal image size disparity in axial anisometropia.

- Maintenance costs.
- Greater overall expense.
- Administrative procedures for disposable lens supplies.

5.2.2 Indications and contraindications

Indications

There are many patients for whom contact lenses are not merely a matter of cosmetic choice, but the best means of providing a satisfactory visual correction.

Visual

- Anisometropia.
- High myopia.
- Aphakia.
- Irregular corneas, scarring, keratoconus, grafts.
- Failures with refractive surgery.

Occupational

- Theatre, film and other stage performers.
- Armed forces.
- Professional sports.

Cosmetic

- To avoid spectacles.
- Change eye colour.
- Prosthetic lenses or shells.

Medical

- Therapeutic.
- Bandage.

Psychological

- Where the patient cannot accept wearing spectacles.

Other

- Sports.
- Physical inability to wear spectacles (e.g. allergy to frame materials, nasal problems).

Contraindications

There are a great many factors that may be considered as contraindications. Few of them are absolute, but all must be carefully assessed prior to fitting.

Visual

- Low refractive errors (e.g. +1.00/−0.75, −0.25/−0.50).
- Correction required only for near vision.
- Acuity with lenses may be worse than with spectacles.
- Prism required horizontally or >3 vertically.

Occupational

- Where legal constraints apply (e.g. commercial pilots, fire brigade).

Cosmetic

- Where spectacles are better with a large-angle squint.
- Where spectacles hide facial disfigurement.
- Where a patient has previously been reconciled to a long-standing scarred eye.

Medical

- Active infection or pathology.
- Recurrent corneal erosions (in some cases).
- Severe sinus or catarrhal problems.
- Allergies.
- Vernal catarrh.
- Diabetes (fragile epithelium).
- Anatomical (e.g. misshapen lid).
- Smoking.

Psychological

- Cannot accept the idea of a lens on the eye.
- Cannot tolerate any level of discomfort.
- Unable to cope with insertion and removal.
- Total perfectionist.

Sensitivity

- Cornea too sensitive.
- Lids or lid margins too sensitive.

Dryness

- Poor volume or quality of tears.
- Poor blinking.
- Dry environment.
- Drug-induced (e.g. antihistamine).
- Work-induced (e.g. VDUs).

Environment

- Dust.
- Fumes.
- Dryness (central heating, air conditioning, aeroplanes).
- Altitude (low EOP).

Other factors

There are other factors that may not necessarily be contraindications but which should be carefully considered:

Age

There are many patients such as aphakics who have been successfully fitted at an advanced age but the following should be assessed:

- The ability to handle lenses.
- Reduced pupil size.
- Reduced lid tonus.
- Tendency to ptosis and reduced palpebral aperture.
- Reduced tear flow.

Complexion

Patients with fair skin and blue eyes may well have more sensitive corneas and find adaptation more difficult.

Motivation

Patients must be sufficiently motivated to be successful with contact lenses. For example, those whose fitting is given as a present by a friend or relative often do less well if they do not really wish to wear lenses.

Compliance

It is obvious from the outset that some patients are unlikely to be compliant with instructions. It is better not to commence fitting

unless the practitioner is certain that they will follow advice in respect of:

- Lens cleaning and disinfection.
- Correct use of disposable lens supplies.
- General hygiene.

5.3 Advantages and disadvantages of lens types

5.3.1 Soft lenses

Advantages

- Good initial comfort.
- Ease of adaptation.
- Natural facial expression and head posture.
- Long wearing times.
- Low incidence of oedema.
- Rare occurrence of overwear syndrome.
- Absence of spectacle blur.
- Maintenance of corneal sensitivity.
- Good for intermittent wear.
- Low incidence of photophobia and lacrimation.
- Low incidence of flare, even with large pupils.
- Few problems with foreign bodies.
- Low risk of loss.
- Good for sports.

Disadvantages

- Astigmatism not corrected with spherical lenses.
- Variable vision.
- Near vision problems.
- Lens dehydration.
- Liable to damage.
- Deposits and ageing with conventional lenses.
- Disinfection and hygiene essential.
- Solutions allergies.
- Lens cleaning more difficult.
- Lens contamination.
- Limited life span.
- No modifications possible.
- Difficult to check.
- Conventional trial lenses are no longer available.

- Corneal vascularization with thicker or low water content lenses.
- Contact lens-induced papillary conjunctivitis (CLIPC).
- Expensive to maintain or replace regularly.

5.3.2 Hard gas-permeable lenses

Advantages

- Excellent visual acuity
- Correct corneal astigmatism.
- Variety of complex designs available.
- Ease of maintenance.
- Few solutions allergies.
- Minimal deposits with proper cleaning.
- High oxygen permeabilities (*Dk*s).
- Do not cover the entire cornea.
- Tear pump on blinking.
- Good long-term ocular response.
- Easy to check.
- Modifications possible.
- Lenses available in a range of tints.

Disadvantages

- Initial discomfort.
- Precise fitting required.
- Stringent regulations concerning the use and disinfection of diagnostic lenses.
- Foreign bodies.
- Risk of loss.
- Flare.
- 3 and 9 o'clock staining.
- Lens adhesion.
- Breakage and scratching.
- Greasing with some patients.
- Instability of some materials.

5.3.3 Polymethyl methacrylate (PMMA) lenses

PMMA lenses, despite their historical importance, are now almost never used as a first choice. They may be regarded as a little-fitted sub-group within the general category of hard lenses but are still worn by a sizeable number of long-standing patients.

Advantages

- Inertness of material.
- Stability of material.
- Reproducibility.
- Surface wettability.
- Quality of vision.
- Myopia control.
- Ease of manufacture.
- Ease of modification.
- Wide range of tints.
- Inexpensive.

Disadvantages

- Slow adaptation.
- High incidence of oedema.
- Corneal distortion.
- Spectacle blur.
- Risk of overwear syndrome.
- Endothelial polymegathism.
- Severely reduced corneal sensitivity.

5.4 Visual considerations

Corneal and residual astigmatism

Two basic assumptions are made when assessing the potential success of patients with astigmatism:

1 Total ocular astigmatism = corneal astigmatism + lenticular astigmatism.
2 Most corneal astigmatism is transferred through a soft lens to its anterior surface.

Patients may therefore be divided into four groups at their initial examination by reference to spectacle correction and 'K' readings.

Spherical cornea with spherical refraction

Rx: −3.00 DS
'K': 7.85 mm along 180° (43.00 D)
7.85 mm along 90° (43.00 D)

This is the ideal optical case for contact lens fitting. Vision should be equally good with either hard or soft lenses.

Spherical cornea with astigmatic refraction

Rx: $-2.00/-1.75 \times 90$
'K': 7.85 mm along 180° (43.00 D)
7.90 mm along 90° (42.75 D)

The astigmatism is almost entirely lenticular, so that the visual result is the same with either a hard or a soft lens. In either case, a front surface toric lens is required to correct the 1.50 D of residual astigmatism. For reasons of comfort a soft lens is the first choice.

Toric cornea with astigmatic refraction

Rx: $-2.00/-1.75 \times 180$
'K': 7.80 mm along 180° (43.25 D)
7.50 mm along 90° (45.00 D)

All of the astigmatism is corneal. A spherical hard lens, which neutralizes 90% of corneal astigmatism, or a toric soft lens should therefore be fitted.

Toric cornea with spherical refraction

Rx: −3.00 D
'K': 7.80 mm along 180° (43.25 D)
7.50 mm along 90° (45.00 D)

There is 1.75 D of with-the-rule corneal astigmatism together with an equivalent degree of against-the-rule lenticular astigmatism, giving a resultant spherical refraction. A hard lens form would neutralize the corneal but not the lenticular astigmatism. It would therefore leave a residual cylinder of -1.75×90. A soft lens should be used *because* it transfers all of the corneal astigmatism through to its front surface without optically neutralizing it.

General advice

Where there is an equal choice between fitting either a toric hard or toric soft, because of the much greater comfort it is generally better to fit a soft lens.

Near vision

Near vision can often cause problems despite good distance acuity. There are several reasons,[1] the main ones being:

- Altered accommodation/convergence ratio.
- Low myopes who previously did not wear spectacles.
- Early presbyopes requiring greater accommodation with lenses compared with spectacles.
- Conversely, hypermetropes are usually delighted with improved near vision.

Intermediate vision

Intermediate visual tasks such as VDU operation or painting can also cause problems. Particular difficulties occur with reading music, especially in dim illumination.

Contrast sensitivity and 'quality of vision'

Contact lenses of all types do not always give the absolute stability of vision achieved with spectacles.[2] Variations may be due to either the lens or environmental factors. The 'quality of vision' is very much a subjective interpretation and does not necessarily correlate with Snellen acuity. This can be confirmed by marked differences in contrast sensitivity readings while visual acuity remains the same.[3]

Monocular patients

Particular care is necessary when fitting essentially monocular patients. They are much more disturbed by factors such as lens mobility, flare, or unstable vision with toric and bifocal lenses. Similar considerations apply when fitting complex lenses to the dominant eye.

Practical advice

- Stability of vision is usually as important as acuity.
- Snellen acuity is not always a reliable guide to a patient's potential success. In some circumstances a good 6/9 may be more acceptable than a poor 6/6.
- Assess distance, near and intermediate vision separately in relation to work and visual requirements.
- Take particular care with monocular patients.

5.5 External eye examination

External examination prior to fitting is essential to allow the practitioner to:

- Confirm the normality of ocular tissues.
- Discover any condition that would preclude contact lens wear.
- Record for the future any other abnormality.
- Refer for medical treatment any active disease unrelated to contact lens considerations.
- Record for future reference any other abnormality or unusual feature.

Most parts of the examination are carried out using the slit lamp (*see* Section 2.1.3), looking for any evidence of the following conditions.

Cornea and limbus

- Vascularization or neovascularization.
- Staining.
- Desiccation.
- Infiltrates or other signs of previous infection.
- Scarring or opacification.
- Other signs of injury.
- Central thinning.
- Peripheral thinning (dellen).
- Pterygium.

Bulbar conjunctiva

- Injection.
- Prominent surface vessels.
- Desiccation.
- Pinguecula.
- Other irregularity.

Lids

- Position and size of palpebral aperture and any tendency towards ptosis.
- Lid tension.
- Irregularity of lid margins.
- Styes and cysts.
- Blepharitis.

- General condition of skin.
- Vesicles on lid margins.
- Patency of meibomian glands.
- Vernal conjunctivitis.
- General condition of the papillary conjunctiva and tarsal plate.
- Contact lens-induced papillary conjunctivitis (CLIPC) in previous lens wearers.
- Concretions.
- Make-up on palpebral conjunctiva.

Blinking

- Frequency.
- Completeness.

Practical advice

- Lid eversion to examine the tarsal plate and papillary conjunctiva is an essential preliminary.
- Most patients find it rather unpleasant.
- Eversion also gives clues to sensitivity and to how patients will react to having their eyes manipulated.
- Where eversion proves very difficult, it is often possible to examine sufficient of the papillary conjunctiva by instructing the patient to hold the head as far back as possible and look down. The upper lid is gently pulled away from the globe and the light from a pen torch directed towards the upper fornix.

5.6 Assessment of tears

Assessment of tears is an important part of the preliminary examination in order to:

- Predict potential success.
- Eliminate likely failures.
- Discover marginally dry eyes that would be adversely affected by a contact lens.
- Decide on the most appropriate lens type.

There are several ways of assessing the tears. Each has its own limitations depending upon factors such as temperature, humidity and whether the method is invasive or non-invasive.[4]

5.6.1 Assessment of the tear volume

Tear prism observation

The upper and lower tear prisms hold 90% of the tears, so that the height and width give a reasonable assessment of tear volume. Reduce the height of the slit lamp beam and adjust it to the horizontal position. The width value can then be used as a measurement guide for the height of the tear prism.

- Slit lamp observation either with or without fluorescein gives an overall view of the entire prism.
- The approximate height of the prism in a normal tear film is 0.2–0.4 mm at the centre and 0.1–0.2 mm at the periphery.[5]
- Reduced height suggests reduced tear volume.
- Increased height could indicate poor drainage because of obstructed puncta or an excessive aqueous layer giving a watery tear film.
- The regularity of the prism along the length of the lid margins indicates the potential of the film to wet the eye consistently. This reduces with age.
- Frothing of the tears within the prism indicates lipid contamination, probably due to meibomian gland dysfunction.

Practical advice

- To gain this experience, routinely observe all patients to get used to the norm. Initially, aim to recognize an obviously defective prism of half normal height and subsequently refine observation to three-quarters of normal. The value in millimetres is less important than the departure from normal.
- Insertion of fluorescein destabilizes the tear film and can increase the height of the prism.

Schirmer test

This is a quantitative test of tear production which uses strips of Whatman no. 1 filter paper with notched ends 5 mm wide (Figure 5.1).

The notched end is folded twice to give better balance on the lower lid and placed against the bulbar conjunctiva near the outer canthus. The eye looks up and in, to avoid contact with the cornea.

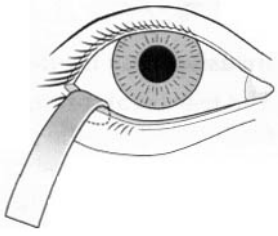

Figure 5.1 Schirmer tear production test

The lower lid is released to retain the folded part in place. The remainder of the strip projects at right-angles from the lid.

The result is recorded either as the length of paper moistened in 5 minutes (normal = 15 mm) or the time taken to wet a length of 10 mm (normal = 3 minutes).

Practical advice

- The invasive nature of the strip causes reflex tearing.
- The results do not necessarily represent the patient's norm, but do indicate the presence or absence of reflex lacrimation.
- The result is quantitative and can be recorded for future comparison.

Phenol red thread

The test consists of a cotton, two-ply thread impregnated with phenol red (ZoneQuick – phenolsulphonphthalein). The thread is pH sensitive and changes from yellow to red as it is wetted by the tears.[6] The folded 3 mm portion of the thread is placed as for the Schirmer test (Figure 5.2). The normal result gives 10–20 mm moistened in 15 seconds. Measurement must be taken of the entire length actually wetted regardless of the position of the fold.

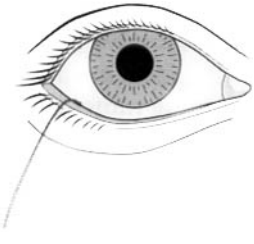

Figure 5.2 Phenol red thread

5.6.2 *Tear film stability*

Invasive tear break-up time

The tear break-up time (BUT, or TBUT) is the time in seconds for the break-up of the precorneal tear film in a non-blinking eye. It is a convenient and simple test to perform, but its invasive nature requires careful interpretation of the results.

A drop of fluorescein is instilled into the eye. The slit lamp with blue light is used to observe the patient after a few blinks have mixed the fluorescein completely into the tear film. The patient stares while a wide blue beam is focused onto the cornea. The time is recorded for the first break in the tear film, shown as a dark blue patch against the otherwise green background of fluorescein.

A normal result gives a BUT of 15 seconds or greater.

Practical advice

- If 15 seconds elapse with no break in the tear film, ask the patient to relax since the tear film is well within normal limits and the test can become uncomfortable after about 20 seconds.
- The position of the first break is often significant, especially if it corresponds to an area of staining or occurs at the lower limbus, since it suggests potential problems of desiccation.
- A supplementary test, possibly of even greater value, is to observe the relaxed patient blinking normally to determine whether the tear film breaks up between blinks or remains unbroken until the next blink.
- The use of fluorescein destabilizes the tear film and can give erroneous results.
- The temperature and humidity of the consulting room can affect the result.
- Only a large variation in results (5–10 seconds) is significant.

Non-invasive tear break-up time

Non-invasive break-up time (NIBUT) methods measure the stability of the tear film without a staining agent. Most show only tear thinning rather than a true break in the tear film.

- One position keratometer with circular mires (e.g. Bausch & Lomb). The time is recorded when distortion is first seen in any part of the mire pattern. The three mires cover only a very limited

amount of the central 3.00 mm of corneal surface, making this a rather inaccurate method.

- Hir-Cal grid. An extension of the above technique using a circular grid set within the Bausch & Lomb keratometer.[7] Observation is still made only of the central corneal cap so that the first signs of break-up may be missed if they occur in the periphery.
- Loveridge grid. A modification of the Klein keratoscope (*see* Section 2.6) with a fine grid pattern and +22.00 D observation lens. A convenient hand-held method with inbuilt stopwatch.[8]
- Tearscope. Uses a cold cathode ring light source[9] (*see* Section 5.6.3). Observation of the reflected light will show a true NIBUT, the norm being about 40 seconds.

5.6.3 Tear film analysis

Slit lamp techniques

- Specular reflection. Observes the bright zone of specular reflection with the slit lamp (*see* Section 2.1.3). Allows debris in the tears to show up as dark spots which move on blinking.
- Narrow-field specular reflection. The first Purkinje image, seen with reduced slit lamp illumination, appears either plain or enhanced with coloured fringes. It gives a relative estimate of lipid layer thickness and can indicate contamination of the lipid layer. Coloured fringes alone are difficult to assess, but when found together with irregularity of the tear prism, they strongly suggest a poor tear film.

Keeler Tearscope-Plus

The original Tearscope was devised to make use of specular observation of the tear film over the entire cornea. The Tearscope-Plus was the redesigned model with a range of inserts for more extensive tear film and ocular surface imaging.[10] These included:

- Concentric rings for Placido disc type observation.
- A coarse grid for hand-held observation of the rings. Coarser grids are also used to visualize localized corneal surface damage.
- A fine grid insert for tear film observation and NIBUT using the slit lamp.
- Blue and yellow filters for fluorescein observation (*see* Section 2.1.1).
- Dark field observation of contact lenses is made possible by observing the lens position at the back of the Tearscope-Plus.

The illumination source of the Tearscope-Plus, now also out of production, is a double concentric, cold cathode light. The design positions the light away from the corneal surface, eliminating heat transfer and avoiding tear evaporation.

Other observations can be made for the pre-ocular tear film (POTF):

- Lipid layer contamination and classification.
- Lipid layer spread during blinking.
- Tear prism classification for regularity and height.
- Tear prism continuity in the corneal and conjunctival area.
- Measurement of NIBUT with or without a grid.
- Meibomian gland manipulation and observation of lipid secretion spreading over the tear surface.

Only the lipid layer is visible by specular reflection. As it thickens, a pattern of flowing lipids appears. An amorphous pattern (i.e. devoid of detail) is seen with increased thickness. The ideal picture appears without coloured patterns. These are produced by interference and relate to abnormal clumps and irregularity in the thickness of the lipid layer. If the aqueous layer is observed, it will be seen as a dark grey surface where the lipid layer has broken (Table 5.1).[11]

Similar observations can be made on contact lenses for the pre-lens tear film (PLTF):

- Lipid layer when present.
- Coloured interference fringes of the aqueous layer.
- NIBUT.
- Surface contamination.

For soft lens wearers, the most common use of the Tearscope-Plus is the early detection of dry-eyed patients. This in turn can be used to suggest the optimal frequency of replacement for disposable lenses. With dry eyes, the lipid layer may be absent and the thin aqueous layer will display coloured fringes with surface contamination and a reduced NIBUT.

With hard gas-permeable lenses the lipid layer rapidly disappears. The aqueous layer consequently thins, showing a coloured fringe distribution over the lens surface. The NIBUT recorded when the tear film is seen breaking is typically about 5 seconds.

The non-invasive drying-up time (NIDUT) is recorded when the coloured fringes have all disappeared, on average at about 20 seconds. At this point, the surface is devoid of tears.

Table 5.1 Description of the appearance and the approximate thickness of the lipid layer patterns (with abbreviations) observed by specular reflection with the Tearscope Plus

Lipid layer pattern	Code	Appearance	Estimated thickness (nm)
Absent	Abs	No lipid layer visible	<10
Open marmoreal meshwork	M(o)	Indistinct, grey, marble-like pattern, frequently visible only by the post-blink movement	10–20
Closed marmoreal meshwork	M(c)	Well defined, grey, marble-like pattern with a tight meshwork	20–40
Flow	F	Constantly changing, wave-like pattern	30–90
Amorphous	A	Blue-whitish appearance with no discernible features	80–90
Normal coloured fringes	CF(n)	Appearance of coloured interference fringes	>100
Abnormal coloured fringes	CF(ab)	Discrete areas of highly variable coloured fringes. These change rapidly in colour over a small area	Variable

Staining agents (*see* Section 4.2)

Fluorescein

Fluorescein staining in the horizontal or inferior sectors of the cornea is an indication of tear film dehydration. Staining of the conjunctiva will also be seen at the nasal and temporal positions and in the region of any elevated tissue.

Under normal conditions, fluorescein blends immediately with the tear film. If there is poor mixing, the tear prism and any conjunctival staining may both present a dull orange hue. This effect is often unilateral, and with time the colour changes to the more usual bright fluorescein green. On fluorescein instillation, the patient should initially be encouraged not to blink. If a dull orange hue is seen, this indicates tear film dysfunction, either temporary or habitual. Often there is a marked difference between the eyes.

On blinking, the dye will eventually mix normally with the tears when the lipid layer has been penetrated.

Rose bengal

Rose bengal can be used to assess the severity of any staining and help decide on the future management of the patient. Any significant uptake of the dye prior to fitting suggests that it is unwise to proceed with contact lenses. The dye is viewed with white light and in the examination routine it follows fluorescein observation.

Patient questionnaire on dry eyes

Screening with the aid of a questionnaire prior to contact lens fitting can give valuable information in assessing a marginally dry-eyed patient. Questionnaires have been published by McMonnies[12] and, in a modified version, by CooperVision and others.[13] The topics covered are:

- Symptoms experienced and extent of problems.
- Atmospheric conditions that make the eyes sensitive.
- Effects of alcohol.
- Medication taken (e.g. hormone replacement therapy, antihistamines, tranquillizers).
- Presence of systemic conditions with dry eye side effects.
- Reports of dryness in other parts of the body.
- Sleep-induced problems.

5.7 Patient suitability for lens types

The majority of patients are now fitted with either hard gas-permeable or soft lenses, although most patients given the choice will opt for soft on grounds of comfort. PMMA, scleral or other lens forms are needed only occasionally. It is often immediately obvious from the preliminary examination and discussion which type is likely to be more suitable. Many patients can be successful with either hard or soft lenses, but ideally diagnostic lenses of each type should be used in order to evaluate lens performance on the eye.

5.7.1 Hard gas-permeable lenses

Hard gas-permeable lenses should be considered in the following cases:

New patients

- Soft trial lenses give unsatisfactory vision.
- Significant corneal astigmatism is present (>1.00 D).
- Corneal irregularity is present (e.g. keratoconus, grafts).
- Dry eyes have been diagnosed.
- An extremely high *Dk* is required.
- VDUs are used full-time.
- Dry geographic or working environment.
- There is a history of hay fever, vernal conjunctivitis or giant papillary conjunctivitis prior to fitting.
- The appearance of the limbal vessels prior to fitting suggests that vascularization is a likely consequence with soft lenses.
- Patients are unlikely to comply with soft lens disinfection and daily disposables are not appropriate.
- Handling difficulties are likely with soft lenses (e.g. low myopes with ultrathin lenses; very small palpebral apertures).

Refits or previous failures

Where soft lenses have failed because of:

- Poor vision.
- Poor comfort.
- Dry eyes.
- Poor centration or fitting.
- Poor handling or repeated breakage.
- Corneal vascularization.
- CLIPC.
- Repeated infections.
- Unacceptably short life span with conventional lenses.
- Frequent deposits.
- Solutions allergies.
- Materials allergy.

5.7.2 Soft lenses

Soft lenses are the likely first choice in the following cases:

New patients

- Hard diagnostic lenses give unsatisfactory comfort because the lids or cornea are obviously too sensitive.
- Hard diagnostic lenses give poor centration.

- The *Rx* is spherical and hypermetropic.
- The *Rx* is spherical with astigmatic 'K' readings (*see* Section 5.4).
- The pupils are very large or decentred.
- Rapid adaptation is required.
- An irregular wearing schedule is expected.
- Where there is poor or incomplete blinking prior to fitting.
- Older patients.
- There are awkward anatomical features likely to give poor hard lens positioning (e.g. low lower lid; proptosed eyes; decentred corneal apex).
- Dusty geographic or working environment.
- Patients need the security of a lens which it is almost impossible to dislodge from the eye (e.g. sports or vocational use).

Refits or previous failures

Where hard lenses have failed because of:

- Poor comfort.
- Poor vision.
- Flare and reflections.
- Poor centration.
- Oedema (consider silicone hydrogels).
- Poor blinking.
- 3 and 9 o'clock staining or vascularization.
- Other persistent corneal staining.
- Persistent conjunctival injection.
- Poor handling or repeated loss.

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CHAPTER 6

Lens types and materials

The international standard method for the classification of both hard and soft contact lens materials is BS EN ISO 11539: 1999. This is a published European Standard and so has the status of and replaces the former British Standard for contact lenses.

Each material is classified by a six-part code (Table 6.1):[1]

- Prefix.
- Stem.
- Series suffix.
- Group suffix.
- *Dk* range.
- Surface modification code.

The oxygen permeability (*Dk* range) part of the code is a numerical designation that categorizes the oxygen permeability in ISO *Dk* units at intervals which are considered significant in contact lens wear. For both lenses and materials, the oxygen permeability is measured according to ISO 9913-1 or ISO 9913-2 and the *Dk* range is then denoted by numbers as indicated in Table 6.2.

Table 6.1 Material classification (after Hough[1])

Prefix	This is one of two parts of the code administered by United States Adopted Names (USAN). Use of the prefix is optional for all countries other than the USA. For example, etafilcon A has the USAN code 'eta'; the use of this code is optional outside of the USA.	
Stem	*filcon* for soft lenses (hydrogel-containing lenses having at least 10% water content by mass) and *focon* for rigid lenses.	
Series suffix	Also administered by USAN, a capital letter added to the stem to indicate the revision level of the chemical formula: A is the original (first) formulation, B the second and so on. Can be omitted if there is only one formulation.	
Group suffix	**Rigid lenses**	**Soft lenses**
I	Does not contain either silicon or fluorine	<50% water content, non-ionic
II	Contains silicon but not fluorine	≥50% water content, non-ionic
III	Contains both silicon and fluorine	<50% water content, ionic
IV	Contains fluorine but not silicon	≥50% water content, ionic
***Dk* range**	A numerical code which identifies the permeability in ranges which are considered significant in contact lens wear. *Dk* is expressed in ISO units: $(cm^2/s) \cdot [ml\ O_2/(ml \cdot hPa)]$.	
Modification code	A lower case m which denotes that the surface of the lens is modified, having different chemical characteristics from the bulk material.	

Example 1. ISO classification applied to a hard gas-permeable material, Paragon HDS:

Paflufocon B III 3

Paflu: USAN prefix.
focon: Stem, indicating a hard lens material.

Table 6.2 Oxygen permeability (*Dk* range). *Dk* units are: $(cm^2/s) \cdot [ml\ O_2/(ml \cdot hPa)]$ (after Hough[1])

0	<1 *Dk* unit
1	1–15 *Dk* units
2	16–30 *Dk* units
3	31–60 *Dk* units
4	61–100 *Dk* units
5	101–150 *Dk* units
6	151–200 *Dk* units
7, ...	Add new categories in increments of 50 *Dk* units

B: USAN series suffix, indicating the second formulation of this polymer.
III: Group suffix, indicating a material containing both silicon and fluorine.
3: A *Dk* in the 31–60 range of ISO units.

Example 2. ISO classification applied to a soft lens, Acuvue 2

Etafilcon A IV 1

Eta: USAN prefix.
filcon: Stem, indicating a soft lens material ≥10% water by mass.
A: USAN series suffix, indicating the first formulation of the polymer.
IV: Water content ≥50% and the material is ionic.
1: A *Dk* in the 1–15 range of ISO units.

6.1 Hard gas-permeable lenses

Hard gas-permeable lenses are available in a wide range of materials and *Dk*s. Oxygen considerations, however, must take into account:

- The barrier effect, which reduces the *Dk* on the eye to approximately 55% of that measured in air in the gas/gas situation.[2]
- Centre and average lens thickness.[3,4]

For physiological reasons, lenses should be as thin as possible, although in practical terms making them too thin is counterproductive since they are very likely to distort throughout the

power range and also become too brittle. In most cases, a realistic minimum centre thickness is 0.14 mm, even for high minus powers.

Although *Dk* is important, there are several other considerations which affect comfort, vision and life span. These include:

- Surface wetting properties.
- Lens design.
- Fitting method.
- Manufacturing technique.
- Mechanical stability.
- Optical quality.

6.1.1 Cellulose acetate butyrate

Cellulose acetate butyrate (CAB) was one of the first non-PMMA materials, introduced in 1977. By modern standards, its *Dk* (between 4 and 8×10^{-11} Fatt units) is low, and it is now fitted very infrequently. Its main difficulty when manufactured by traditional lathing methods was dimensional instability. However, when manufactured by moulding, this problem was largely overcome, and lenses such as Conflex and Persecon E have given very good clinical results. They are still occasionally used for problem solving.

Advantages of CAB

- Good wettability.
- Relatively inert.
- Does not attract protein.
- Low breakage rate.
- Very low incidence of CLIPC.
- Relatively good for 3 and 9 o'clock staining.

Disadvantages of CAB

- Low *Dk*.
- Moulding necessary for dimensional stability.
- Limited range of lens designs.
- Scratches easily.
- Attracts lipids from the tears.
- Corneal adhesion in some cases.
- Lens flexure and distortion on toric corneas with tight lids.

6.1.2 Silicon acrylates (siloxanes)

Silicon acrylates are copolymers in varying proportions of acrylate (PMMA), which provides lens rigidity, and silicon, which controls the degree of oxygen permeability. Also included are cross-linking agents to improve the strength of the material and wetting agents such as methacrylic acid to improve the naturally hydrophobic properties of silicon. A good range of materials is now available with widely different physical properties and *Dk* values (Table 6.3). They give a superior oxygen and physiological performance compared with CAB and most have stood the test of time in terms of dimensional stability and optical and mechanical results. They are routinely fitted for daily wear and to a limited degree were once used for extended wear.

Table 6.3 Silicon acrylates[5]

Lens	*Dk* at 35°C
Polycon II	14.2
Paraperm O2	16
Boston IV	20.8
Vistacryl 18	18
Vistacryl	32
SGP2	43
Paraperm EW	54

Dk in Fatt units

Advantages of silicon acrylates

- Wide range of materials available.
- Wide range of designs with practitioner control.
- Low to medium *Dk*s available.
- Good dimensional stability.
- Good vision with limited lens flexure.
- Good scratch resistance.

Disadvantages of silicon acrylates

- Attract protein from the tears.
- Some materials are brittle with a breakage problem.
- High incidence of 3 and 9 o'clock staining.
- Some incidence of CLIPC.

6.1.3 Fluorosilicon acrylates

Fluorosilicon acrylates (sometimes loosely described as *fluorocarbons*) are composed of fluoromonomers and siloxy acrylate monomers.

The addition of fluorine atoms to replace some of the hydrogen present in methacrylate monomers improves surface wettability, tear film stability and deposit resistance[6] as well as increasing oxygen permeability. The solubility of oxygen in fluoromaterials is enhanced and so higher *Dk*s can be achieved (Table 6.4). Alternatively, moderate *Dk*s can be achieved with a lower siloxy acrylate content and hence provide improved wettability. The silicon content ranges from 5–7% with Boston 7 to 16–18% with Fluoroperm 90.

Table 6.4 Fluorosilicon acrylates[5]

Lens	*Dk* at 35°C
Fluoroperm 30 (Fluorocon 30)	30.3
Boston ES	27.3
Paragon HDS	58
Fluoroperm 60 (Fluorocon 60)	42.7
Equalens I	58
Fluoroperm 90	64
Quantum	55
Boston 7	60.4
Boston XO	100
Aquila	143
Fluoroperm 151	99.3
Paragon HDS 100	145
Optacryl F	160
Quantum 2	130
Z-Alpha	163

Dk in Fatt units

Advantages of fluorosilicon acrylates

- Very high *Dk*s possible.
- Suitable for flexible extended wear.
- Better wettability.
- Fewer deposit problems.
- Lower incidence of CLIPC.
- Modification possible.

Disadvantages of fluorosilicon acrylates

- Brittle if too thin.
- Require careful manufacture.
- Dimensional stability depends on material and manufacture.
- Corneal adhesion in some cases.

General advice

- Fluorosilicon acrylates are suitable for almost all straightforward patients and resolve many of the problems found with lower *Dk* materials. They have also proved suitable for flexible extended wear.
- Silicon acrylates are also suitable for most straightforward patients and give good dimensional stability. They are suitable for normal daily wear and for most problem solving with the exception of CLIPC. They are feasible but not ideal for flexible extended wear.
- CAB lenses might be considered where a low *Dk* is sufficient, and where CLIPC and 3 and 9 o'clock staining are a problem with other materials.

6.1.4 Fluoropolymers

Fluoropolymers contain no silicon and have a fluorine content of up to 50% by weight, several times that incorporated into fluorosilicon acrylates. They have so far found limited application despite their high *Dk*, good surface wettability, good deposit resistance and lack of brittleness. These advantages have been outweighed by problems associated with lens flexure, high specific gravity and cost.

6.1.5 Hydrophilic gas-permeable hard lenses

Silicon acrylate lenses with an improved hydrophilic surface are sometimes used to assist initial comfort, surface wettability and deposit resistance.

The Novalens (Ocutec) has a *Dk* of 55 $\times 10^{-11}$ and a 'soft' coating of OH groups which gives the surface characteristics of a hydrophilic lens. The lens itself does not absorb water but has good wettability and improved comfort.

Aquasil (No. 7) has a *Dk* of 50 and a surface containing OH groups similar to HEMA. The refractive index is 1.463 and water absorption less than 2%. Following manufacture by conventional methods, lenses are immersed for 120 minutes in a 10.6% solution of sulphuric acid which creates a surface layer of OH groups. These hydroxyl groups are permanently bonded to the polymer and are not reactive.

A different approach is adopted by Aquasil RSP, and the Hybrid FS and FS Plus from Contamac where the latter's 'fluid surface technology' combines fluorosilicon acrylate material with

a hydrophilic component. Prior to hydration, the hydrophilic molecules are distributed throughout the polymer matrix so that after lens manufacture the surface is guaranteed to contain a number of hydrophilic sites. After hydration the hydrophilic components attract water molecules which it is claimed then improve both comfort and oxygen permeability. No additional treatment is necessary and lenses are compatible with all standard solutions. The Hybrid FS has a refractive index of 1.4465 in dry and wet states, a *Dk* of 23 and a water uptake of less than 0.94%. The Hybrid FS Plus has the same refractive index but a *Dk* of 60 and a water uptake of less than 0.85%.

The Millennium Lens (Vista) is produced differently, by the polymeric grafting of hydrophilic polymers onto a fluorosilicon acrylate material with the surface covalently bonded to the entire lens surface.

Surface-treated lenses are fitted according to hard lens criteria and assessed in the normal way with fluorescein. They may be cleaned and soaked in nearly all conventional hard lens systems. Miraflow, which contains alcohol, and aggressive cleaning solutions containing particulates (e.g. Boston cleaner) should be avoided.

6.1.6 Carbosilfocon

Carbosilfocon is used to manufacture the EpiCon lens for keratoconus (*see* Section 32.8.3). The material has a *Dk* of 52 and is prepared by interpenetrating a network of PMMA with a block copolymer of bisphenol A carbonate and polydialkylsiloxane. The material is flexible and the large diameter lenses are produced by Gelflow moulding technology.

6.2 Polymethyl methacrylate

Polymethyl methacrylate (PMMA) has been in use since the 1940s, firstly as a replacement for the earlier glass scleral lenses, and subsequently as the material of choice with the development of corneal lenses. There are many patients who have worn PMMA successfully for over 40 years, although it has now largely fallen into disuse with the advent of modern hard lenses, by comparison with which its permeability is negligible. However, its original merits of inertness and stability mean that it may retain a place for very occasional new patients as well as a small minority of existing wearers.

There are many long-standing patients who exhibit neither signs nor symptoms and are best left without refitting, although their corneas should be carefully monitored (*see also* Chapter 13).

6.2.1 Modified PMMA

Although PMMA has relatively good surface-wetting properties by comparison with many modern materials, various versions with modified surface properties (e.g. BPflex) were introduced in the mid 1970s. The improved wettability gave moderately better comfort, and the increased tear flow beneath the lens proved beneficial in reducing some of the oedema problems almost inevitable with an impermeable material like PMMA.

6.3 Soft lenses

Soft lenses are classified according to the system shown in Table 6.1,[1] and Example 2 on page 80 shows how the system is applied to Acuvue 2. Lenses are generally discussed according to the interrelated properties of water content, *Dk* and material type.

Water content and uptake

The definitions for water content and uptake are given in Section 1.3.2. Care must be exercised when interpreting brand names that include a numerical suffix because these do not always accurately reflect the true water content.

Ionic and non-ionic polymers

Polymers are categorized into four groups linking water content to ionic properties. The classification relates to materials rather than clinical considerations, and in this context high water content is defined as greater than 50%. Ionic polymers contain more than 0.2% methacrylic acid and these high water content lenses may therefore contain the negatively charged carboxylic acid. The polymers are more sensitive both to temperature and the composition of care products, so lens parameters show greater variability with environmental factors. The materials attract higher levels of deposit from the tears, particularly protein, and are generally more suitable for disposable lenses where life span is less important.

The four groups are:

1 Low water content, non-ionic polymers, e.g. crofilcon (CSI), 38.5%, polymacon (Bausch & Lomb HEMA lenses), phemfilcon A (Durasoft 55) and lotrafilcon A (Night & Day 24%). Materials generally show lower levels of protein deposit.
2 High water content, non-ionic polymers, e.g. lidofilcon A (Bausch & Lomb 70%), surfilcon A (Permaflex 74%). Heat and sorbic acid should be avoided for disinfection because of the risk of lens discolouration.
3 Low water content, ionic polymers, e.g. balafilcon A (Purevision 36%).
4 High water content, ionic polymers, e.g. etafilcon A (Acuvue 58%), perfilcon (Permalens 71%), vifilcon A (Focus 55%). These polymers show the highest level of protein deposition and, as with group 2, heat and sorbic acid should be avoided for lens disinfection.

6.3.1 Clinical implications of soft lens water content

Hydrophilic lenses have been produced with water contents from 18% to 85%. However, many of the lenses currently being used are still HEMA-based in the region of 38% to 46%.

Advantages of low water content lenses

- Greater tensile strength.
- Less breakage.
- Longer life span.
- Smaller swell factor during manufacture.
- Better reproducibility.
- Easier to manufacture.
- Can be made thinner.
- Less dehydration on the eye.
- Less discolouration with age.
- Fewer solutions problems.

Disadvantages of low water content lenses

The disadvantages of low water content lenses relate mainly to their relatively low *Dk* values.

- A greater tendency to cause corneal oedema.
- A long-term tendency with thicker lenses (e.g. with high powers) to cause vascularization.

Advantages of high water content lenses

Most high water content materials have *Dk*s between three and five times that of HEMA. Apart from their obvious application in oedema cases, they have several other advantages:

- Better comfort because of material softness.
- Faster adaptation.
- Longer wearing time.
- Extended wear.
- Easier to handle because of greater thickness.
- Better vision because of greater thickness.
- Better for intermittent wear.

Disadvantages of high water content lenses

Despite these good features, there are nevertheless disadvantages with conventional high water content lenses which preclude their use in some cases. These problems are less significant with disposable lenses.

- Shorter life span.
- Greater fragility.
- More deposits, especially white spots.
- More discolouration.
- Reproducibility less reliable.
- More difficult to manufacture by lathing.
- Greater variation with environment.
- Fitting requires longer settling time.
- Greater variability in vision.
- More solutions problems.
- Lens dehydration.
- Corneal desiccation.

6.3.2 Clinical implications of soft lens thickness

The typical centre thickness for a 'standard' corneal diameter HEMA lens of power −3.00 D is in the region of 0.10–0.14 mm. Lenses below 0.10 mm may be regarded as thin; those below 0.07 mm as ultrathin; and those thinner than 0.05 mm have been termed superthin or hyperthin. They represent a very satisfactory way of increasing transmissibility (*Dk/t*) and improving physiological performance as well as giving an inherent safety factor for patients who accidentally fall asleep while wearing their lenses.

Low plus and aphakic lenses cannot truly be considered ultrathin because of their necessarily greater centre thickness. Nevertheless, 'thin' plus lenses give a more satisfactory overall performance.

Oxygen performance for a lens cannot be judged solely in relation to its specified centre thickness but must be considered for the entire lens. If an 'average' or 'mean' thickness is used, this itself requires definition to avoid error and enable valid comparison.[7]

Advantages of thin lenses

- Lower incidence of oedema.
- Reduced lid sensation because of thinner edges.
- Reduced limbal irritation because of thinner edges and larger total diameter.
- Different fitting characteristic may provide better centration than standard lenses.
- Easier to fit because fewer fitting steps are necessary.
- Safer if patients accidentally fall asleep.

Disadvantages of thin lenses

- Handling is more difficult, especially in low minus powers below about −2.00 D.
- Higher breakage rate than standard thickness lenses.
- Life span is shorter, especially with heat disinfection.
- Visual acuity may be less good with toric corneas.
- Greater tendency to dehydrate on the eye and disturb precorneal tear film.

6.3.3 Dehydration of soft lenses

One of the main reasons for the clinical success or failure of a particular lens on the eye relates to its dehydration characteristics.

Effects of lens dehydration

- Change in parameters and fitting.
- Reduction in comfort.
- Reduction in *Dk*.
- Disruption of tear film.
- Corneal desiccation and staining.
- Increased deposits.
- Reduction in vision.

Factors influencing lens dehydration

Ocular factors

- Volume of tears.
- Quality and stability of tear film.
- Osmolarity of tears.
- Blinking habits.
- Size of palpebral aperture.

Other factors

- Lens material.
- Lens thickness.
- Temperature changes.
- Relative humidity.
- Drafts and wind.
- Systemic drugs.
- Alcohol.

The water content contained within the polymer matrix consists of *bound* water directly attached to hydrophilic sites by hydrogen-bonding Van der Waals forces and *free* water, which is more readily lost by evaporation. The higher the bound water (e.g. with biocompatible polymers), the less any particular material will dehydrate on the eye.[8]

Generally, most water loss occurs within the first few minutes and high water content materials give greater dehydration. Tear film stability is better with thicker lenses and low water contents: it is worse with ultrathin and high water content lenses.

6.4 Silicone hydrogels

Silicone hydrogels were introduced to the UK during 1999 and represented a major advance in materials technology by combining silicone rubber (*see* Section 6.6) with hydrogel monomers. These materials also use the classification suffix *-filcon*. The silicone constituent permits very high oxygen permeability whilst the hydrogel component ensures that the lenses are soft and comfortable and in addition provides fluid transport through the lens. Silicone-based materials are inherently hydrophobic and require surface treatment to render finished lenses hydrophilic and comfortable. The treatment must firstly have no effect on the oxygen transmission and secondly become an integral part of the lens so that it

cannot be removed with use and handling, or interaction with disinfecting solutions.

When considering the *Dk* values, there is one significant difference from more standard hydrogel lenses where the *Dk* value is directly linked to the water content. With silicone hydrogels, because the majority of the oxygen flow takes place within the silicone components, a lower water content can have a higher *Dk* value.[9] Two varieties of lens are currently available.

The Bausch & Lomb Purevision (balafilcon A) is a homogeneously copolymerized combination of the hydrophilic monomer *N*-vinyl pyrrolidone and the silicone monomer polydimethylsiloxane, which is itself a vinyl carbamate derivative of trimethylsiloxy silane (TRIS). The resultant material has a water content of 36% and a *Dk* of 110×10^{-11} Fatt units. Purevision lenses are treated in a gas plasma chamber to modify the surface to hydrophilic silicate compounds – so-called 'glassy silicate islands'.

The CIBA Vision Focus Night & Day (lotrafilcon A) has a biphasic molecular structure. It consists of a fluorether macromer copolymerized with TRIS and N,N dimethylacrylamide (DMA). The fluorosiloxane phase allows the storage and transmission of oxygen whilst the hydrogel phase transmits both oxygen and water. Lotrafilcon A has a water content of 24% and a *Dk* of 140^{-11} Fatt units.

Advantages of silicone hydrogels

- Very high *Dk*s available.
- Suitable for extended wear.
- Rapid adaptation.
- Suitable for patients with vascularization.
- Good dehydration characteristics.
- Easier handling because of lens rigidity.
- Low rate of deposits.
- Good tensile strength with low breakage rate.
- Low uptake of fluorescein during aftercare.

Disadvantages of silicone hydrogels

- Not available in complex designs (torics, bifocals).
- Available only as disposables.
- More likely to create arcuate staining (*see* Section 29.3).
- Frequently exhibit mucin balls (*see* Section 29.3).
- Expensive.

See also Chapter 20.

6.5 Biocompatible and biomimetic lenses

Biocompatible lenses

Biocompatibility has been defined as 'the ability of a material to interface with a natural substance without provoking a biological response'. The advantages of biocompatible materials are their good physiological response with reduced evaporation of tears, corneal desiccation and deposits. Current lenses and materials include Proclear, Vistagel PLUS and Benz 5f-x.

The Proclear materials include phosphorylcholine (PC), a naturally occurring component in the cell membrane of red blood cells which has a high affinity for water and is resistant to protein adsorption. Similar technology is used for intraocular lenses as well as cardiac, orthopaedic and other health care products. The range of contact lenses includes both conventional, manufactured by lathing, and disposable, produced by cast moulding.

In biomimesis the principles of the complex structure and chemistry of nature are emulated by much simpler scientific means that nevertheless achieve the same results. The Vistagel PLUS material is based on the idea of biomimesis.

In its main features, Vistagel PLUS is modelled on the structure of the cornea, which experiences no deposit problems within the environment of the tear film. This logic is applied to the composition of the lens material. Two versions of Vistagel PLUS are available with water contents of 40% and 55%.

Collagen lenses

Collagen lenses are also produced from biological polymers and show good biocompatibility. Their main applications have been therapeutic. They dissolve after a number of days and are therefore never permanent.

6.6 Silicone lenses

6.6.1 Silicone rubber lenses (elastomers)[10,11]

Silicone lenses differ from hard lenses in several ways. They can be flexed, stretched and turned inside out. They have excellent elastic properties, partly conform to the shape of the cornea in wear, and have extremely high *Dk*s in the region of 200×10^{-11} Fatt units.

They are also unlike hydrophilic lenses because their natural state is dry and they are extremely tough. Since they do not absorb water to any significant extent, fluorescein can be used in their fitting and they do not need disinfecting in the same way as soft lenses.

Because of the amorphous nature of the silicone rubber raw materials, lenses are produced by a moulding and vulcanization technique, which also assists in maintaining good reproducibility. The main difficulty with silicone is that its natural surface is extremely hydrophobic, and it has been necessary to devise methods of rendering the surface permanently hydrophilic without interfering with any of its optical or physical properties. The final stage of manufacture is therefore surface treatment by ion bombardment.

Because of the following advantages and disadvantages, silicone has remained very much a minority lens with limited therapeutic applications and is now difficult to obtain (*see* Section 32.9).

Advantages of silicone lenses

- Very high *Dk*.
- Better and more stable vision than many soft lenses.
- Little variation in comfort or fitting with environmental factors.
- Low risk of loss or damage.

Disadvantages of silicone lenses

- Difficult to fit, requiring as much precision as hard lenses.
- A negative pressure effect producing lens adhesion, particularly if not correctly fitted.
- Breakdown in surface coating and difficulties with wetting.
- Build-up of deposits.
- Foreign bodies, especially with loose fittings.

6.6.2 Silicone resin lenses

Resin lenses differ from silicone elastomers because they are not flexible, having many of the physical properties of hard lenses. *Dk* values, however, are significantly lower than the elastomers and they have so far found only limited application.

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CHAPTER 7

Principles of hard lens design

7.1 Basic principles of hard lens design

- Lenses may be spherical, aspheric or a combination of both.
- Most corneal lenses have a central zone which is fitted just apically clear or in alignment with the central cornea, combined with a much flatter peripheral zone which is designed to lift away from the cornea.
- Central alignment gives optimal acuity.
- Peripheral clearance is necessary for adequate tears exchange.
- The transition between the central portion and the periphery is sharp for a spherical bicurve design, becoming smoother as additional curves are added.
- Aspheric lenses have a much smoother transition and for some designs can be compared with very well-blended spherical multicurves (*see* Chapter 11).

7.2 Forces controlling design

Corneal lenses of all materials are affected by a variety of forces when placed on the eye. These factors are both ocular (*see* Chapter 5) and physical in nature.[1]

7.2.1 Centre of gravity

- The centre of gravity of a lens lies somewhere behind the back surface (Figure 7.1).
- It is affected by radius, diameter, thickness and power.
- Steep lenses have the centre of gravity further back than flat lenses and therefore give better centration (Figure 7.2a).
- Flat lenses have the centre of gravity further forward and give worse centration (Figure 7.2b).
- Large diameter lenses have the centre of gravity further back than small lenses and give better centration.
- Small lenses have the centre of gravity further forward and give worse centration.

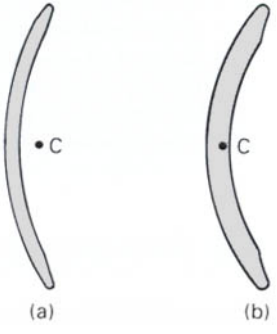

Figure 7.1 Centre of gravity (C) in (a) minus and (b) plus lenses

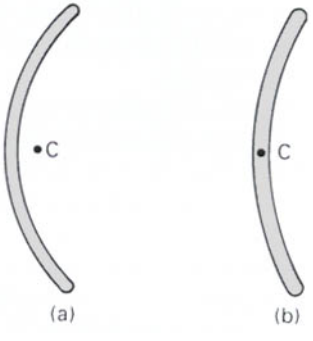

Figure 7.2 Centre of gravity (C) in (a) steep and (b) flat lenses

7.2.2 Frictional forces

The viscosity of the tear film maintains the lens in a stationary position by means of frictional forces. Thinning of the tear film or an increase in its aqueous content (e.g. during adaptation) reduces the centration ability of these forces.

7.2.3 Capillary attraction

- The more closely the lens matches the shape of the cornea, the greater the capillary attraction and stability.
- Since a hard lens cannot ever exactly match the shape of the cornea, a balance has to be found between sufficient capillary attraction for lens stability and sufficient movement for tears exchange.
- An excessively flat fitting gives less capillary attraction and greater movement.
- A steep fitting can create a negative pressure or suction effect.
- The tears meniscus at the edge of the lens also provides forces for centration. The greater the meniscus, the better the adhesion.

7.2.4 Specific gravity

- The clinical significance is demonstrated when two lenses of the same design (and volume) but different specific gravity behave differently on the eye. The lens with the lower specific gravity has less weight.
- A lens that drops because gravitational forces are greater than fluid forces may achieve better centration by using a material of lower specific gravity and vice versa.
- With prism ballast, a material of high specific gravity is advantageous as it gives a greater difference in weight between the apex and base of the lens.

7.2.5 Thickness and lenticulation

Thickness depends on back vertex power (BVP), design and material. Centre thickness (t_c) and edge thickness (t_e) are both important (Tables 7.1 and 7.2).

- BVPs greater than −6.00 D or +4.00 D should be lenticulated to reduce excess thickness and mass.
- Lenticulation reduces thickness in the centre for plus and towards the edge for minus lenses by making the front optic zone diameter (FOZD) smaller (Figure 7.3).
- The FOZD should be approximately 0.5 mm larger than the back optic zone diameter (BOZD).
- The carrier portion of a lenticulated lens can be plano, negative or positive in shape (Figure 7.4). The choice depends upon the intended effect (e.g. lid attachment techniques, *see* Section 7.5).

Table 7.1 Typical thickness values assuming a constant TD = 9.60 and BOZD = 7.80 mm

BVP (D)	t_c (mm)	t_e (mm)
−10.00	0.13	0.25
−6.00	0.13	0.22
−3.00	0.15	0.20
−1.00	0.18	0.18
+1.00	0.22	0.12
+3.00	0.26	0.13
+6.00	0.34	0.15
+10.00	0.45	0.16

Table 7.2 Suggested minimum thicknesses for different materials (BVP −3.00 D)

Material	t_c (mm)	t_e (mm)
PMMA	0.10	0.12
CAB	0.16	0.12
Silicon acrylate	0.15	0.13
Fluorosiliconacrylate	0.14	0.15

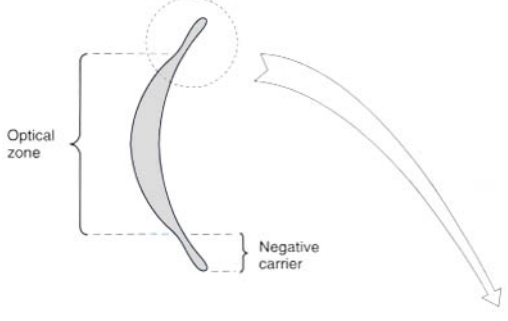

Figure 7.3 Lenticulation of plus lens

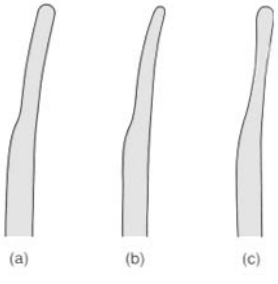

Figure 7.4 Carrier portion shapes of a lenticulated lens: (a) plano; (b) positive; (c) negative

7.2.6 Refractive index of materials

The following are typical examples of refractive index:

PMMA	1.49
CAB	1.47
Silicon acrylate	1.471–1.48
Fluorosiliconacrylate	1.453–1.471
Silicone	1.43

- The higher the refractive index, the thinner the lens can be made.
- Modern hard lenses have a lower refractive index than PMMA and are therefore thicker.
- High refractive index plastics are used for bifocal segments. They can incorporate fluorescent dye to assist fitting.
- The refractive index is important in toric lens fitting (*see* Chapter 23).

7.2.7 Edge shape

- Extremely important for comfort.
- Must be smooth and well finished.
- Should blend into the final peripheral curve.
- Can help lens removal.

Practical advice

- Do not order centre thickness less than 0.14 mm with most modern materials because of lens flexure, particularly with toric corneas and tight lids.
- Edge thickness should be a minimum of 0.12 mm. A 'knife edge' causes discomfort and is fragile, especially with plus lenses.
- Minus lenses usually give a natural lid attachment.
- A negative carrier helps give lid attachment with a low-riding or plus lens.
- A positive carrier helps reduce a high-riding tendency.
- Varying degrees of taper and roundness are used, depending on fitting philosophy (see Section 7.5) and lid sensitivity. Edges are described as (a) posterior, (b) central, (c) anterior, (d) blunt, and (e) sharp[2] (Figure 7.5).
- Edge thickness depends on BVP (see Section 7.2.5).

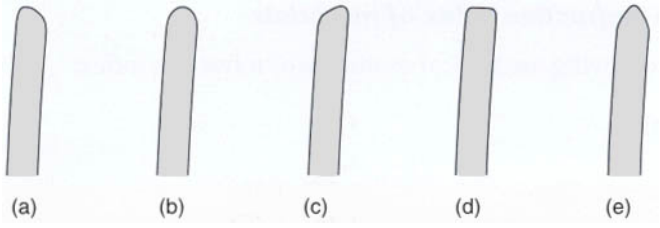

Figure 7.5 Edge shapes of lenses: (a) posterior; (b) central; (c) anterior; (d) blunt; (e) sharp

7.3 Concept of edge lift

The concept of edge lift is related to the lens design off the eye. It embodies the series of curves that lead into the edge shape. Edge lift can be specified in an axial or a radial direction.

Axial edge lift is defined as the distance between a point on the back surface of a lens at a specified diameter and the continuation of the back central optic zone, measured parallel to the lens axis[3] (Figure 7.6). The flatter the BOZR, the greater the degree of peripheral curve flattening that is required to maintain a particular edge lift.

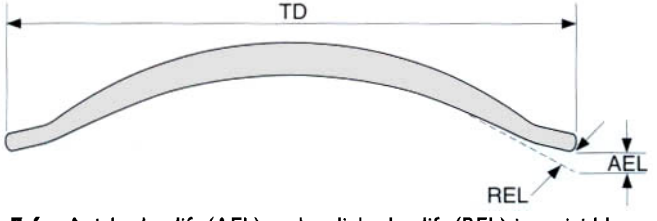

Figure 7.6 Axial edge lift (AEL) and radial edge lift (REL) in a rigid lens design (TD, total diameter)

Current lens designs are usually defined in respect of axial edge lift (AEL). Lenses are sometimes designed by deciding on the AEL required and calculating the peripheral curves needed. The edge lift of each individual curve contributes to the total figure.

Historically, the concept of edge lift has used a variety of terms:

- Z *value*, or axial edge lift.
- Constant axial edge lift (CAEL) (*see* Section 8.3).
- Z *factor*, or radial edge lift.
- Flattening factor.

The usual value of axial edge lift varies between 0.09 mm and 0.15 mm. If the same increase is given to the peripheral curves of both steep and flat lenses, the steep lens has, relatively, a greater edge lift.[4]

Example:

r	$r + 0.5$	$r + 2.2$	$r + 4.7$	
8.40:7.00/	8.90:8.00/	10.60:8.50/	13.10:9.00	AEL = 0.117 mm
7.20:7.00/	7.70:8.00/	9.40:8.50/	11.90:9.00	AEL = 0.172 mm

CAEL lenses[4] are multicurves which for a given TD are designed to give the same AEL throughout the range of radii. The clinical appearance and performance are therefore consistent.

The Z factor[5] or radial edge lift (REL) is defined as the distance between a point on the back surface of the lens at a specified diameter and the continuation of the back central optic zone, measured along the radius of the latter (*see* Figure 7.6).

The ratio of axial to radial edge lift is approximately 5:4.

Example:
7.40:7.00/8.10:7.80/9.30:8.60/10.50:9.00
Taken from 0.15 mm CAEL trial set with a total diameter (TD) of 9.00 mm.[6]
AEL at 7.80 = 0.025; AEL at 8.60 = 0.095; AEL at 9.00 = 0.15
The designated value for the final peripheral curve
REL at 9.00 = 0.12 Ratio REL/AEL = 0.80

The flattening factor (ff) defines the extent to which the peripheral curve flattens in relation to the central radius in an offset lens (*see* Section 8.2).

There are two approaches to calculating the contribution of each peripheral curve of a given lens design:

Band width method

The band width method considers the edge lift at the edge of the intermediate curve.[7]

Step-by-step method

The step-by-step method calculates the AEL of the mid-curve as the AEL produced as if the mid-curve were extended out to the total diameter (TD) of the lens.

Compared with the band width approach, the step-by-step method produces a larger AEL for the mid-peripheral curve and a smaller AEL for the third curve.

For a tricurve, the mid-curve produces two-thirds of the AEL, with the third curve contributing one-third. For a tetracurve lens, the first peripheral curve provides half of the AEL, the second one-third, and the fourth one-sixth. The contribution of each curve is easily calculated with the aid of a computer programme.

7.3.1 Concept of edge clearance

The term *edge clearance* relates to the lens on the eye and is estimated by the fluorescein pattern. The lens periphery must be fitted flatter than the cornea to:

- Provide tears exchange beneath the lens for the maintenance of corneal metabolism.
- Give a tears meniscus so that capillary attraction and lens centration forces can function (*see* Section 7.2).
- Assist lens removal by the lids.
- Avoid pressure and corneal insult at the lens edge.
- Avoid lens adhesion.

Too little edge clearance gives:

- Inadequate tears exchange.
- Poor lens movement.
- Pressure at the lens edge and arcuate staining.
- Difficulty with lens removal.
- Lens adhesion.

Too much edge clearance gives:

- Excessive lens movement.
- Bubbles under the lens periphery which can cause frothing or dimpling.
- Poor centration.
- Lens displacement off the cornea.
- 3 and 9 o'clock staining because of tear film disruption.

Practical advice

- AEL relates to the lens design off the eye.
- Edge clearance relates to the lens on the eye.

7.4 Tear layer thickness

- Tear layer thickness (TLT) is the clearance between the back surface of the lens and the cornea, usually in respect of the central area (typical example, Figure 7.7).

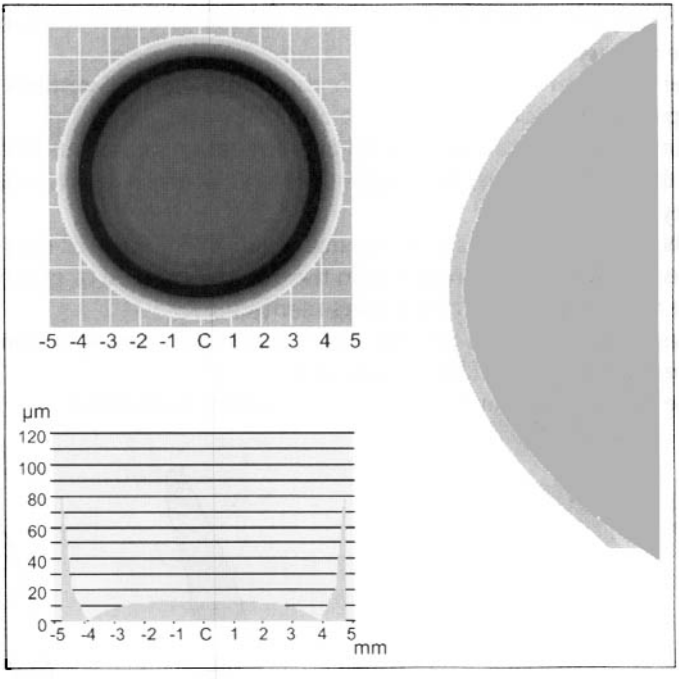

Figure 7.7 Tear layer profile (Plate 1)

- The fitting technique and lens design govern the values for apical (and edge) clearance.
- TLT is expressed in microns (µm) (1 µm = 0.001 mm), whereas edge lift is given in millimetres and relates only to the physical dimensions of the lens.
- Fluorescein with a TLT of <20 µm cannot be seen with a Burton lamp.

Typical values[8]

Tear layer thickness = 5–10 µm.
Edge clearance (EC) = 75–80 µm.

7.5 Lid attachment lenses

Lid attachment (hitch-up) utilizes the edge contour and shape of the anterior peripheral surface of the lens to increase lid–lens adhesion.[9,10]

- Lid attachment occurs when the peripheral lens contour remains in constant contact with the upper lid margin after blinking or eye closure.
- The lens therefore moves with the upper lid and returns to a superior position on the cornea after blinking.
- Minus lenses give a natural lid attachment on most eyes because of their edge shape, but larger diameter lenses are often necessary (Figure 7.8).
- When the upper lid is in its normal position, its upward retention effect on the lens is greater than the downward pull of gravity or the centration forces of the tears meniscus.
- Plus lenses give the reverse effect and tend to escape from lid retention because of their edge shape.
- The correct anterior lenticular construction is essential.

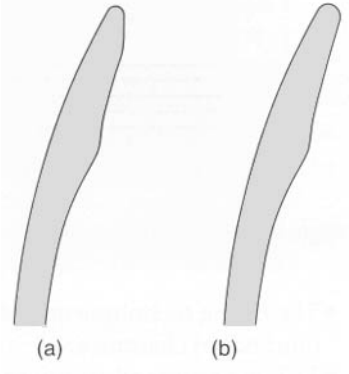

Figure 7.8 Korb edge contour (a), compared with a standard edge design (b)

Advantages

- More comfortable.
- Helps maintain normal blinking.
- Counteracts low-riding lenses.
- Helps tears exchange on blinking.
- Lenses can be made thinner with high powers.
- Less 3 and 9 o'clock staining.

Disadvantages

- Flare from lower edge of pupil.
- Peripheral curves may need to be individually designed.
- Front surface may require complex construction.

7.6 Interpalpebral lenses

The technique aims to give good centration using very thin lenses with a total diameter smaller than the vertical palpebral aperture. It has mainly been applied to PMMA to improve the physiological performance and where thinner lenses can be more easily manufactured.

Fitting

TD: At least 2.00 mm larger than maximum pupil diameter, i.e. usually 7.50–8.50 mm.

BOZR: Up to 0.15 mm steeper than flattest 'K' to give the appearance of an alignment fit.

BOZD: 5.00–7.00 mm.

Example 1: 7.80:6.50/8.60:7.50/10.40:8.50t_c = 0.10
Example 2: 7.80:7.00/10.50:8.00t_c = 0.08

Advantages

- Better for narrow lid apertures.
- Less sensation with sensitive lids.
- Better for corneas with irregular periphery.
- Often successful with moderate or even highly toric corneas where a small lens may permit a spherical design.
- Less disturbance of corneal metabolism.
- Lens positions away from the limbus and may help with 3 and 9 o'clock staining or limbal disturbance.

Disadvantages

- More difficult to manufacture because they must be made thinner.
- Difficult to handle.
- Difficult to remove.
- Fragile edges.
- Flare.
- Disincentive to blinking and may give increased 3 and 9 o'clock staining.

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CHAPTER 8

Development of hard lens design

8.1 Introduction

The first PMMA corneal lens was designed in 1947.[1] It consisted of a single curve approximately 0.30 mm flatter than 'K' and a total diameter of about 11.00 mm. Limited practical success was achieved for physiological reasons. It was not until practitioners such as Bier in the early 1950s realized that the cornea was more complicated than a simple sphere that a bicurve construction was introduced. Further improvements were made by adding a flatter, third curve to assist tear circulation. The complex elliptical shape of the cornea was more fully understood by the late 1960s and multicurve lenses evolved together with the first aspheric constructions.[2] Most designs were fitted as:

- Either central alignment or minimal clearance with peripheral clearance.
- Central clearance with peripheral alignment.

The following ISO terminology, abbreviations and symbols are used:

BOZR (r_0) = back optic zone radius
BOZD ($\varnothing_0$) = back optic zone diameter
r_1 = first back peripheral radius

$\varnothing_1$ = first back peripheral zone diameter
r_2 = second back peripheral radius
TD ($\varnothing_T$) = total diameter

In addition, 'K' is used to refer to flattest keratometry reading.

8.2 Early lens designs

Bier contour technique

Developed in the UK by Bier in 1957.[3] A spherical bicurve design, fitted with apical alignment and peripheral clearance. Now rarely used except for refitting existing problem-free wearers.

BOZR = 'K' ± 0.10 mm
r_1 = BOZR + 0.40–0.80 mm
BOZD = 6.50–7.50 mm
TD = 8.50–10.00 mm

Example: 7.80:6.80/8.60:9.65 –3.00 (Figure 8.1)

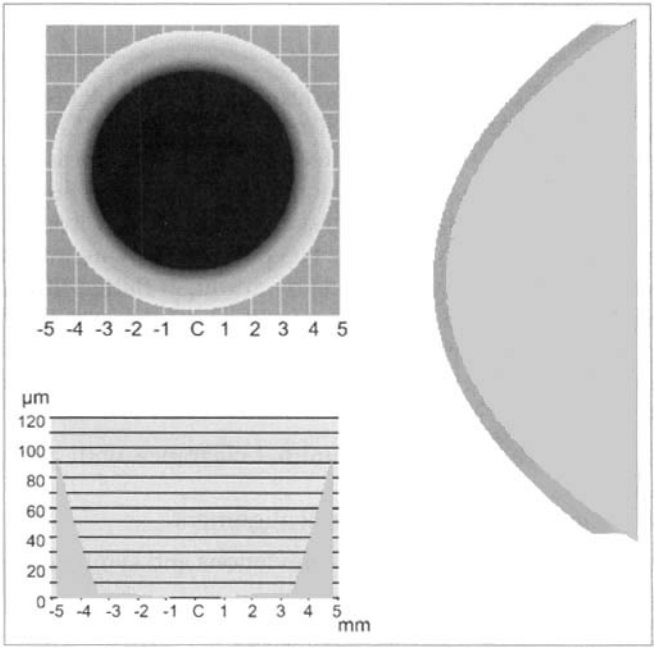

Figure 8.1 Tear layer profile/Bier contour technique (Plate 2)

Modified contour technique

A tricurve, modified version of the Bier contour technique. The fitting is central alignment with the first peripheral curve, giving some degree of corneal alignment; the final curve is small and flat. Occasionally used for refitting and where large edge lift is required with PMMA.

BOZR = 'K' ± 0.500 mm
r_1 = BOZR + 0.30–0.50 mm
r_2 = 9.50–12.50 mm, 0.20–0.40 mm wide
BOZD = 6.00–7.50 mm
TD = 8.50–9.50 mm

Example: 7.80:6.50/8.30:9.10/12.25:9.50 –3.00 (Figure 8.2)

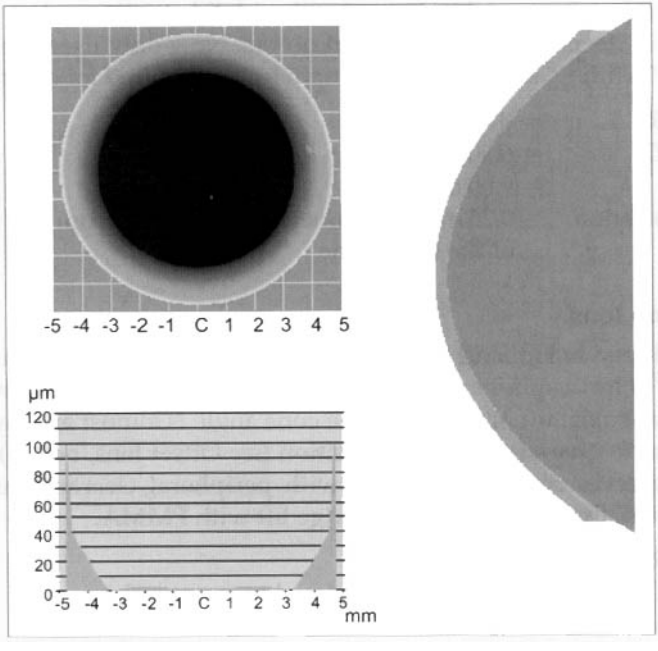

Figure 8.2 Tear layer profile/modified contour technique (Plate 3)

Bayshore technique

Developed in the USA by Bayshore in 1962.[4] A small tricurve corneal lens, fitted to give central clearance and peripheral alignment. Occasionally used to give a tight interpalpebral fitting.

BOZR	= 'K' – 0.30 mm
BOZD	= 5.60–6.60 mm
TD	= 7.00–8.80 mm (0.20 mm less than the vertical palpebral aperture)
r_1	= BOZR + 1.00–1.50 mm (aligned with cornea)
r_2	= 17.00 mm, 0.10–0.30 mm wide
Fenestration	= central, 0.20–0.25 mm in diameter

Example: 7.60:6.00/8.80:7.00/17.00:7.60 –3.00
Single central fenestration, 0.20 mm

Conoid lens

Developed in Australia by Thomas in 1967.[5] Fitted to give apical clearance, it has a spherical BOZR with a conical periphery commonly tangential to the BOZR.

Comfort is good because of reduced lid sensation, but gross corneal steepening and distortion occurs. Now only used for occasional refitting and where a very tight lens is required for centration.

BOZR	= 'K' – 0.30 mm
BOZD	= 6.50 mm
TD	= 9.00 mm
Fenestration	= 0.25 mm in diameter, 0.20 mm in from the edge, of the optic zone

Percon lens

Developed in Holland by Stek in 1969[6] and in the UK by Cantor in 1970.[7] It has a spherical BOZR and a conical peripheral zone with a constant axial lift of 0.10 mm. The cone angle is almost exactly tangential to give virtually no transition (*see* Offset lens, below). The fitting gives central alignment with peripheral clearance and is occasionally used to give large edge lift with PMMA.

BOZR	= 'K' + 0.05 mm
BOZD	= 6.60–7.20 mm (related to cone angle)
TD	= 8.60–9.40 mm
Cone angle	= depends on both BOZR and TD

Example: 7.80:6.80/9.00 Cone angle 130°

Offset lens

Developed in the UK by Ruben in 1966.[8] The centre of curvature of the back peripheral curve is offset to the opposite side of the central

axis, virtually eliminating any transition. It has been termed a *continuous bicurve lens*[2] or *contralateral offset* (Figure 8.3). A *homolateral offset* is also possible, where the centre of curvature of the peripheral curve is displaced to the same side of the central axis.

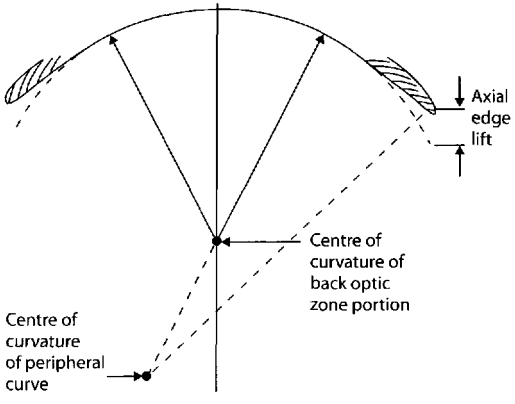

Figure 8.3 Contralateral offset or continuous bicurve lens (from Phillips and Speedwell, *Contact Lenses*, 4th edn, Butterworth-Heinemann, Oxford, by permission)

The degree of flattening is referred to as the *axial edge lift*, *Z value* or *flattening factor*. It is usually specified by the distance at the lens edge between the extension of the BOZR and the peripheral curve. The distance in millimetres is measured along a line parallel to the axis of symmetry.

Offset lenses give good comfort because of the minimal transition and are useful for early keratoconus and where large edge lift is required with PMMA. The small optic, however, gives flare and special offset lathes are required for manufacture.

Offset No 1 BOZD: 6.00 mm TD: 9.00 mm
Offset No 2 BOZD: 6.90 mm TD: 10.00 mm
Offset No 3 BOZD: 5.50 mm TD: 8.50 mm

All the above had a flattening factor (AEL) of 0.10 mm in low minus powers. Nowadays, with new computer lathes, the BOZD and AEL can both be varied.

Example: 7.00:6.00 AEL 0.1 at 9.00−5.00

8.3 Current designs: bicurve, tricurve, multicurve

Corneal lenses are now designed with one or more peripheral zones that are deliberately intended to lift away from the cornea. Most modern spherical lenses are based on these designs.

Bicurve (C2)

Consists of a central radius and one flatter peripheral curve (Figure 8.4). There is a sharp transition between the two curves.

Examples: 7.80:7.00/8.70:9.00 (Figure 8.5)
7.80:7.80/10.50:9.00 (Figure 8.6)

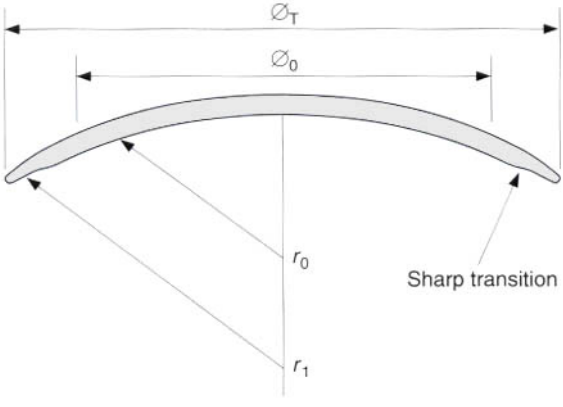

Figure 8.4 Bicurve corneal lens ($\varnothing_T$, total diameter; $\varnothing_0$, back optic zone diameter; r_0, back optic zone radius; r_1, first back peripheral radius)

Tricurve (C3)

Consists of a central radius and two flatter peripheral curves (Figure 8.7). It is the basic design of most modern hard lenses, where the final curve is much flatter than first peripheral radius.

Example: 7.80:7.80/8.50:8.70/10.50:9.50 (Figure 8.8)

Multicurve

Consists of a central radius and three or more peripheral curves (Figure 8.9). It follows the flattening of cornea better than bicurves

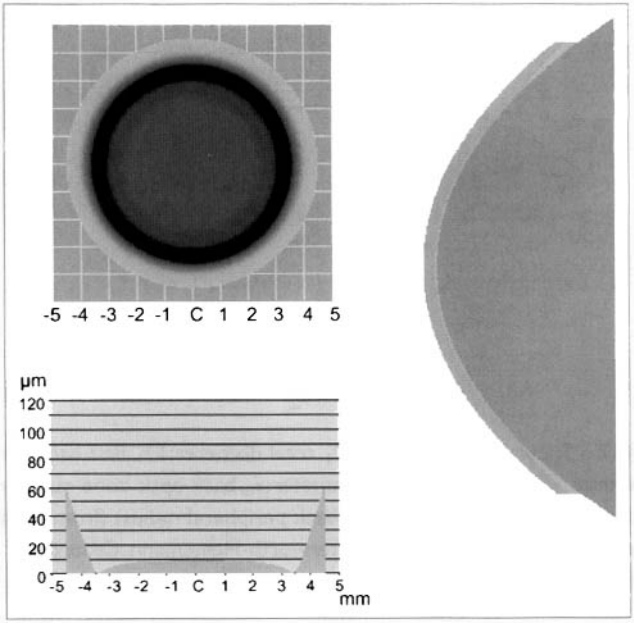

Figure 8.5 Tear layer profile/bicurve (C2) (Plate 4)

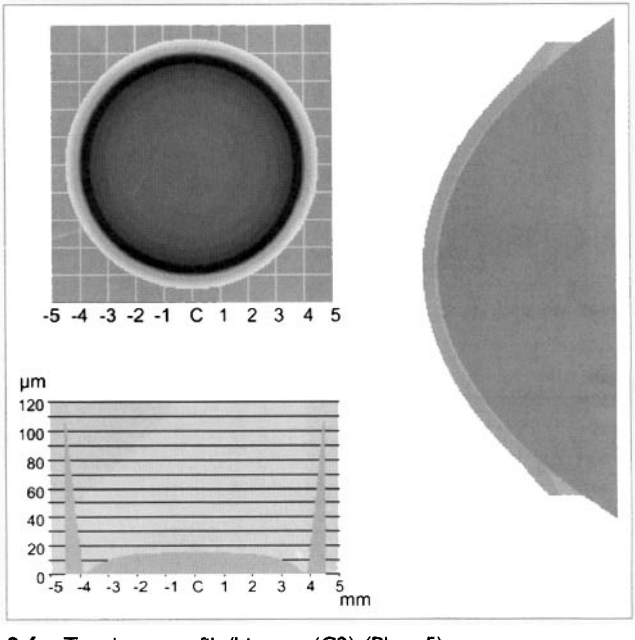

Figure 8.6 Tear layer profile/bicurve (C2) (Plate 5)

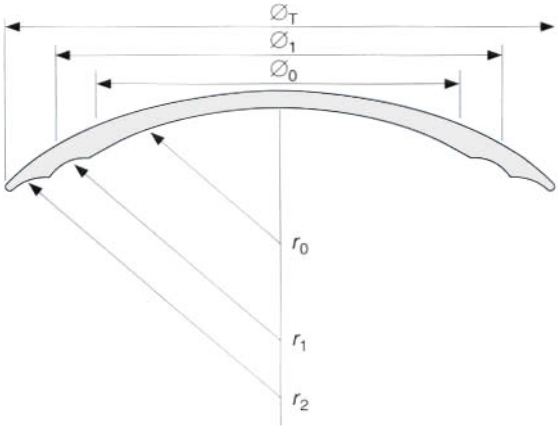

Figure 8.7 Tricurve corneal lens ($\varnothing_T$, total diameter; $\varnothing_1$, first back peripheral zone diameter; $\varnothing_0$, back optic zone diameter; r_0, back optic zone radius; r_1, first back peripheral radius; r_2, second back peripheral radius) (from Phillips and Speedwell, *Contact Lenses*, 3rd edn, Butterworth-Heinemann, Oxford, by permission)

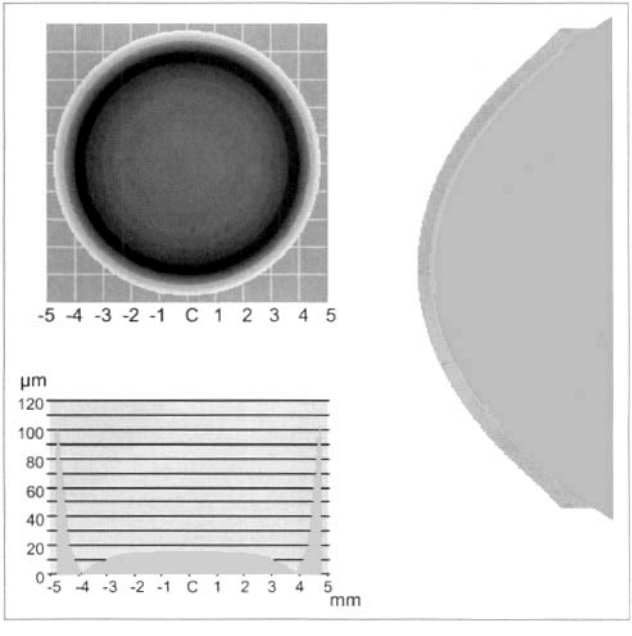

Figure 8.8 Tear layer profile/tricurve (C3) (Plate 6)

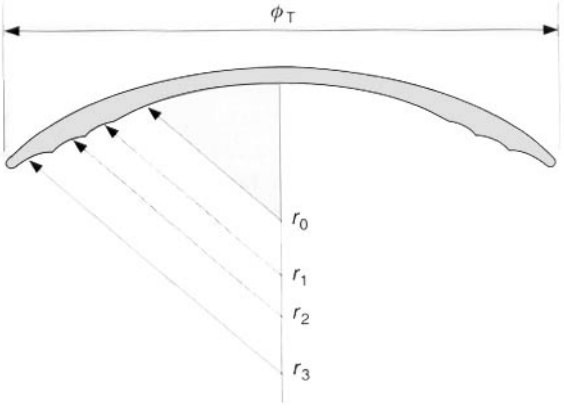

Figure 8.9 Multicurve corneal lens (r_3, third back peripheral radius; other symbols as in Figure 8.4)

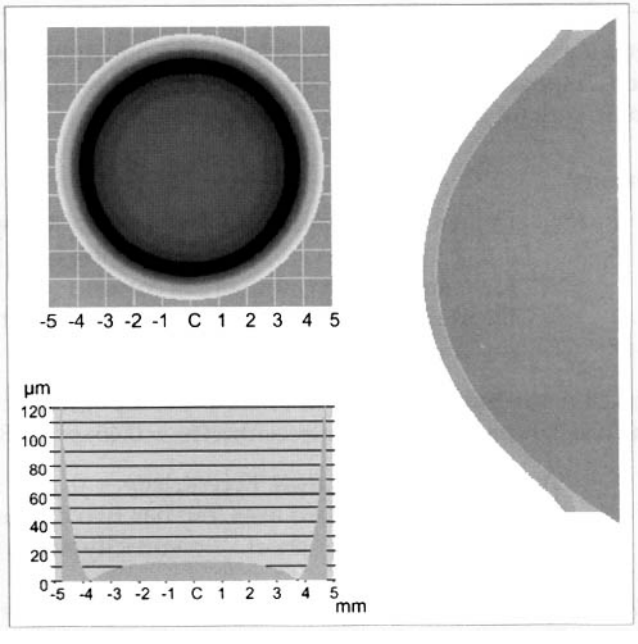

Figure 8.10 Tear layer profile/multicurve (Plate 7)

and tricurves, and when the transitions are well blended, behaves like a continuous curve lens.

Example: 7.80:7.50/8.40:8.20/9.00:8.90/11.50:9.50 (Figure 8.10)

Constant axial edge lift

CAEL lenses[9] (*see* Section 7.3) were developed as a further refinement of multicurve lens design to give a constant linear clearance between the edge of the lens and the cornea, over the whole range of radii for a given diameter. The axial edge lift of the peripheral curves is calculated to remain constant for all BOZRs, unlike conventional lenses where the calculated AEL is greater with steeper lenses than with flatter lenses.

N.B. AEL relates to the lens design off the eye.

Average CAEL for a TD of 8.60 mm; 0.105 mm
Average CAEL for a TD of 9.20 mm; 0.11 mm
Average CAEL for a TD of 9.60 mm; 0.14 mm

8.4 Aspheric lenses

Aspheric lenses have one or both surfaces of a non-spherical construction. Aspherics usually take the form of a parabola, ellipse or hyperbola and are defined by eccentricity.

Definitions

Eccentricity (e): Defines mathematically the departure of an aspheric curve from a circle. Used to describe both a lens form and the curvature of the cornea.

p value: Defines the rate of flattening with eccentricity: $p = 1 - e^2$.

The closest mathematical approximation to the topography of the human cornea is an ellipse. Mean eccentricity = 0.45; $p = 0.8$.

Circle: Completely symmetrical. Eccentricity = 0; $p = 1$.

Ellipse: Symmetrical about two axes, but has two diameters – one long and one short. Eccentricity = $0 < e < 1$; p = <1.

Parabola: Symmetrical about one axis. Eccentricity = 1; $p = 0$.

Hyperbola: Eccentricity >1; p = <0.

All aspheric curves can be defined by two different peripheral radii – the sagittal radius which is steeper and the tangential radius which is flatter. The relationship between the vertex radius (at the apex) and the two peripheral radii determines the eccentricity value of the lens and consequently its shape.

Two subgroups of aspheric surfaces commonly used in contact lens design are (1) conicoids and (2) higher order curves termed polynomials. A conicoidal curve is derived from taking a section through a cone (*see* Figure 8.11a and b). As the section is made more oblique the curve becomes increasingly elliptical, then parabolic and finally changes to a hyperbola. The hyperbola produces the greatest peripheral flattening and so is used for the peripheral zone of bi-aspheric designs. A polynomial is a progressive eccentric curve increasing from the apex outwards. It is described as a differentially flattening aspheric curve, departing only slightly from a sphere centrally but with a rapid increase of axial edge lift in the periphery.

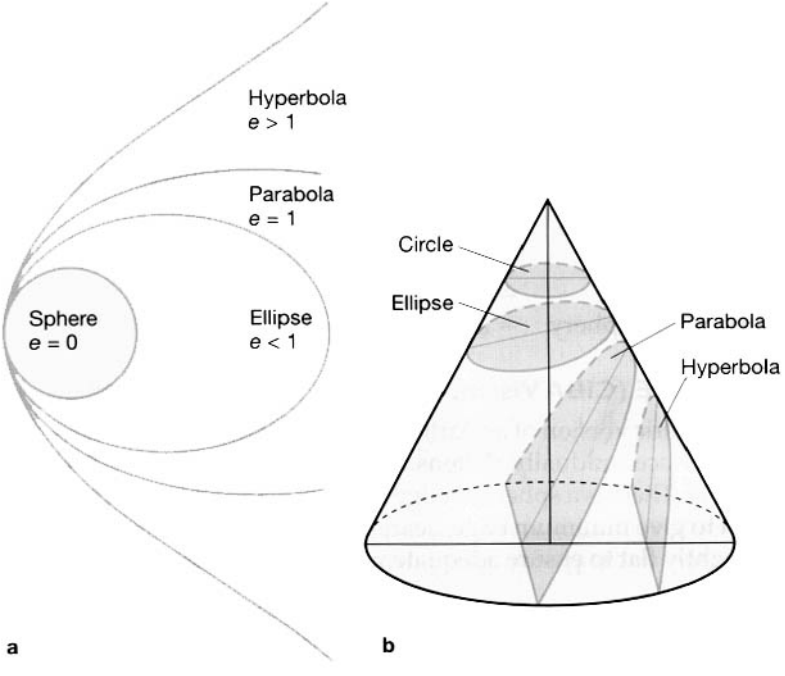

Figure 8.11a, b Representations of aspheric surfaces

8.4.1 Aspheric designs

Nissel aspheric

The Nissel design (1967),[10] now rarely used, was based on the US Volk lens. It had a central aspheric portion with a 7.80 mm diameter, two spherical zones at diameters of 8.40 mm and 8.80 mm, and an

0.50 mm wide bevel of radius 10.00–12.00 mm to assist tear flow. It was fitted 0.10 mm steeper than 'K' to give central alignment with the appearance of a multicurve.

Conflex (Wohlk, 1982)

Moulded from Anduran material (CAB + ethyl vinyl acetate), this lens[11] consists of a spherical optic with three aspheric peripheral zones. The edge shape is termed *ski-tip*. The lens is fitted 2.00 mm less than the horizontal visible iris diameter (HVID) to give central alignment, or just flatter than 'K' with slight superior decentration.

TD	= 9.40 mm, 9.90 mm, 10.20 mm
BOZR	= 'K' + 0.00–0.10 mm
Aspheric periphery	= 0.80 mm, 1.60 mm, 3.50 mm flatter than BOZR

Conflex air (Wohlk, 1989)

A fully aspheric design in a fluoropolymer material, fitted with central alignment.

TD	= 9.30 mm, 9.80 mm, 10.30 mm
BOZR	= 7.20–8.60 mm
Aspheric periphery	= (e = 0.4)

Persecon E (CIBA Vision, 1981)

The aspheric version of an earlier spherical design, both in CAB. The back surface gradually flattens to the periphery with e = 0.40 and p = 0.84. There is a spherical edge curve to assist tears exchange. It is fitted to give minimum edge clearance either with central alignment or slightly flat to ensure adequate movement and tears exchange.

BOZR	= 'K' + 0.10 mm
Spherical edge width	= 0.20–0.30 mm
Spherical peripheral radius	= 10.00–12.00 mm
TD	= 8.80 mm, 9.30 mm, 9.80 mm, 10.30 mm
Edge clearance	= 20–60 μm

TD (mm)	*AEL* (mm)
8.80	0.016–0.030
9.30	0.020–0.041
9.80	0.025–0.053
10.30	0.033–0.069

Quasar (No. 7, 1994)

The lens is designed to be a progressive eccentric aspheric, based on a corneal model with $e = 0.458$. The eccentricity value at the lens apex is 0 and increases with the semi-diameter from the centre outwards. The back surface consists of a modified conic profile giving a central, differentially flattening aspheric geometry. An aspheric 'ski-bevel' peripheral band and a specially lathed edge curve are added to generate edge clearance and edge form respectively. The central lens geometry aims for a TLT of 6.5 μm with a fluorescein pattern showing no obvious bearing area. There is also an even band of peripheral clearance about 0.50 mm wide, increasing in intensity towards the lens edge.[12]

BOZR	= flattest 'K', with up to 1.50 DC
Diameter of central zone	= 6.00 mm
FOZD	= 8.00 to 6.80 mm depending on BVP
TD	= 9.20 mm, 9.60 mm, 10.00 mm
Edge thickness	= 0.10 mm (radial)
Centre thickness	= 0.17 mm at –3.00 D

Asphericon (CIBA Vision, 1998)

The design consists of a progressive aspheric back surface with a spherical ski-tip periphery 0.40 mm wide. The lens has a standard eccentricity of $e = 0.55$ (p value = 0.7) which gives a constant edge clearance equivalent to an axial edge lift of 0.12 mm. Flatter ($e = 0.70$) and steeper ($e = 0.40$) eccentricities are also available. The front surface is spherical and lenticulated where necessary.

The optimal fluorescein pattern shows central alignment or slight apical clearance and gives the appearance of a well-fitted multicurve. The ski-tip edge should be 0.40 mm to 0.70 mm wide with an edge clearance between 0.10 mm and 0.12 mm. The fitting can be adjusted by selecting either the larger or the smaller eccentricity. The 9.30 mm diameter is selected first, except for large corneas or tight lids which would cause lens decentration.

BOZR	Aspheric equivalent to 7.00 to 8.60 mm in 0.1 mm steps
Total diameters	9.30 mm and 9.80 mm
Eccentricities	0.55 ($p = 0.70$), 0.70 ($p = 0.50$), 0.40 ($p = 0.84$)
Centre thickness	At –3.00 D, 0.12 mm

Menicon Z-Alpha (Menicon, 2002)

Aspheric geometry and aberration-controlled optics which are achieved by an aspheric front surface with a back aspheric design for better centration and dynamics on the eye.

BOZR	Aspheric equivalent to 6.50 to 9.00 mm in 0.10 mm steps
Total diameters	8.00 to 11.00 mm
Centre thickness	At –3.00 D, 0.13 mm

8.5 Use of corneal topography in lens design

Videokeratoscopy (*see* Section 2.4) can be used in the design of contact lenses to fit individual corneal topography. This can often be more satisfactory than using a conventional fitting set and has the added advantages that simulated fluorescein patterns can be generated to accompany any change in lens design and no diagnostic lenses are required (*see also* Section 9.7).

8.6 Reverse geometry lenses

Reverse geometry lenses differ from conventional designs in that the intermediate curve is *steeper* than the base curve. Such lenses are used to improve centration (e.g. with corneal flattening procedures such as orthokeratology, *see* Chapter 14) and for some therapeutic applications (*see* Section 32.4.1).

Reverse geometry lenses are fitted by a combination of corneal sag calculation and careful fluorescein evaluation. The required tear layer thickness (TLT) is added to the sag value and the nearest matching radius selected from the trial set (*see* Section 14.3). The correct lens is significantly flatter than 'K' (0.30–0.40 mm) and chosen to maintain a TLT of at least 10 μm.

The fluorescein pattern consists of central touch over the central 3.5 to 4.5 mm surrounded by an annulus of fluorescein representing the steeper tear reservoir. The TR is in turn surrounded by an area of peripheral touch and a band of edge clearance. This gives a typical 'bulls-eye' pattern.

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CHAPTER 9

Hard lens selection and fitting

9.1 Introduction

Opinions differ as to what constitutes a satisfactory hard lens fitting but the alignment method is the most commonly accepted concept. Alignment means that the majority of the back surface of the lens is made to align with the cornea so that the weight is distributed over as large an area as possible. Alignment must be consistent with good tears interchange behind the lens and with satisfactory vision.

The following information is required:

- Accurate refraction. The ocular refraction should be calculated as this enables a subsequent check on the liquid lens power.
- Accurate keratometry readings. These give the corneal astigmatism and govern the choice of BOZR.
- Horizontal visible iris diameter (HVID). This is approximately the corneal diameter and governs the choice of total diameter (TD).
- Vertical palpebral aperture. This also governs the TD.
- Pupil size in average and low illumination. This influences the BOZD.

Practical advice

The maximum pupil size can be measured using the blue light of the Burton lamp.

9.2 Back optic zone radius (BOZR)

- Diagnostic lenses are usually available in steps of 0.10 mm, although most prescription lenses can be ordered in 0.05 mm steps.
- The preferred fitting for most corneal lenses is alignment or very slightly flatter.
- Diagnostic lens selection is based on keratometry.
- The initial lens usually has a BOZR nearest to flattest 'K'.
- Toric corneas (1.00–3.00 D of astigmatism) should also be fitted on or near flattest 'K' to minimize flexure and achieve good acuity with a spherical lens.[1]
- The radius must be considered in relation to BOZD. Where a very large optic is required (e.g. 8.40 mm), the radius is usually flatter (e.g. 'K' + 0.10 mm) to achieve an alignment fitting.
- Additional factors such as lid tension, BVP and centre of gravity must also be considered (*see* Section 7.2).
- Right and left eyes generally require radii within 0.05 mm of each other, except in cases of anisometropia.

Practical advice

As keratometry measures only the central cornea, patients with the same corneal curvature do not necessarily give the same fluorescein pattern if fitted with the same BOZR.[2] Peripheral topography may differ, as can other influences such as lid tension.

Example 1:	(Alignment): 'K' 8.00 × 7.95 Initial radius selected: 8.00 mm
Example 2:	(Alignment): 'K' 7.97 × 7.83 Initial radius selected: 8.00 mm
Example 3:	(Toric cornea): 'K' 8.00 × 7.50 Initial radius selected: 7.95 mm

9.3 Total diameter (TD)

- TD is chosen on the basis of corneal size to be approximately 2.00 mm smaller than HVID.
- TD depends on pupil size, especially in low illumination.
- TD depends on the size of vertical palpebral aperture.
- The choice can be regarded as *small* (<9.20 mm), *medium* (9.20–9.70 mm) or *large* (>9.80 mm).
- Changing to a larger diameter generally stabilizes the fitting, although it does not always have a significant effect on the fluorescein pattern.
- Highly toric corneas need either small lenses to avoid excessive edge stand-off in the steep meridian or large lenses for lid attachment.
- The TD should be evaluated in relation to BVP. High powers require larger diameters for lens stability.
- The final choice of diameter also depends on the method of fitting (e.g. whether lid attachment or interpalpebral).
- Right and left eyes almost always require the same TD.

9.4 Back optic zone diameter (BOZD)

- Often predetermined by the laboratory.
- Depends on pupil size, especially in low illumination.
- The pupil position must be assessed for aphakics.
- BOZD is chosen to be at least 1.50 mm larger than pupil size.
- The choice may be regarded as *small* (<7.30 mm), *medium* (7.30–7.90 mm) or *large* (>7.90 mm).
- A larger BOZD for a particular radius gives a greater sag and therefore a steeper fitting.
- A smaller BOZD is often chosen with a toric cornea to reduce the area of mismatch.
- A larger BOZD is often chosen to permit a flatter BOZR which gives less flexure on a toric cornea.
- An excessively large BOZD gives a periphery which is very narrow. The peripheral curves must therefore be much flatter than normal for adequate edge clearance. This results in a sharp transition.
- The BOZD should be considered in relation to BVP and lenticulation. High minus lenses frequently require very large BOZDs to avoid flare.

Typical fittings:

Example 1: 7.80:7.50/8.60:8.30/10.50:9.30 (Figure 9.1)
Example 2: 7.80:8.20/8.70:8.90/10.50:9.80 (Figure 9.2)

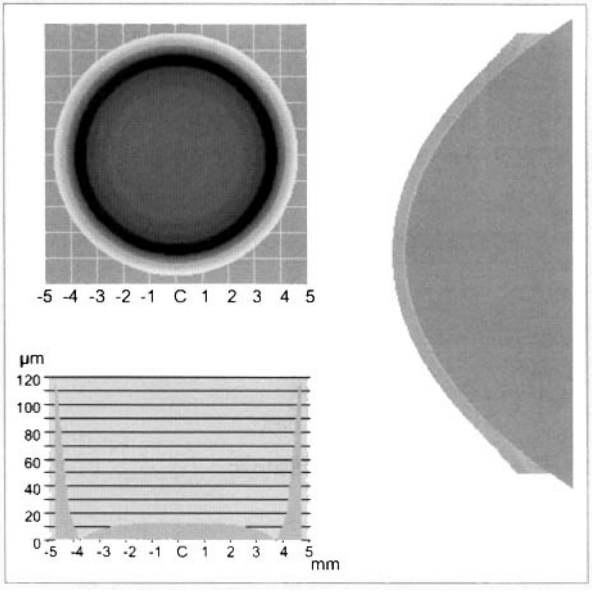

Figure 9.1 Tear layer profile/BOZD (Plate 8)

9.5 Peripheral curves

- The first peripheral curve should be at least 0.70 mm flatter than the BOZR and rather more for lenses at the flatter end of the scale.
- For a tricurve, the final peripheral curve is typically chosen as 10.50 mm, with a width of 0.50–1.00 mm.
- A flat peripheral curve gives less corneal irritation but greater lid sensation.
- Too little peripheral clearance gives unsatisfactory tears exchange because of increased capillary attraction. It can also cause arcuate staining and lens adhesion (*see* Section 7.3).
- Excessive clearance results in an unstable fitting because of an inverted tears meniscus and reduced lens adhesion (*see* Section 7.3). It can also cause peripheral dimpling and 3 and 9 o'clock staining.

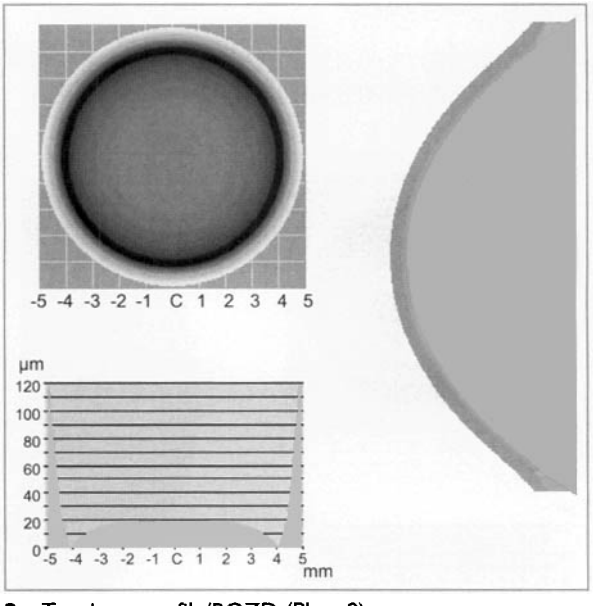

Figure 9.2 Tear layer profile/BOZD (Plate 9)

Examples:

Tight periphery	7.90:8.00/8.60:8.60/9.15:9.20 AEL = 0.05 mm (Figure 9.3)
Average periphery	7.90:8.00/9.10:8.60/12.30:9.20 AEL = 0.12 mm (Figure 9.4)
Loose periphery	7.90:7.00/8.85:7.80/10.40:8.60/11.50:9.00 AEL = 0.15 mm (Figure 9.5)

9.6 Back vertex power (BVP) and over-refraction

- Diagnostic lenses should be as near as possible to the anticipated BVP. Minus diagnostic lenses for hypermetropes should be avoided and vice versa.
- If a lens is fitted *steeper* than 'K', a *positive* liquid lens is created, requiring more negative power in the over-refraction (Figure 9.6a).
- If a lens is fitted *flatter* than 'K', a *negative* liquid lens is created, requiring more positive power in the over-refraction (Figure 9.6b).

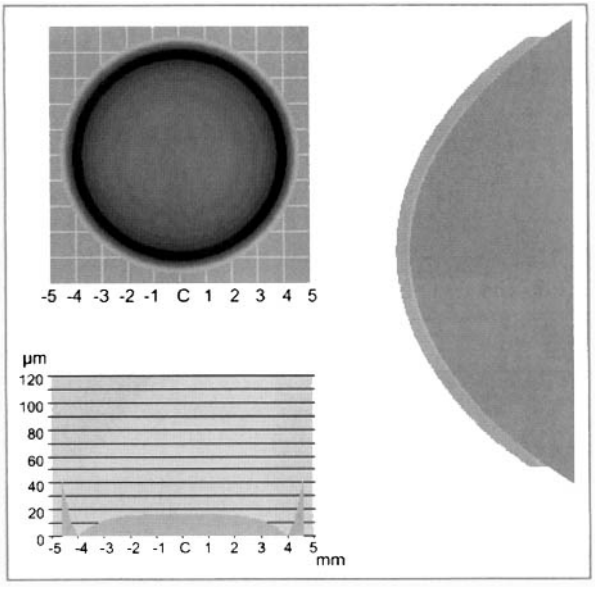

Figure 9.3 Tear layer profile/tight periphery (Plate 10)

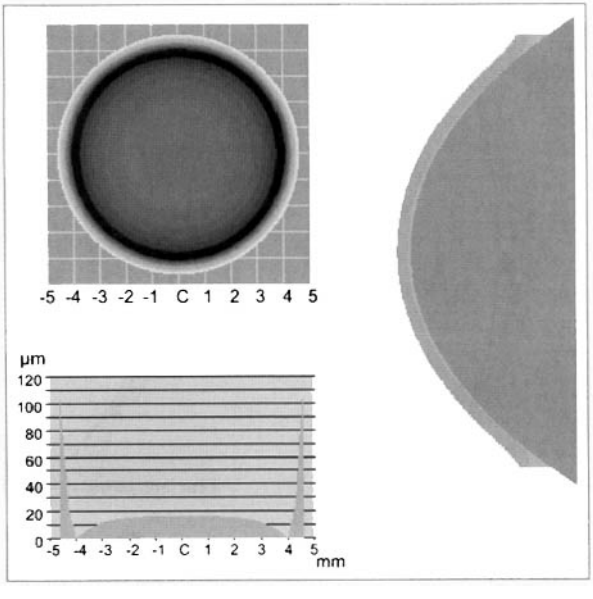

Figure 9.4 Tear layer profile/average periphery (Plate 11)

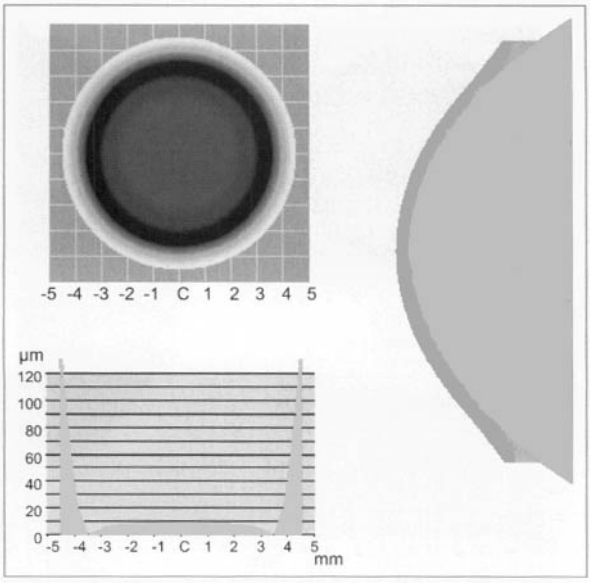

Figure 9.5 Tear layer profile/loose periphery (Plate 12)

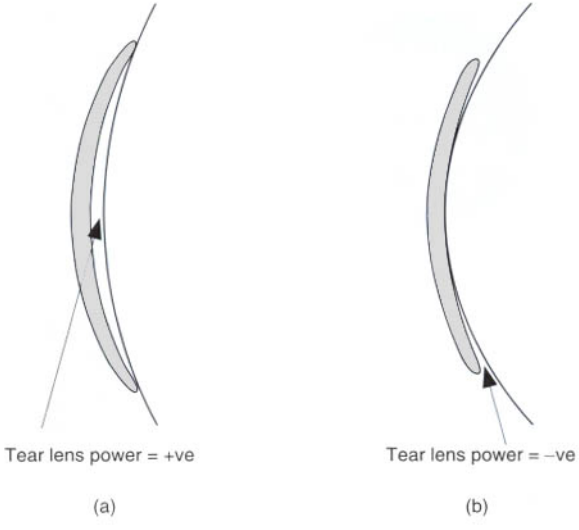

Figure 9.6 (a) Steep contact lens – positive tear lens power; (b) flat contact lens – negative tear lens power

- Different BVPs are likely for the same degree of with- and against-the-rule astigmatism.
- The final BVP should correlate with the spectacle *Rx* after taking into account the vertex distance.

Examples: Spectacle *Rx*: −3.00 DS 'K': 8.00 mm @ 180
7.95 mm @ 90

(1)	BOZR	8.10 mm	over-refraction	= −0.50 D
	Trial lens	−2.00 D	liquid lens	= −0.50 D
			final BVP	= −2.50 D
(2)	BOZR	8.00 mm	over-refraction	= −1.00 D
	Trial lens	−2.00 D	liquid lens	= plano
			final BVP	= −3.00 D
(3)	BOZR	7.90 mm	over-refraction	= −1.50 D
	Trial lens	−2.00 D	liquid lens	= +0.50 D
			final BVP	= −3.50 D

Rule of thumb

A change in radius of 0.05 mm ≡ 0.25 D change in power (if the radius is in the region of 7.80 mm).

General advice

- As right and left eyes nearly always require the same TD, use different diameter diagnostic lenses in each eye to observe two fittings at the same time.
- Use a similar technique to evaluate two BOZRs at the same time, as they do not often differ by more than 0.05 mm for similar 'K' readings.
- Check that the BVP from over-refraction correlates with the spectacle *Rx* and astigmatism after allowing for vertex distance. Repeat with a different diagnostic lens in case of doubt.
- Do not over-refract hypermetropes with minus diagnostic lenses and vice versa. The results are nearly always unreliable.
- If the patient was previously a PMMA wearer, order the lenses 0.02 mm thicker than normal to reduce the risk of breakage with more modern materials.

Practical advice

Hard lenses give best vision if:

- The BOZD is relatively large (>8.00 mm).
- The TD is relatively large (>9.80 mm).
- The periphery is not too wide (<1.00 mm).
- The periphery is not too flat (AEL <0.14 mm).
- Centre thickness is 0.14 mm or greater.
- Fitting is on or near flattest 'K'.

9.7 Lens design by corneal topographers

Videokeratoscopes for corneal topography measurement often include contact lens design programmes[3,4] to determine:

- The temporal keratometry reading for the initial BOZR.
- Whether the initial BOZR will allow unobstructed vertical lens movement and redesign curves if necessary.
- The mid-peripheral corneal curvature for superior, temporal and inferior positions.
- The degree and symmetry of any mid-peripheral corneal astigmatism and whether a toric lens is necessary.

Comprehensive computer programmes are available to custom design most types of hard gas-permeable lens from C2 to C5. Some programmes automatically suggest the optimal lens while others allow the practitioner to insert the BOZR, diameters and AEL in order to compute the intermediate curves.

The value of videokeratoscopy is enhanced by providing simulated fluorescein patterns for the calculated lens design and demonstrating the bearing areas on the cornea. It is also possible to show the effect on the fitting when the various lens parameters are changed. An alternative approach where instruments are able to provide details of AEL and edge clearance is to design lenses using the principle of TLT. Topographical fitting nomograms based on corneal eccentricity are able to select an appropriate initial BOZR according to a preferred fitting philosophy without the need to apply a variety of diagnostic lenses.

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CHAPTER 10

Fluorescein patterns and fitting

10.1 Use of fluorescein

10.1.1 Instillation of fluorescein

- A fluorescein strip is moistened with saline and excess removed by shaking.
- The patient is asked to look down while the upper lid is lifted and the wet strip gently touched onto the conjunctiva above the superior limbus, taking care not to instill excess.
- Fluorescein flows beneath the lens with the tears after two or three blinks.
- If a minim of 2% fluorescein is used, one drop only is applied with a glass rod. Some of it is allowed to wash away before inspecting the fit.

Practical advice

- *Never* use tap water to wet fluorescein strips. *Pseudomonas aeruginosa* has a strong affinity for fluorescein and may be present together with other micro-organisms such as *Acanthamoeba*.
- Do not apply the strips dry, as they can be very uncomfortable.
- It is usually more comfortable for the patient to look down to reduce lid sensation, especially with an unadapted patient.
- Sometimes, however, with very tight lids and squeamish patients it is better applied in the lower outer canthus, gently pulling down the bottom lid and resting the paper flat against the lower palpebral conjunctiva.
- Insertion of the contact lens with a viscous wetting solution may encourage the fluorescein to spread across the front surface of the lens and mask the posterior fluorescein pattern. Either use saline or give the lens longer to settle.
- Do not paint the wet strip over the conjunctiva, since too much fluorescein masks the true pattern. The excess can also stain skin and clothes.
- *Never* reuse strips on another patient because of the risk of cross-infection. Discard after use to avoid error. Use a different strip for each eye if infection is suspected.
- If a strip is reused for the same patient, fold it as shown in Figure 10.1 to avoid contaminating the tip.

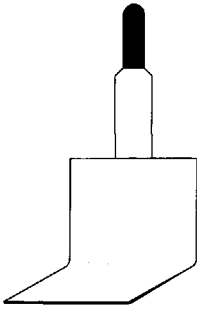

Figure 10.1 Folded fluorescein strip

10.1.2 Ultraviolet inhibitors

Some materials contain ultraviolet (UV) inhibitors, so that the fluorescein pattern with the Burton lamp shows an apparently black lens with an almost imperceptible green annulus at the periphery.

Additional fluorescein does not change the appearance and it is necessary to use the slit lamp with a blue filter to give a meaningful picture.

10.2 Examination techniques

10.2.1 Burton lamp

Blue light

The essential principles in observing fluorescein patterns are:

- The method gives a dynamic assessment of lens fitting.
- Dark blue represents corneal touch.
- Green represents corneal clearance.
- Compared with slit lamp observation, the patient is more relaxed with the Burton lamp, so that both head and eyelids maintain a normal position.
- The Burton lamp uses UV light.

Practical advice

- Exercise care with nervous patients. They sometimes feel faint and the UV lamp is often the trigger mechanism. If in doubt, delay fluorescein examination until they are more at ease.
- Despite this, they nearly always make very good contact lens wearers.

White light

White light with low magnification allows initial investigation of lens position and movement prior to fluorescein assessment, but care is required with a photophobic patient.

10.2.2 Slit lamp

- The cobalt blue filter of the slit lamp permits evaluation of the fluorescein pattern with relatively low magnification (6 to 10).
- A wide beam of 3–5 mm is used for general assessment.
- A narrow slit beam with higher magnification gives a qualitative indication of tear layer thickness and corneal clearance.
- The head and lids are not in a relaxed position on the instrument, so that the assessment of lens centration is not completely reliable.
- The fluorescein pattern appears normal even if the lens material contains a UV inhibitor.
- Contrast is enhanced using a filter, Wratten yellow 6 or 12.

10.3 Fitting

- The central and peripheral fit are independent variables and should always be assessed separately.[1]
- The fitting should be evaluated with the lens both centred on the apex of the cornea and in a decentred position.
- Lens movement during and after a blink should be noted.
- Lens position after a blink is important.
- Lens movement on eye excursions is also significant.

10.4 Correct fitting

10.4.1 Assessment with white light

Excursion lag

With the lids in a normal position, the lens periphery should not extend beyond the limbal area even with wide excursions of the eye.

Static lag

If the lids are held apart and the lens pushed upwards, it should drop slowly of its own accord.

10.4.2 Assessment with fluorescein

Alignment fitting (e.g. with modern multicurve designs)

Appearance

The ideal fluorescein pattern should show three fitting areas (Figure 10.2):

- Alignment or the merest hint of apical clearance over the central 7.00 mm.
- Mid-peripheral alignment over about 1.50 mm.
- Edge clearance about 0.5 mm wide.

Apically clear fitting (e.g. with PMMA)

Appearance

Fluorescein pooling over the central 5.00 mm.

- Mid-peripheral alignment.
- Edge clearance about 1.00 mm wide.

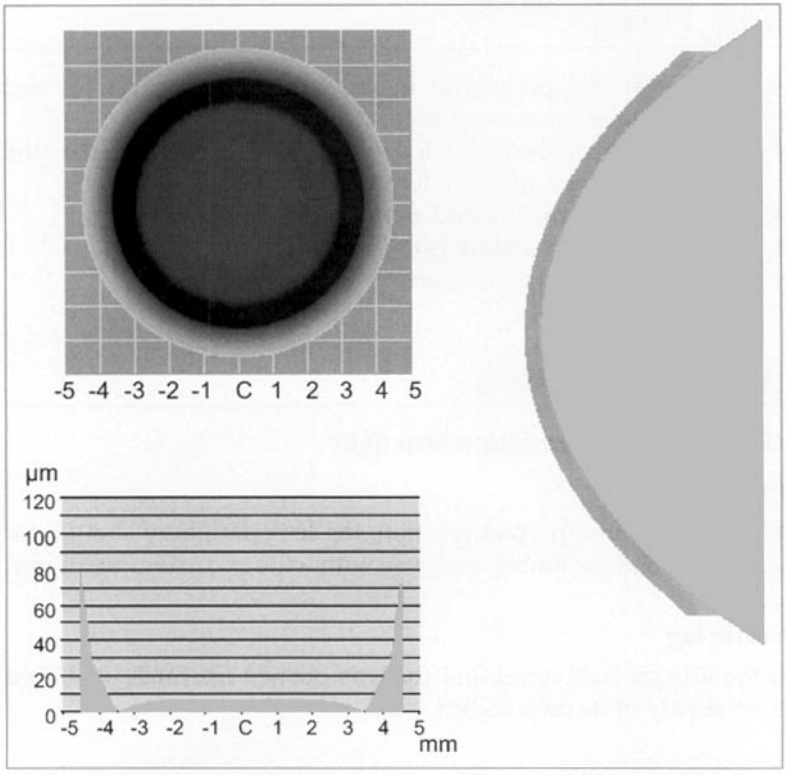

Figure 10.2 Alignment fitting (Plate 13)

Flatter than 'K' fitting (e.g. most aspherics)

Appearance

- Alignment or light touch over the central 5.00 mm.
- Mid-peripheral alignment.
- Narrow edge clearance just under 0.5 mm wide.

10.5 Flat fitting

Appearance (Figure 10.3)

- The fitting pattern gives a dense central area of dark blue touch surrounded by fluorescein to the edge of the lens.
- The area of touch is small with an indistinct as opposed to a sharply demarcated border.

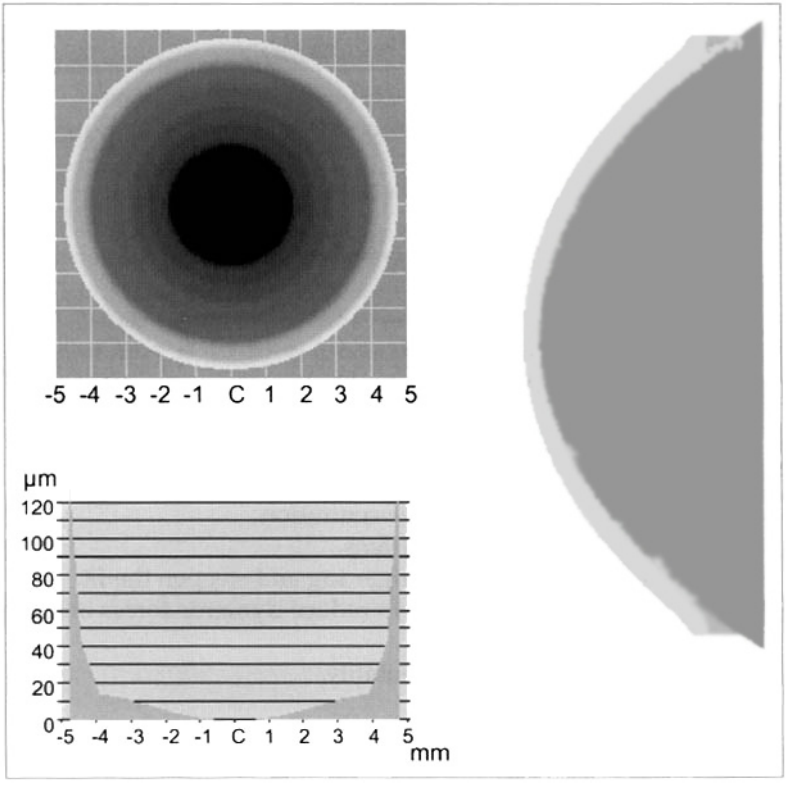

Figure 10.3 Tear layer profile/flat fit (Plate 14)

- Fluorescein encroaches beneath the periphery of the central portion where alignment would be expected with a correct fit.
- The lens is unstable and decentres.
- If the lens drops, it may show inferior fluorescein pooling. This is not an indication of steepness, since the lens is overhanging the lower peripheral cornea. If it is repositioned, central touch is observed.
- The entire periphery of the lens shows clearance as a wide area of fluorescein.
- Blinking gives excessive and rapid lens movement that may well be uncomfortable.
- Arcuate movement occurs when dropping between blinks or with static lag.

Practical advice

- Use a steeper BOZR for greatest effect on the fluorescein pattern.
- All other remedies have a lesser effect and the choice of action depends on the degree of flatness.
- Carefully evaluate the TD. If the lens is already large enough, further increase might not be feasible.
- Increasing the BOZD has a greater effect on the fluorescein pattern than making the lens larger.
- Use tighter or narrower peripheries to help the lens centre better.
- All modifications to an existing lens tend to loosen the fit. A flat fitting almost invariably requires a new lens.

To correct a flat fit

- Use a steeper BOZR to improve centration.
- Increase the TD to stabilize the lens.
- Increase the BOZD to give a larger sag and steepen the fit.
- Use tighter peripheral curves to reduce dynamic forces and the effect of the lids.
- Use a thinner lens to reduce mobility.

10.6 Steep fitting

Appearance (Figure 10.4)

- The fluorescein pattern gives central pooling.
- An air bubble is sometimes present with excessive central clearance.
- Heavy bearing is seen at the transition as an area of dark blue touch beyond the central pooling.
- The smaller the area of central pooling, the greater the degree of steepness.
- The periphery gives only a thin annulus of fluorescein around the lens edge.
- There is little lens movement on blinking.

To correct a steep fit

- Use a flatter BOZR.
- Decrease the TD to increase lens mobility.
- Decrease the BOZD to give a smaller sag.

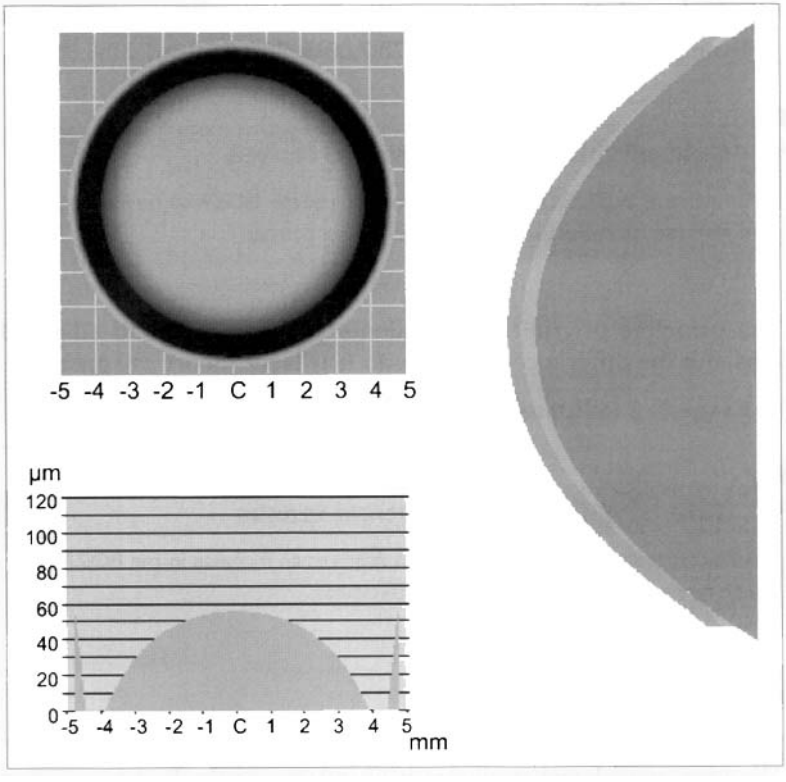

Figure 10.4 Tear layer profile/steep fit (Plate 15)

- Use flatter peripheral curves to increase the dynamic forces on the lens.
- Use a thicker lens.
- Fenestrate (*see* Section 26.3).

Practical advice

- Use a flatter BOZR to give the greatest effect on the fluorescein pattern.
- Carefully evaluate corneal and pupil sizes before reducing the TD and BOZD.
- Central fenestration is generally a last resort, but encourages tear flow beneath the lens apex and increases mobility.
- All modifications tend to loosen the fit. Several adjustments can therefore be made to improve an existing steep lens.

Clinical equivalents (*see* Section 16.3)

Example 1 (spherical lens): 7.70:7.00 ≡ 7.75:7.50 ≡ 7.80:8.00

Rule of thumb for spherical lenses

An increase in the BOZD of 0.50 mm requires the BOZR to be flattened by 0.05 mm to maintain the same fluorescein pattern.

The principle of clinical equivalents still applies to an elliptical lens, but the differences found with tear layer theory are greater.[2]

Example 2 (elliptical lens): 7.70:7.00 ≡ 7.75:7.70 ≡ 7.80:8.50

Rule of thumb for elliptical lenses

An increase in the BOZD of 0.70 mm requires an increase in the BOZR of 0.05 mm to give the same tear layer thickness.

10.7 Peripheral fitting

The ideal peripheral clearance is 60–80 μm, equivalent to an edge lift of 0.12–0.15 mm. It depends on corneal topography and method of fitting. In practical terms, this gives an annulus of fluorescein about 0.50 mm wide at the edge of the lens. The limit of clinical significance is about 10 μm.[3]

Tight periphery

Appearance

- Good centration.
- Periphery presses the limbus on blinking and may cause discomfort.
- Poor tears exchange under the lens and several blinks necessary for fluorescein circulation.

To improve a tight periphery

An increase in edge clearance of at least 10–15 μm is necessary to give a discernible change in fluorescein pattern. Axial edge lift

should be increased in increments of 0.03 mm (e.g. from 0.12 mm to 0.15 mm).

- Use a flatter peripheral radius (e.g. 10.75 mm instead of 10.25 mm).
- Add one or more flatter peripheral curves (e.g. 12.25 mm, 0.4 mm wide; or 15.00 mm, 0.2 mm wide).
- Increase the width of the peripheral curves.
- Use a flatter BOZR and smaller BOZD.
- Increase blending of peripheral curves.
- Change the lens design. Centration affects the peripheral interaction with the cornea.

Loose periphery

Appearance

- Lens rides high and does not drop after a blink.
- Bubbles are found at the edge and superior dimpling may occur.
- The edge lifts away from the cornea on blinking.
- The lens is unstable on excursion movements.
- Frequently gives 3 and 9 o'clock staining.

To improve a loose periphery

To improve a loose periphery requires a decrease in edge clearance of at least 10–15 μm. The axial edge lift is decreased in increments of 0.03 mm (e.g. from 0.15 mm to 0.12 mm).

- Use a tighter peripheral radius (e.g. 10.00 mm instead of 10.50 mm).
- Reduce the width of the peripheral curves.
- Use a larger BOZD, possibly with a flatter BOZR to compensate.
- Change the lens design and possibly try an aspheric.

Lens position (Table 10.1)

The position the lens assumes on the cornea may indicate a fitting problem in respect of lid tension or possible decentration of the corneal apex.

General advice

- Use a negative carrier for low-riding plus lenses.
- Aspheric lenses sometimes give better centration and comfort with plus lenses.

continued

- A displaced corneal apex causes lens decentration even if the fitting is not too flat. Use a larger TD if flare is a problem.
- Tight lids with a toric cornea also cause decentration. Consider a back surface toric lens.

Table 10.1 Lens position

Lens position	Possible cause	Remedy
Always high, not dropping after blink	Flat peripheral zone	Steepen periphery
	Wide periphery	Narrow periphery
	Too large TD	Reduce TD
	Lens edge too thick	Reduce centre or edge thickness
	With-the-rule cylinder	BS toric design
Always low, rapid drop after blink, or never lifted by blink	Lens too small	Increase TD
	Lens too thick	Reduce centre thickness
	No lid attachment	Use negative carrier
Always decentred laterally	Displaced corneal apex	Increase TD
	Lens too small	Increase TD
	Lens too flat	Steepen fit
	Against-the-rule cylinder	BS toric design
		Soft lens
Immobile	Lens too steep	Flatten fit
	Adhesion	Alter design (see 29.3.6)
Excessive decentration beyond limbus	Excess lacrimation	Check other symptoms
	Lens too flat	Steepen fit
	Excess corneal cylinder	Toric design

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CHAPTER 11

Aspheric lenses

Aspheric lens design has evolved because clinical models have shown the overall form of the cornea to be elliptical.[1–3] The variation in the shape of an ellipse is called the eccentricity (e) and is an important factor in lens design and fitting. Mathematically, it is always less than 1 (*see* Section 8.4).

11.1 Advantages and disadvantages of aspherics

Advantages of aspherics

- Fit more closely to the corneal topography (Figure 11.1).
- Distribute pressure more evenly over the cornea.
- Edge lift or Z value is smaller, giving less lid sensation.
- Can sometimes fit up to 4.00 D of astigmatism.
- Some designs can give improved distance vision, others can assist presbyopia (*see* Section 25.4.2).
- Absence of transition zones assists tear flow.

Disadvantages of aspherics

- Manufacture requires sophisticated lathes.
- Reproducibility and verification more difficult.
- Aberrations with some back surface designs.

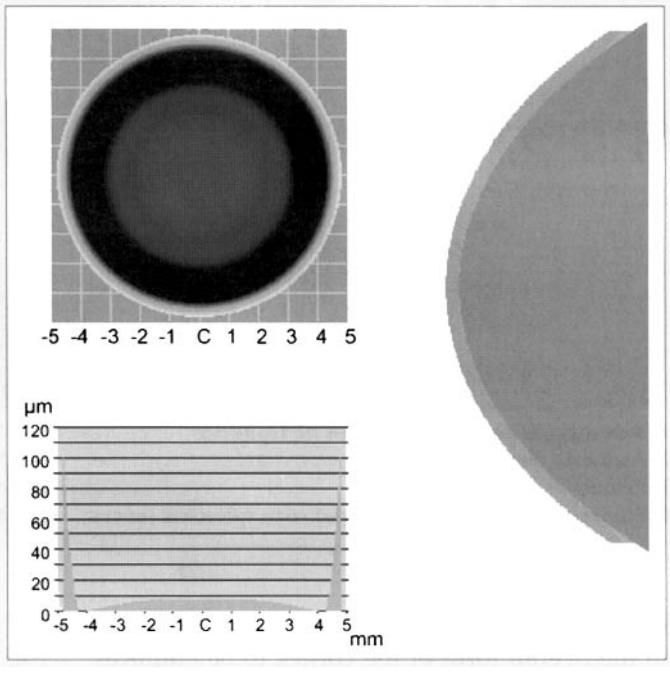

Figure 11.1 Aspheric lens showing close fit to corneal topography (Plate 16)

- Decentration if fitted flatter than 'K' to obtain movement.
- Decentration with a decentred corneal apex.

11.2 Aspheric designs

Aspheric lens designs show significant advantages in achieving true alignment but the peripheral flattening of the lens may reduce the sag compared to the equivalent spherical lens. It is necessary, therefore, to select a lens steeper than flattest 'K'. However, in most designs the lens geometry has been fine-tuned to permit the selection of lens BOZR equivalent to flattest 'K' while still providing the desired fitting relationship.

11.2.1 Fully aspheric lenses

A completely aspheric back surface can cause problems if the eccentricity chosen fits the corneal topography too closely, resulting in the lens edge pressing into the peripheral cornea. A narrow, spherical

bevel or separate aspheric edge is therefore usually incorporated into the design.

If a bi-aspheric lens with fixed high eccentricity decentres, it can induce residual astigmatism because of the differential power effect of the sagittal and tangential radii towards the lens periphery. Conversely, with designs which have differential flattening, there can be a significant reduction in both positive and astigmatic aberration in the optic portion of the lens.

Quasar

The Quasar design[4] (No. 7 Laboratory) has a back surface consisting of a conic profile with a central differentially flattening aspheric geometry. A further aspheric 'ski-bevel' peripheral band ensures adequate edge clearance. The eccentricity value at the lens apex is zero and increases with the semi-diameter from the centre outwards. The reduction in initial flattening results in a more spherical central optic portion. The edge clearance of 80 μm is based on a corneal model with $e = 0.458$ (Figure 11.2).

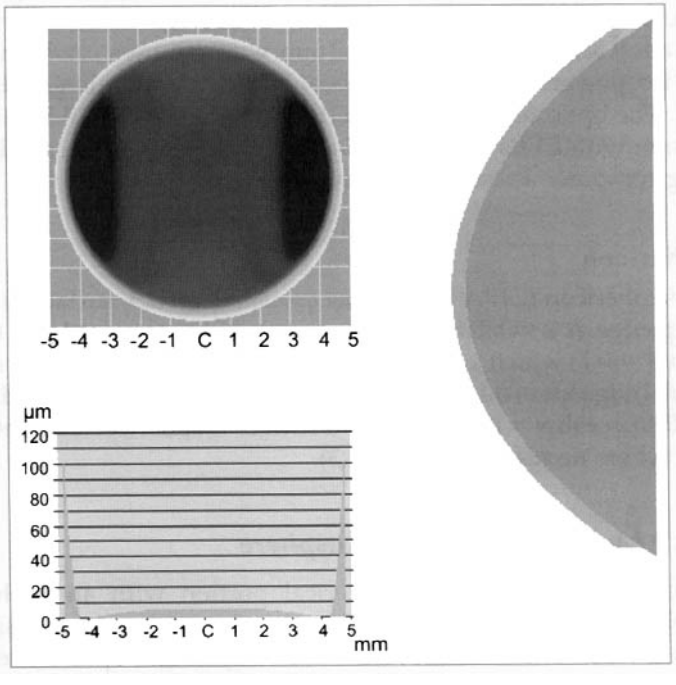

Figure 11.2 Tear layer profile/Quasar (Plate 17)

11.2.2 Mainly aspheric/part sphere

These designs consist of a mainly aspheric back surface with a spherical peripheral curve between 0.2 mm and 0.3 mm wide giving 20–60 μm of edge clearance. The spherical curve is needed to prevent the elliptical edge from pressing into the cornea. It also assists tears exchange and lens removal.

The common designs are the Persecon E (CIBA Vision), Aquila (CIBA Vision) and Asphericon (CIBA Vision).

Persecon E

The Persecon E has an eccentricity of $e = 0.4$ and rate of flattening $p = 0.84$. It has a spherical periphery between 10 mm and 12 mm in radius and between 0.20 mm and 0.30 mm wide, to give an edge clearance of 20–60 μm.

Aquila

The Aquila and Persecon 92E designs (CIBA Vision) have an aspheric back surface design which is bi-elliptic with an integrated tangential bevel. The eccentricity has an average value of $e = 0.4$. TDs are 9.3 mm, 9.8 mm and 10.3 mm with a minus carrier available for powers of +2.00 D or greater with the two larger diameters. The optic zone varies with the TD, ranging from 7.50 mm to 8.00 mm with BVPs over ±8.00 D. The lens geometry is calculated using computer assisted design (CAD).

Asphericon

The Asphericon (CIBA Vision) has an aspheric back surface with a ski-tip edge. It is available in three eccentricities: standard ($e = 0.55$, p value = 0.7) which gives a constant edge clearance equivalent to an axial edge lift of 0.12 mm; high ($e = 0.70$, p value = 0.50); and low ($e = 0.40$, p value = 0.84). The front surface is spherical and lenticulated where necessary (Figure 11.3).

11.2.3 Mainly spherical/part asphere

These consist of a central spherical portion with an aspheric peripheral zone area and are termed *polynomial aspheric designs*. The aspheric zone is, in turn, surrounded by a small spherical edge bevel.

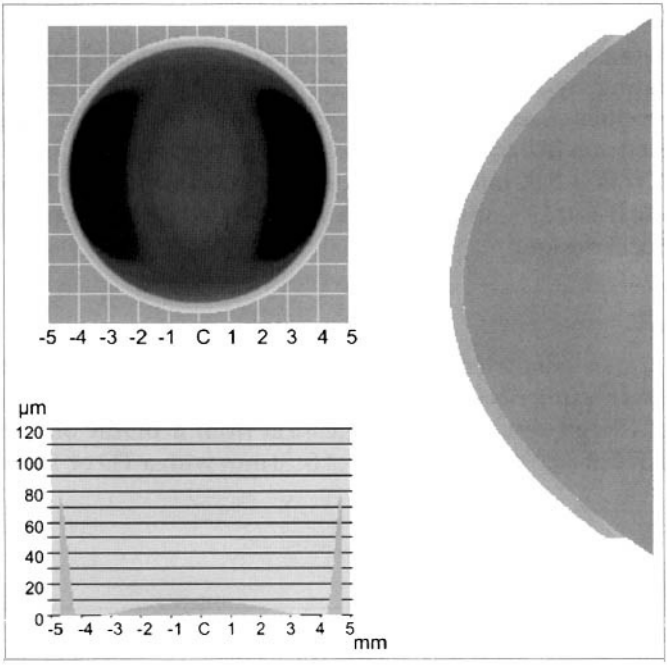

Figure 11.3 Tear layer profile/Asphericon (Plate 18)

Quantum

The Quantum lens (Bausch & Lomb) has a 3.50–4.00 mm central spherical portion with an aspheric periphery. The edge has a radius of 11.25 mm, 0.3 mm wide.[5]

Reflex 60

The back surface design of Reflex 60 (CooperVision) has a spherical central curve tangentially connected to a conic 'mid-section' which is in turn tangentially connected to a ski-bevel peripheral radius.[6] The aspheric/conic section starts at the junction of the BOZD and varies with BOZR. In all cases it has a constant chord diameter of 8.40 mm. The ski-bevel extends from 8.40 mm out to the TDs of 9.00 mm, 9.30 mm, 9.70 mm or 10.00 mm. Both the eccentricity of the conic section and the total AEL of the lens vary with BOZR. They range from 1.16 to 2.26 and from 0.109 mm to 0.186 mm, respectively.

Astrocon

The Astrocon HDS (CIBA Vision) has a spherical back optic zone graduating into an aspheric periphery of $e = 0.60$. Two further eccentricities, 0.45 and 0.75, are available. The BOZR range is 7.00–8.60 mm in 0.05 mm steps with TDs of 9.60 mm and 10.20 mm. The BOZD is 5.00 mm for each diameter and the centre thickness at −3.00 D is 0.135 mm. The Astrocon is the basis of a front surface multifocal design.

Metro[2]

A computer generated constant axial edge lift design (Cantor + Nissel) with spherical optic zone and aspheric periphery. The incremental design results in a progression from a BOZR of 7.00 mm with a TD of 8.80 mm to a BOZR of 8.70 mm with a TD of 10.50 mm.

11.3 Principles of fitting

11.3.1 Fully aspheric lenses

Progressive eccentric aspheric lenses (e.g. Quasar) are generally fitted on flattest 'K'. The fluorescein pattern shows no obvious area of bearing over the central and mid-peripheral area while the lens edge gives a well-defined tears meniscus. The lens position should be central with 1.5–2 mm of movement on blinking. If the TD needs to be ordered larger (10.00 mm) or smaller (9.20 mm) than the 9.60 mm diagnostic lenses, there is no need to change either the BOZR or BVP.

With toric corneas, the central radius is chosen 0.10 mm steeper than flattest 'K'. The lens should still give good centration but will show greater peripheral clearance along the vertical rather than horizontal meridian. Mid-peripheral bearing indicates the need for a flatter lens, whereas hard central touch or decentration requires a steeper fitting.

11.3.2 Mainly aspheric/part sphere

Persecon E

The Persecon E design is manufactured from CAB (*see* Section 6.1). It is fitted slightly flatter than flattest 'K'. The total diameter is

chosen according to corneal size: 8.80 mm or 9.30 mm for corneas up to 11.00 mm, and 9.80 mm or 10.30 mm for those larger than 11.00 mm.

A correct fitting shows alignment or the suggestion of light central touch. In the case of decentration, a larger lens should be tried before steepening the curvature. The edge bevel is cut with a common tangent to the ellipse to give good comfort.

Example: 'K' 7.89 mm × 7.83 mm
Persecon E: 8.00:9.30

Aquila and Persecon 92E

Aquila and Persecon 92E are fitted at least 0.05 mm flatter than flattest 'K'. The fluorescein fit is alignment to slightly flat with a small degree of edge clearance. As the elliptical base curve flattens towards the edge of the lens in the same way as the cornea, the TD can be altered without causing any change to the fluorescein pattern. However, if the base curve is altered, the BVP requires compensation in the usual way.

Practical advice

The design of the Aquila and Persecon 92E differs from that of the earlier Persecon E so the correct diagnostic set must be used to achieve an optimal fitting.

11.3.3 Mainly spherical/part asphere

Quantum

The spherical central radius is selected 0.10 mm steeper than flattest 'K' to allow the aspheric mid-peripheral portion to align with the cornea. The fluorescein pattern gives slight central pooling surrounded by an area of alignment with peripheral edge clearance. The lens design can give excessive edge clearance with steep corneas and too little clearance with flat corneas. Quantum does not ride as high as some of the flatter fitting designs and is useful where it is desirable to avoid lid attachment. The usual total diameter is 9.60 mm. To help centration, 10.20 mm lenses are available, but even 9.60 mm is too large for some small corneas. Only plus lenses are available in a 9.00 mm diameter.

Reflex 60, Metro^2 and Maxim Ultra

The initial trial lens is chosen on flattest 'K' or slightly steeper for up to 1.00 D of astigmatism. This should maintain the appearance of alignment over the central area of the lens with gradually increasing clearance in the periphery. With greater than 1.00 D of astigmatism, the BOZR is selected 0.10–0.15 mm steeper than 'K'. The lens should centre with 1–1.5 mm of movement on blinking.

Astrocon HDS

The first lens is chosen 0.10 mm steeper than 'K' for cylinders up to 0.75 D, on 'K' for up to 1.75 DC, and 0.10 mm flatter than 'K' for cylinders up to 2.50 DC. Movement should be between 1.0 mm and 2.0 mm. The fluorescein picture should show alignment or minimal apical clearance. There should also be slight mid-peripheral bearing and 0.10–0.12 mm edge clearance. If the initial fit appears flat, the 0.45 '*e*' value option should be tried, and, if steep, the 0.75.

11.3.4 General fitting considerations

Aspheric lenses:

- Do not require such critical fitting because fewer parameters.
- Need to be fitted slightly flat to give adequate movement and sufficient edge clearance (except designs like Quantum).
- Flat fitting, however, tends to give decentration as a common problem.

Spherical cornea

The ideal fit is alignment or slightly flatter than alignment. A slightly flat fit gives light central touch, but because of even pressure distribution any stress to the cornea is kept to a minimum.

A flat fit shows hard central touch surrounded by an excessive annulus of fluorescein. There is increased lid sensation and unstable vision.

A steep fit gives excessive central pooling with a sharp border, surrounded by a peripheral ring of hard touch and a very narrow meniscus of fluorescein at the periphery.

Toric cornea

The ideal fit is also alignment or slightly flatter than flattest 'K' to minimize lens flexure and maintain good acuity.

11.4 Fluorescein patterns compared with spherical lenses

- A much more gradual change in the fluorescein pattern from centre to periphery.
- True alignment can be achieved if the correct eccentricity has been assessed, as the *p* value of the lens and cornea can be chosen to be the same (e.g. using a videokeratoscope).[7]
- The peripheral tear layer thickness increases more gradually towards the edge.
- Larger lenses have to be used to help centration.[8]

Practical advice

The axial edge lift of an aspheric lens is less than with the equivalent multicurve. It is sometimes possible to fit higher degrees of astigmatism because of the reduced edge stand-off in the steeper meridian.

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CHAPTER 12

Hard lens specification and verification

12.1 International Standards

The *Glossary of Terms and Symbols* is a dual publication of International Standard ISO 8320–1986. 'Rigid' lens specifications are given in ISO 8321–1:1991.

ISO 9000 covers manufacturers of assessed capability and implies that verification, production, tolerances, quality assurance and sampling conform to this standard.

12.1.1 International Standard terms

The terminology for a standard tricurve lens in ISO 8320–1986 symbols is:

r_0	:	$\varnothing_0$ / r_1	:	$\varnothing_1$ / r_2	:	$\varnothing_T$ t_c	F^1V *Tint*
BOZR	:	$BOZD/BPZR_1$	:	$BPZD_1/BPZR_2$	:	*TD*	*BVP*

Example:

7.90:7.80/8.70:8.60/10.75:9.20 t_c *0.15 BVP* −*3.00* D *Tint light blue*

7.90 = *back optic zone radius (BOZR)* r_0
7.80 = *back optic zone diameter (BOZD)* $\varnothing_0$
8.70 = *first back peripheral radius* r_1

8.60 = *first back peripheral zone diameter* $\varnothing_1$
10.75 = *second back peripheral radius* r_2
9.20 = *total diameter* $\varnothing_T$
0.15 = *geometric centre thickness* t_c
−3.00 = *back vertex power (BVP)*

For a lenticular lens (reduced optic):

7.90:7.80/8.70:8.60/10.75:9.20 t_c 0.45 t_e 0.16 BVP +10.00 D
FOZD 8.30 Tint light blue

0.45 = geometric centre thickness t_c
0.16 = edge thickness t_e
+10.00 = back vertex power (BVP)
8.30 = front optic zone diameter $\varnothing_{a0}$

The subscript 'a' indicates an anterior surface component and the format is the same for both plus and minus lenses.

12.2 Examples of hard lens types and fittings

(Assuming a spherical 'K' reading of 7.75 mm and low minus power.)

Individual designs

- TD 8.60 mm CAEL 0.12 mm[1]
  7.80:7.00/9.00:7.80/10.90:8.60
- TD 9.00 mm CAEL 0.15 mm[1]
  7.80:7.00/8.75:7.80/10.10:8.60/11.30:9.00
- TD 9.20 mm CAEL 0.12 mm[2]
  7.80:8.00/8.80:8.60/12.30:9.20
- TLT 13 μm, EC 60 μm
  7.80:7.70/8.30:8.20/9.20:9.20
- TD 9.50 mm CAEL 0.175 mm[3]
  7.80:7.50/8.90:8.50/10.00:9.00/11.15:9.50
- TLT 12 μm, EC 60 μm
  7.80:8.30/8.20:8.80/9.00:9.80

Proprietary designs

- Series II (No. 7 laboratory) 7.80:7.80/8.65:8.70/9.90:9.50
- Quantum (Bausch & Lomb): 7.70/9.60
- Aquila (CIBA Vision): 7.80/9.30 or 7.80/9.80

- Standard Polycon II (CIBA Vision): 7.80:7.80/AEL 0.10 at 9.00
- Asphericon (CIBA Vision): 7.80/9.80 standard *e*

12.3 Hard lens verification

All lenses should ideally be checked:

- To ensure the accuracy of diagnostic lenses.
- To ensure prescription lenses are suitable for dispensing.
- To establish the specification of the patient's existing lenses.
- Where lens parameters are thought to have altered.
- Where lenses are thought to have distorted.
- To confirm that lenses are being worn in the correct eyes.
- To confirm that current and old lenses have not been confused.
- To ensure records contain full details of lens specification.

12.3.1 Back optic zone radius (BOZR)

Radiuscope

Based on Drysdale's method, which measures the distance between the lens surface and the centre of curvature.

- To obtain a good image, ensure the lens is well dried before being placed on a drop of distilled water in the concave holder.
- To help location of the images, ensure the instrument light beam is at the centre of the lens.
- Travelling from the zero to the second position the image of the bulb filament is seen. The quality of this image gives an indication of any lens distortion.
- Always take two or three readings and average the results.
- The image at the lens surface is usually much larger and brighter than that at the centre of curvature, as well as showing any surface scratches.
- The zero reading with unstable hard lenses can 'creep' and may require several attempts before giving a reliable result. If the creeping does not stop, average the first three readings.

Other methods

Keratometer

Uses a lens holder with a front surface silvered mirror. 0.03 mm is added to correct for the concave surface.[4] Autokeratometers can also be used.

Radius-checking device

The radius is derived from the focimeter front vertex power (FVP), using refractive index and thick lens formula.[5]

Toposcope

Uses moire fringes.[6]

12.3.2 Peripheral radius (BPZR)

Peripheral radii can be measured with the radiuscope if the lens is tilted and the band width is at least 1 mm.

A qualitative assessment can be made with a Burton lamp by observing the reflection of the white light tube in the lens surface.

12.3.3 Total diameter (TD) and zone diameters (BPZD)

Measuring magnifier (band magnifier)

Consists of an engraved graticule plus an adjustable eyepiece with ×7 magnification. The lens is repositioned on the scale for different zones, and measurement is easier with sharp transitions.

V gauge

Consists of a V-shaped channel graduated between 6.0 mm and 12.5 mm. Only measures TD.

Projection magnifier

Projects a magnified image of the entire lens onto a calibrated screen (e.g. Zeiss DL2).

Practical advice

- Ensure that the lens is dry; otherwise it can be difficult to remove from a smooth surface because of capillary attraction.
- Avoid wet cell instruments because of difficulty in lens manipulation.

12.3.4 Back and front vertex power (BVP and FVP)

Focimeter

- Place focimeter in a vertical position or use a V-slot holder.
- For BVP, place the concave surface towards the focimeter.

- The lens must be placed as close as possible to the focimeter, either by using a very small stop or by removing the stop cover. The reading may still give more plus or less minus than the true BVP because of the steep lens radius.
- For FVP, place the convex surface towards the focimeter stop. FVP reads less than the BVP, with a greater difference in plus powers than minus.

Practical advice

- Note the quality of the image on the focimeter. Distortion indicates a poor optic.
- A good image does not necessarily guarantee a distortion-free optic because a small stop is used and only the centre of the lens is measured.

Power profile mapping (e.g. VC 2000)

An extremely accurate computerized method, mainly used by manufacturers, for the bi-dimensional measurement of the contact lens power map. Hard contact lenses are evaluated in air and soft lenses in a saline wet cell. The power profile of both spherical and toric lenses can be made by computation from thousands of measurement points. Information is obtained on tolerances for all lens designs and provides automatic axis measurement relative to the true optical parameters for toric lenses. It is also possible to achieve accurate results for multifocal lenses.

12.3.5 Centre and edge thickness (t_c and t_e)

Thickness gauge

Consists of a spring-loaded, ball-ended probe geared to a direct reading scale.

Practical advice

- Take several readings of the lens edge, as the thickness may vary around the circumference.
- Take care not to damage a thin edge.

Radiuscope

The lens holder is left dry and the target focused on each lens surface in turn. The distance between the two images multiplied by the refractive index of the material gives the central lens thickness.

12.3.6 Edge form

Edge form is best examined with about ×20 magnification using either a hand loupe or the slit lamp.

12.3.7 Surface quality

Surface scratches and defects can be assessed in a variety of ways:

- Projection magnifier with a clean dry lens.
- Slit lamp, using transillumination.
- Band magnifier.
- Radiuscope by examining the first image.

12.3.8 Material

Confirming lens material is difficult, although comparison of specific gravity measurements can give an approximate guide. The most reliable indication can sometimes be colour, since certain hard gas-permeable lenses are available in only one distinctive tint (e.g. EQU125, very pale lilac; Conflex, very pale blue; Polycon II, medium blue).

12.3.9 Other features

- Engravings (e.g. 'R' or a dot for the right lens).
- Laboratory codes.
- Fenestrations: number, position, size and finish.
- Tint.
- Prism ballast: increased edge thickness at the base.
- Truncation.
- Carrier design: assessed by edge measurement.

12.4 Tolerances

See Table 12.1.

Table 12.1 Suggested tolerances

Parameter	ISO suggested tolerances
BOZR	±0.05 mm
BPZR	±0.10 mm
BOZD	±0.20 mm
TD	±0.10 mm
Edge and centre thickness	±0.02 mm
BVP	±0.12 D up to ±5.00 D ±0.18 D from ±5.00 D to ±10.00 D ±0.25 D from ±10.00 D to ±15.00 D ±0.37 D over ±15.00 D to ±20.00 D ±0.50 D over ±20.00 D

Practical advice

- The easiest methods for practitioner verification are:

BOZR	Radiuscope
DIAMETERS	Band magnifier
POWER	Focimeter
THICKNESS	Thickness gauge
CONDITION	Projection or band magnifier.

- Hard and PMMA lenses flatten on both front and back surfaces with hydration.[6] Flattening relates to BVP (greater with high minus) and centre thickness.
- New lenses should be hydrated for 24 hours before a reliable measurement can be made.
- Very rapid changes in BOZR also occur on dehydration.[7]
- Hard gas-permeable diagnostic lenses should be kept hydrated. PMMA lenses in powers $< \pm 10.00$ D are reliable if dry.

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CHAPTER 13

Refitting PMMA wearers

13.1 Physiological problems caused by PMMA

PMMA lenses are hardly ever fitted although they have in many cases now been worn for over 40 years. Patients are very often quite happy with their lenses and it is only at an aftercare examination that the practitioner may detect corneal changes. In other cases, patients seek advice because of reduced wearing time, red eyes or depressed vision.

The common changes found with long-term PMMA wear are:

- Epithelial oedema.
- Reduced corneal sensitivity.
- Central punctate epithelial staining.
- Chronic 3 and 9 o'clock staining.
- Stromal oedema.
- Folds in Descemet's membrane.
- Endothelial distortion.
- Endothelial polymegathism.

These changes are due to chronic lack of oxygen, drying of the corneal tissue and the mechanical action of the lens. The combination of these long-term effects produces the loss of tolerance known as 'corneal exhaustion syndrome'.

Also found, although less commonly, are:

- Dellen.
- Opacification and vascularization at 3 and 9 o'clock.
- Vertical striae.
- Fischer–Schweitzer mosaic pattern.
- Hyperaemic lids.
- CLIPC.

13.2 Refitting PMMA wearers

Refitting long-term PMMA wearers can represent one of the more difficult aspects of modern practice, especially where there are no previous details available. The procedure is further complicated because however carefully measurement and fitting are carried out, changes are likely to occur as the cornea comes 'off the influence' of PMMA. The correct course of action in nearly all cases is to refit with modern hard lenses. It is not generally feasible to move directly from PMMA to soft lenses (*see* Section 13.3.3).

13.2.1 Problems at initial refitting

- The cornea may show considerable signs of oedema and distortion.
- 'K' readings may be very different from the measurements when fitting has ultimately been completed.
- 'K' readings may exhibit considerable distortion.
- Accurate refraction may be very difficult if not impossible with poor retinoscopy reflex.
- Visual acuity may be depressed because of corneal oedema.
- It is frequently impossible to measure accurately the BOZR of a patient's old, distorted lenses.

13.2.2 Problems as refitting progresses

- 'K' readings change, possibly making the initial fitting unsatisfactory. This may occur as long as six months later.
- The degree of corneal astigmatism alters.
- The BVP often requires more minus power after 1–3 weeks.
- Patients may experience greater difficulty with foreign bodies as well as greater lens awareness when corneal sensitivity gradually recovers.

13.3 Refitting procedures

13.3.1 General points

- Patients should understand the possible difficulties and that refitting requires careful follow-up.
- Patients should come for their refitting appointment wearing the existing PMMA lenses, as with spectacle prescribing (*see* Section 29.4).
- If they exist, old pre-contact lens spectacles should be examined. They are unlikely to be accurate but offer clues to the original *Rx* and degree of astigmatism.
- Measure the old lenses where possible.

13.3.2 Refitting with hard gas-permeable lenses

Fitting

- The slit lamp is used to observe the extent of any corneal oedema or lens-induced staining.
- The PMMA lenses are assessed with white light and fluorescein, noting where improvements to the physical fitting may be made.
- The PMMA lenses are removed and measured.
- 'K' readings are taken as carefully as possible but they may be distorted, unreliably flat and show an artificial degree of astigmatism.
- An assessment of the refraction is made.
- The initial trial lenses are based on 'K' readings but measurements of old lenses are taken into account. Much more reliance is placed on the fluorescein appearance than 'K's, although this is also difficult because central oedema may give a conus-like fitting.

Choice of design

- Hard gas-permeable lenses give better vision if steep fittings are avoided.
- Fitting both a larger optic and total diameter can often solve PMMA difficulties such as poor centration or flare.
- There is less 3 and 9 o'clock staining with narrower edge clearance.
- For patients with very tight lids, designs are avoided with narrow edge lift, especially aspherics. There may be an increased possibility of lens adhesion (*see* Section 29.3.6).
- If both practitioner and patient are perfectly happy with the existing PMMA design it can be duplicated in a hard gas-permeable material.

Choice of material

- A low to medium *Dk* material can be used if the patient is asymptomatic and there are no particular signs of oedema.
- A medium to high *Dk* should be considered where there are more obvious corneal changes.
- Use fluorosilicone acrylates and avoid silicone acrylates where protein deposits are likely to be a problem (e.g. hay fever sufferers, vernal catarrh).
- Avoid materials with low rigidity or very thin designs for patients with tight lids and toric corneas since lenses may flex and distort.
- Avoid materials that may scratch easily for careless patients who may cause surface damage.
- Avoid brittle materials for initial refitting. Patients used to handling relatively robust PMMA are likely to have breakage problems.

Ordering lenses

- More confidence can be placed on the final fitting if it correlates with 'K' readings, old lens measurements, refraction or calculated lens BVP.
- Refraction frequently shows an increase in minus of 0.25 D to 0.50 D after about two weeks. Myopes should therefore be fully corrected and binocular additions are not usually given except with presbyopes. Take into account the BVP of the old lenses, and for non-presbyopes possibly even overcorrect by −0.25 D.
- Carefully specify centre and edge thickness where possible.

Practical advice

- Use a laboratory to which lenses can be returned for exchange, modification or credit.
- Fees should take into account the additional time and lens costs that may be required in refitting PMMA wearers.

Follow-up

- The first check-up should be after about two weeks to reassess the fitting, corneas and lens powers.
- Reconsider the lens material.

- Unless there is a gross change in fitting or power, lenses should not be modified for another 4–6 weeks. By this time most corneal changes will have stabilized and a spectacle *Rx* may also be feasible.
- In some cases, further minor changes may be found up to 12 months later.

Problems

A minority of patients cannot adapt to gas-permeable hard lenses because of:

- Physical discomfort, relating to surface wetting properties and increased corneal sensitivity.
- Poor visual acuity, relating to lens flexure or distortion.
- Greasing and deposits problems.
- CLIPC.

If these problems cannot be resolved, the practitioner should consider changing to soft lenses after a further 6–8 weeks or possibly refitting with an improved design of PMMA.

Patient advice

Patients should be carefully advised on lens collection about:

- The importance of using the recommended solutions, and enzyme tablets where necessary.
- The shorter life span compared with PMMA.
- The increased risk of scratching and breakage.
- Noting any lens adhesion or difficulty with removal.
- Increased discomfort with foreign bodies.

13.3.3 Refitting with soft lenses

Except in very special circumstances, it is not generally feasible to refit PMMA wearers directly with soft lenses.

- The problems listed at initial refitting and as the fitting progresses are much more significant with soft lenses.
- As the 'K' readings change, the degree of astigmatism may alter in an unpredictable fashion. Initially good acuity may deteriorate as corneal toricity changes.
- Some PMMA wearers find the gelatinous feel of a soft lens quite unpleasant on the eye.

- Many PMMA wearers have solutions difficulties, both with allergic response and the additional complexities of soft lens disinfection.

Practical advice

- Do not refit PMMA wearers directly with soft lenses.
- Where it is essential to provide PMMA wearers with soft lenses, it is generally better to refit first with hard gas-permeable lenses as an intermediate step. After about 6–8 weeks the cornea and refraction may have stabilized sufficiently to make soft lens fitting feasible.
- Disposable lenses have a place in coping with a continuously altering corneal curvature and refraction.

13.4 Possible uses for PMMA

There are still very occasional uses for PMMA:

- When flexure problems with modern hard lenses give unsatisfactory acuity, especially where a very thin lens is necessary.
- PMMA may occasionally be used where a trial lens – which will subsequently be disposed of – is required to check the fluorescein pattern of a complicated fitting (e.g. keratoconus or opaque cosmetic). In these cases, PMMA is significantly cheaper.
- PMMA might also be considered for clumsy patients who may break modern hard lenses too easily; when there are deposit problems with all modern materials; or where an inert material is required because of allergies (e.g. with CLIPC).

13.5 Current PMMA fitting

On the rare occasions when it is necessary to use PMMA, it is fitted according to the following criteria:

- The BOZR is chosen 0.05 mm to 0.10 mm steeper than flattest 'K' to give apical clearance and better tears exchange.
- For a toric cornea, the BOZR is chosen half to two-thirds between flattest and steepest 'K'.

- Where possible, TDs smaller than 9.50 mm are used for low powers. 9.20 mm is a good average diameter.
- A BOZD of approximately 7.00 mm is used for a TD of 9.20 mm; 7.50 mm for a 9.50 mm lens; and 7.80 mm where a 10.00 mm TD is required for a large palpebral aperture.
- A relatively large edge lift is required to promote tears flow.
- Edges should be well rounded and all curves very well blended to reduce the possibility of arcuate staining or oedema.

Practical advice

- Give a much slower wearing schedule (see Section 28.3).
- Laboratory instructions should always state 'very well blended' as modern hard lens blending is inadequate. Younger technicians will have had little or no experience with PMMA manufacture.
- Where it is essential to fit PMMA and oedema occurs, reduce BOZD or TD; increase edge lift or blending.
- Consider fenestration with the original lens order (see Section 26.3).

CHAPTER 14

Orthokeratology and reverse geometry lenses

It has been observed for many years that conventionally fitted PMMA lenses appear to reduce the rate of increase of myopia.[1,2] Modern gas-permeable lenses seem to produce a similar effect but to a lesser extent.[3] A more active approach to myopia control is orthokeratology, defined as 'the reduction, modification or elimination of a visual defect by the programmed application of contact lenses'.[4] The terms corneal refractive therapy (CRT) and reversible corneal therapy (RCT) have also been applied to the same procedure.

In practical terms, orthokeratology applies to myopic eyes and aims to eliminate the refractive error or to reduce it to a sufficiently small degree that the patient can function without spectacles or contact lenses for most of the waking day. The result is achieved by flattening the cornea in a controlled fashion by wearing contact lenses with the BOZR significantly flatter than the corneal radius. When the desired result has been achieved, the new corneal shape is maintained by means of retainer lenses.

14.1 Historical

It is only recently that orthokeratology has begun to achieve any scientific acceptability. The procedure has been practised in the

USA for over 30 years,[5–7] but with controversial and mainly anecdotal results. It developed from the clinical observation that wearing PMMA lenses flattened the cornea and reduced myopia. Early techniques such as the May–Grant and Tabb methods[8,9] used a series of progressively flatter lenses with a TD of about 10.00 mm and BOZD of about 8.50 mm. Results proved unpredictable and lens decentration frequently induced significant corneal distortion. Despite claims of a large reduction in myopia, results were limited to a decrease of approximately 1.25 D.

Orthokeratology has now achieved a degree of clinical reliability with the advent of:

- Reverse geometry lenses.
- Corneal topography measurement so that changes in corneal curvature can be carefully monitored.
- Hard gas-permeable materials to improve corneal physiology.

14.2 Current approach

Modern orthokeratology attempts to use a single set of accurately fitted lenses worn on an overnight basis (*see* Section 14.6.2). A large percentage of the refractive change is achieved after one night of wear and the majority by the end of the first week.

Orthokeratology works by means of a squeeze film force beneath the lens acting tangentially across the corneal epithelium. This is thinned centrally and redistributed towards the mid-periphery.

Because there is thinning of the central cornea, there are some similarities with laser refractive surgery, which uses the Munnerlyn formula to predict how much tissue needs to be removed. This is now also used in orthokeratology as the most reliable way of predicting the refractive change:

$$A = \frac{RD^2}{3}$$

where A = ablation depth (or corneal thinning)
R = refractive error
D = diameter of the treatment zone.

The maximum change in epithelial thickness has been suggested as 20 μm[10] compared with the total thickness of the corneal epithelium of approximately 50 μm. Using this figure of 20 μm for treatment zones of 6.00 mm and 4.00 mm, the anticipated refractive changes would be respectively −1.75 D and −3.75 D.

The cornea is defined mathematically by its apical radius (R_0), eccentricity or *e*-value (*see* Section 8.4), and chord diameter. The shape is in almost all cases that of a prolate ellipse. As the myopia lessens, the *e*-value reduces and the cornea becomes more spherical. The theoretical limit of myopia reduction is achieved when the eccentricity is reduced to zero, although in some cases the cornea may become slightly oblate to give a further small but unpredictable reduction in myopia.

In general, the success of orthokeratology depends on:

- Lid forces.
- Duration of lens wear.
- Type of fitting.
- The corneal rheology of the individual patient.

Advantages of orthokeratology

- Good unaided vision for most of the day.
- It is not a surgical procedure.
- It is reversible.
- It is not painful.
- The technique uses established contact lens procedures with minimal risk of problems.

Compared with laser surgery, orthokeratology:

- Does not involve postoperative pain.
- Does not incur the risk of corneal haze.
- Does not risk loss of visual acuity.
- Is less expensive.

Disadvantages of orthokeratology

- It can treat only low to medium degrees of myopia.
- Several visits are required over the first few months.
- Patients must use retainer lenses or the cornea will revert to its original shape.
- The precise reduction of myopia cannot be guaranteed.
- For the best results, careful patient compliance is necessary.

Indications

- Young, early myopes.
- Sport.

- Vocational use.
- Occasional spectacle wearers.
- Myopia up to −4.00 D.
- Low degrees of astigmatism.
- High corneal *e*-values, over 0.50.

Contraindications

- Myopia greater than −4.50 D.
- With-the-rule astigmatism over −1.25 D.
- Where the astigmatism extends beyond the central region of the cornea.
- Against-the-rule astigmatism.
- Residual astigmatism.
- Low corneal *e*-values.
- Large pupils where flare may be a problem.
- Where proper centration cannot be achieved.
- Loose lids where there is minimal force to mould the corneal shape.
- Keratoconus or other thin or irregular corneas.
- Unrealistic patient expectations.

14.3 Reverse geometry lenses

Reverse geometry lenses have been introduced since the advent of computer-controlled lathes, on which it is feasible to manufacture the secondary curve steeper than the BZOR. Reverse geometry lenses are used in orthokeratology to achieve good centration and optimal pressure distribution under the lens. They also give a more rapid corneal response, and the term *accelerated orthokeratology* is sometimes used.

The first reverse geometry lenses consisted simply of three curves – the central radius, the secondary steep or reverse curve, and the periphery (Figure 14.1). The area beneath the second curve was called the tear reservoir. These lenses can still treat myopia up to about 3.00 D and the likely result is based on corneal eccentricity measured by means of topography. A change in myopia of 1.00 D is approximately equivalent to a reduction in *e*-value of 0.21. It is therefore feasible to expect a cornea with *Rx* −2.50 D and $e = 0.5$ to reduce to emmetropia. If the *Rx* is −4.50 and $e = 0.4$, a reduction to only −2.50 D would be anticipated with three curve lenses.

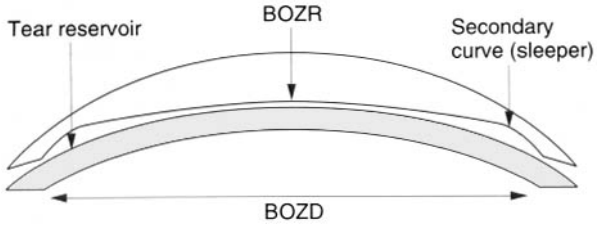

Figure 14.1 Diagram of reverse geometry lens

To give an even more rapid response and treat higher degrees of myopia, more recent designs comprise four or five radii and include an additional reverse curve (*see* Figure 14.2). The term double reverse geometry has been used. The portion of the lens between the central radius and alignment curve has been variously called the reverse, relief or return zone and creates the tear reservoir (TR).

14.3.1 Fitting three curve reverse geometry lenses

Lenses with only three curves have largely been superseded but are still sometimes used for low degrees of myopia, where only a small corneal response is required or for non-orthokeratology fitting (e.g. with grafts or post refractive surgery). Many of the fitting principles still apply to all reverse geometry lenses.

Unlike most hard lens fitting, which is based on flattest 'K' and lens design, reverse geometry lenses are fitted according to:

- The sagittal depth of the cornea.
- Tear layer thickness (TLT) (*see* Section 7.4).

$$\text{Corneal sag } (z) = R_0 - \sqrt{(R_0^2 - y^2 p)p}$$

where R_0 = corneal apical radius
$p = 1 - e^2$
y = 1/2 chord diameter.

The values of R_0 and e are obtained from corneal topography while y depends on the lens diameter.

The ideal lens has the same sag as the cornea with a compensation of 10 μm for the TLT. It gives minimal central clearance with touch at the outer edge of the steep reverse curve. Lenses are therefore calculated on the basis of the chord which represents the TD minus the width of the peripheral curve.

Sag of lens = sag of cornea + tear lens thickness

In practice, the first trial lens is generally determined using a computer programme that can rapidly calculate the radius required for different lens diameters. With average corneal eccentricity and a lens diameter of 10.60 mm, the correct radius is usually about 0.35–0.45 mm flatter than flattest 'K'.

BOZD

The most commonly used BOZDs are 7.00 mm and 6.00 mm although the range is from 6.00 mm to 8.00 mm in steps of 0.50 mm.

Second curve or tear reservoir

The tear reservoir (TR) is responsible for creating the negative pressure, which in turn causes the corneal flattening. The curve is specified in dioptres, between 1.00 D and 9.00 D steeper than the BOZR. The tear reservoir is usually spherical but can be made aspheric for non-orthokeratology use.

- The most commonly used TRs are 4.00 D, usually optimal with a 7.00 mm BOZD, and 3.00 D, usually optimal with a 6.00 mm BOZD.
- TRs of 5.00 D and over permit only small areas of central touch, less than 3.00 mm.
- TRs less than 3.00 D give too large an area of central touch, more than 3.50 mm.

Peripheral curve

The first choice of peripheral curve is usually tangential and 1.00 mm wide. This is designated a T edge. Sometimes either narrower or aspheric peripheries are used.

- The AEL is typically 0.12 mm, but can be from approximately 0.08 mm to 0.16 mm.
- Reducing the edge lift gives an overall tighter fitting.
- Increasing the edge lift gives an overall looser fitting.

Total diameter

Lenses are fitted with large TDs to achieve better comfort and centration.

- The first choice is 10.60 mm, but 11.20 mm lenses are sometimes more successful.
- Small corneas may require TDs of 9.80 mm.

- Lenses are sometimes fenestrated to improve tears flow and reduce adhesion.

Lens specification

Companies such as Contex in the USA produce a very wide range of lenses, but those most commonly used are clinical equivalents and designated the 704 and 603 Series. They achieve the best balance between central touch and depth of TR. The 704 has a 30% greater TR volume than the 603 and is generally the design of first choice. A full specification is recorded as:

8.35:10.60 OK704T −0.75 where

8.35 = BOZR
10.60 = TD
OK = a reverse geometry lens for orthokeratology
70 = BOZD of 7.00 mm
4 = a TR of 4.00 D
T = a tangential peripheral curve 1.00 mm wide
−0.75 = BVP (usually plano or low minus because of the flat fitting)

14.3.2 Fitting four and five curve reverse geometry lenses

Four and five curve (double) reverse geometry lenses can be used to treat myopia of up to about 4.50 D. They also aim to achieve a rapid change of corneal curvature and power. Modern designs include the BE (UltraVision International), E Series (Contex), Dreim, Paragon CRT, and Rinehart & Reeves (Nova).

There are several designs of double reverse geometry lenses, similar in principle to those shown in Figure 14.2.

There are four essential lens components:

1 The BOZR. This is the flatter than 'K' central curve, which for any given cornea will give uniquely the required refractive result. In most cases the BOZR is derived from the original Jessen formula that calculates the radius on the basis of flattest 'K' in dioptres plus the desired refractive change plus an additional flattening factor of 0.50 D or 0.75 D.
2 The reverse curve (or return zone or relief zone). This is the steep tears reservoir that joins the BOZR to the alignment curve. The reverse zone does not itself provide a practitioner fitting variable but when combined with the flat BOZR provides the negative pressure forces to redistribute the corneal epithelium. The reverse

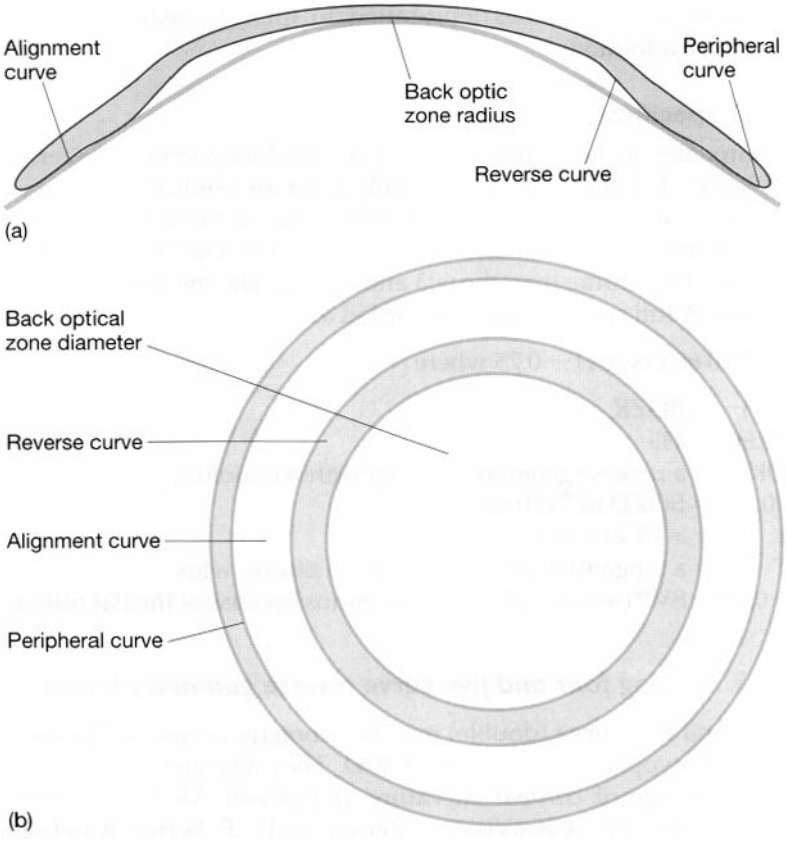

Figure 14.2 (a, b) A four curve reverse geometry lens

zone is usually 0.60 mm to 1.00 mm wide and may be divided into two curves to give overall a five curve lens (e.g. Rinehart & Reeves) or have a continuous sigmoid construction (e.g. Paragon).

3 The alignment curve (AC) (or fitting curve or landing zone), is designed to align with the mid-peripheral cornea and represents the key fitting curve of the lens by controlling centration and movement. It is approximately 0.80 mm to 1.50 mm wide and may be spherical, aspheric or a tangential straight line. It may also be divided into two curves.

4 The peripheral curve, approximately 0.30 mm wide, ensures adequate edge clearance.

Fitting these lenses is not simply a question of steepening or flattening the central radius as all parameters are inextricably linked

to increase or decrease the lens sag in relation to the cornea. The alignment curve is the key to controlling lens behaviour and for this reason it is sometimes called the fitting curve. With many lenses, there are design features that laboratories regard as proprietary. These details are not made available to the practitioner, who therefore does not have full knowledge of all lens curves fitted.

BOZR

Most lens designs select the BOZR on the basis of the original Jessen formula:

Example: *Rx* −3.00/−0.25. Keratometry 8.03 mm/8.00 mm
42.00 D (flattest 'K' in dioptres)
−3.00 D (required power change)
−0.50 D (additional flattening factor – the Jessen formula)
38.50 D = 8.76 mm
Required initial radius = 8.76 mm

Alternatively, the BOZR can be determined by computer calculation using apical radius and eccentricity measurements derived from corneal topography (e.g. with the BE lens). The BOZR is not generally used as a fitting variable since a change of central radius has less effect on the overall sag of the lens.

BOZD

The BOZD is predetermined by the laboratory or calculated from the required reduction in myopia and treatment zone width (the Munnerlyn formula). It is generally about 6.00 mm to give an area of applanation or treatment zone of about 4.00 mm.

Power

The power of the prescription lens is selected to give optimal visual acuity while being worn. Because the lens is fitted flat, the BVP is usually quite low and can be calculated from the BOZR and the patient's refractive error. For those lenses fitted with an additional flattening of −0.50 D or −0.75 D according to the Jessen formula, the BVP is always respectively +0.50 D or +0.75 D.

Alignment curve

The alignment curve is assessed by fluorescein observation. It may be defined by a radius (e.g. Rinehart & Reeves) or by a tangential

angle (e.g. Paragon). For most lenses this is the key piece of information required by the laboratory. With the BE lens it is calculated by the laboratory as part of the overall lens design and assigned a cone angle.

Periphery

The periphery is an integral part of the lens design to ensure adequate edge lift and is usually predetermined by the laboratory.

Total diameter

The most common TD is in the region of 10.60 mm although 11.00 mm lenses may be needed for large corneas or to improve centration.

Typical specifications

BE

8.83 85651050 55.81 11.00 −0.50

Where:

8.83 mm = BOZR
85651050 = TRF number (a mathematically converted algorithm generated by the computer programme and unique for each lens)
11.00 = TD
55.81 = Cone angle
−0.50 = BVP

Paragon

8.60 0.525 34 10.50 +0.50

Where:

8.60 = BOZR
0.525 = Return zone depth (depth of tear reservoir)
34.00 = Landing zone angle (tangential angle)
10.50 = TD
+0.50 = BVP (constant)

Rinehart & Reeves

8.94:6.00/7.94:10.60 +0.75

Where:

8.94 = BOZR
6.00 = BOZD
7.94 = Alignment curve
10.60 = TD
+0.75 = BVP (constant)

Practical advice

- The apical radius is different from flattest 'K' (see Section 2.4).
- Corneas with the same radius but different e-values require different fittings.
- The minimum treatment zone is 3.20 mm to avoid flare.

14.4 Clinical appearance of reverse geometry lenses

14.4.1 Fluorescein pattern

The suitability of the lens fitting is determined with fluorescein. The appearance is quite unlike that found with a conventional hard lens and similar in some respects to that seen with silicone elastomer lenses. The pattern consists of central touch over approximately the central 4.00 mm surrounded by an annulus of fluorescein representing the steeper tear reservoir (reverse, relief or return zone). The TR is in turn surrounded by the alignment curve, an area of mid-peripheral touch which further supports the lens and leads into the band of edge clearance (Figure 14.3).

Practical advice

Fluorescein only becomes visible when the TLT approaches 20 μm. The central area has been calculated for a TLT of 10 μm or less and only gives the *appearance* of touch.

14.4.2 Other fitting points

- The lens must give good centration.
- The area of central touch should be 3.50–4.50 mm wide.
- The TR should have sharply defined edges.

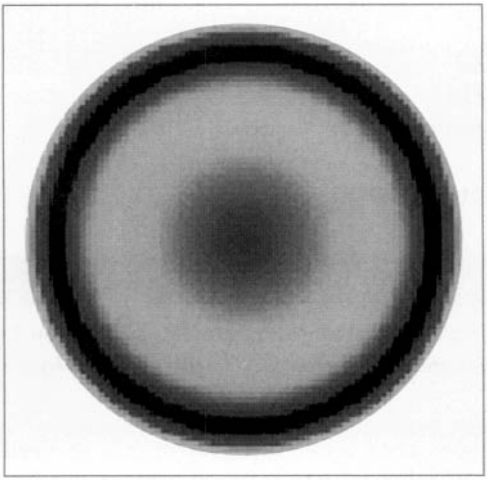

Figure 14.3 Fluorescein pattern of reverse geometry lens (Plate 19)

- TLT must not be less than about 5 μm. A lens that is too flat may cause central abrasion and staining. When in doubt, fit steeper.
- Flat lenses ride high.
- Steep lenses ride low.
- Steep lenses often trap small bubbles in the TR.
- Increase TD to improve centration but any change in parameters must be recalculated to give optimal TLT.
- A change in TD or BOZR gives a smaller change to lens sag than a change in alignment curve.

14.5 Corneal topography

Modern instrumentation enables the mapping of corneal topography over most of its surface (*see* Section 2.3) and this has become an integral part of the fitting and aftercare procedures. Those corneal plots most useful in orthokeratology are the axial, subtractive and numeric. The measurement of corneal topography is essential because:

- It provides measurements for the apical radius (R_0) and eccentricity (e).
- It can help predict potential failures prior to fitting from these measurements.

- It can provide a permanent record of corneal shape and power at all stages of the procedure.
- The subtractive plot gives a record of progress.
- It demonstrates graphically any unacceptable degree of corneal distortion either before or during fitting.
- The type of distortion gives indications as to whether the fit is flat, steep or decentred.
- Some topographers can be used to measure the HVID.

14.6 Fitting routine

14.6.1 Fitting

- Full ocular and slit lamp examination.
- Assessment of pupil diameter.
- Refraction including unaided vision before commencing orthokeratology.
- Corneal topography.
- Numeric plots to establish apical radius and *e*-value.
- Calculation of the first diagnostic lens.
- A wearing period of 6–10 hours, either daily or overnight.

A lengthy trial is necessary to provide the following information:

- The new unaided vision.
- Degree of refractive change.
- Extent of initial shape change.
- Movement and centration of diagnostic lens after settling.
- Corneal response in terms of staining.
- Whether the patient wishes to continue with the procedure.

A satisfactory response usually gives:

- A significant improvement in unaided vision.
- A reduction in myopia of at least 1.00 D.
- No corneal staining or other adverse signs.
- Maintained lens centration and mobility.
- Minimal, if any, corneal distortion.

In some cases it is necessary to repeat the trial with a different lens because of an unsatisfactory result at the end of several hours. This may consist of:

- Borderline or minimal improvement in unaided vision.
- An insignificant reduction in myopia.

- Unacceptable lens decentration.
- Corneal distortion.
- Corneal staining even with a well-fitting lens.
- Excessive dimpling.
- Poor patient tolerance.

14.6.2 Overnight wear

Lenses for orthokeratology were originally worn during the day but most current designs are worn overnight to give a more rapid response. Overnight wear (sometimes called *night therapy*) has several additional advantages. There is no discomfort from dust, foreign bodies, dry eyes or other environmental factors. Lenses are less likely to be lost or damaged, and gradually the waking day becomes increasingly free of both contact lenses and spectacles.

Overnight use is not the same as extended wear because the orthokeratology lenses are removed during the day. Nevertheless, materials should have a high *Dk*, of at least 90, and a *Dk/t* greater than 40.

Patients should be warned of the possibility of lens adhesion on waking and should be advised how to free the lens with careful massage to avoid any risk of corneal abrasion. Fenestration can also be used to facilitate tears flow but may cause dimpling. The first check-up is carried out before the lenses are removed.

14.6.3 Aftercare

Aftercare following the first overnight use and at subsequent visits is directed at assessing the factors mentioned in Section 14.6.1.

- The lens fit is checked on the eye with fluorescein looking for signs of decentration, adhesion or excessive dimpling.
- The acuities are recorded with lenses.
- Lenses are removed and over-refraction carried out, recording both aided and unaided vision. The quality of the retinoscopy reflex gives an indication of corneal distortion.
- Slit lamp examination carefully checks the corneas for any signs of staining or other physiological problems.
- 'K' readings are taken to give a rapid indication of corneal flattening and astigmatism.
- It is essential at this stage to use topography to record the change in corneal shape with the difference maps and confirm the absence

of corneal distortion (*see* Section 14.5.4 below). The desired result is a bull's eye plot (*see* Figure 14.4).

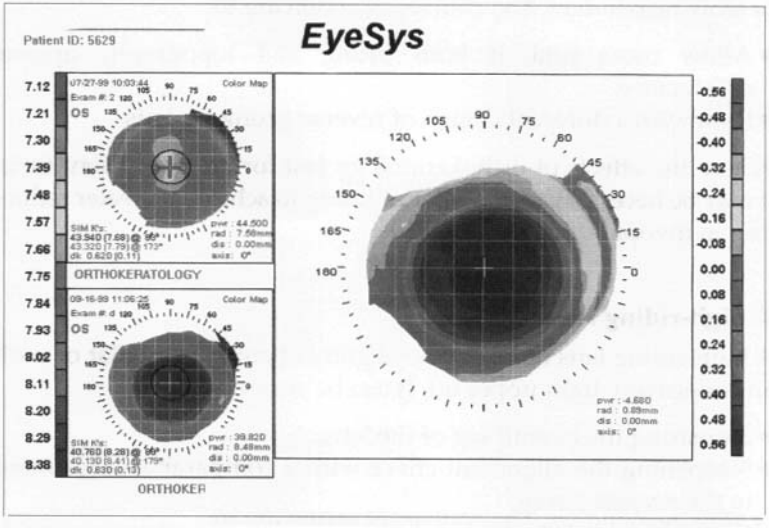

Figure 14.4 Difference map showing bull's eye topographical plot (Plate 20)

Practical advice

After orthokeratology, autorefractometers do not give a reliable assessment of the refractive error and therefore of the anticipated unaided acuity. This is important in some vocations where these instruments are used during a medical examination.

14.6.4 Problem solving

Poor acuity

Poor acuity is generally due to:

- A decentred lens.
- An otherwise poor fitting.
- Uncorrected astigmatism.
- Corneal distortion or induced astigmatism.
- Ghosting at night because of lens decentration or a small treatment area.

Under-responders

Sometimes it is not possible to achieve good acuity because of an insufficient reduction in myopia. These patients are termed under or slow responders. The courses of action are to:

- Allow more time if both fitting and topography appear satisfactory.
- Refit with a different design of reverse geometry lens.

Where the effects of orthokeratology last for an insufficient time, it may be necessary to use a flatter fitting to achieve a greater reduction in myopia.

A high-riding lens

A high-riding lens occurs if the alignment curve is too flat or with an excessively tight upper lid. It can be corrected by:

- Increasing the overall sag of the lens.
- Steepening the alignment curve with a comparable adjustment to the reverse curve.
- Using a larger TD.
- Increasing the lens mass with a greater centre thickness, incorporating prism, or using a material of higher specific gravity.
- Steepening the radius of the front surface lenticulation to reduce the effect of the upper lid or adjusting edge shape and thickness.

A low-riding lens

Low riding occurs if the alignment curve is too steep, or with lid pressure or gravity. It can be corrected by:

- Decreasing the overall sag of the lens.
- Flattening the alignment fitting curve with a comparable adjustment to the reverse curve.
- Decreasing the lens mass with reduced centre thickness or using a material of lower specific gravity.
- Adjusting edge shape, thickness or lenticulation to increase the upward effect of the lid.

Lateral decentration

Lateral decentration may be caused by a flat alignment curve, against-the-rule astigmatism or a decentred corneal apex. It may

be corrected by:

- Increasing the overall sag of the lens.
- A steeper alignment curve.
- A larger TD.

The assessment of lens position is always judged in conjunction with corneal topography maps. The desired result is a centred bull's eye pattern (Figure 14.4) which indicates good centration and accurate corneal topography. Unsatisfactory results give either 'central islands' (Figure 14.5) or a 'smiley face' (Figure 14.6). These patterns are caused by an incorrect sag because of an inappropriate alignment curve, lens decentration or inaccurate topography.

Central islands

Central islands are areas of incomplete treatment (Figure 14.5) caused by a steep fitting or resistant areas of the cornea. They give rise to reduced acuity or distorted vision. Central islands suggest corneal topography that under-estimates the corneal sag indicating a steeper fitting than necessary. Sometimes they resolve with time (another week or so); otherwise correction is carried out by:

- Reducing the overall sag of the lens.
- A flatter fitting to increase the area of central touch.
- Improving centration.

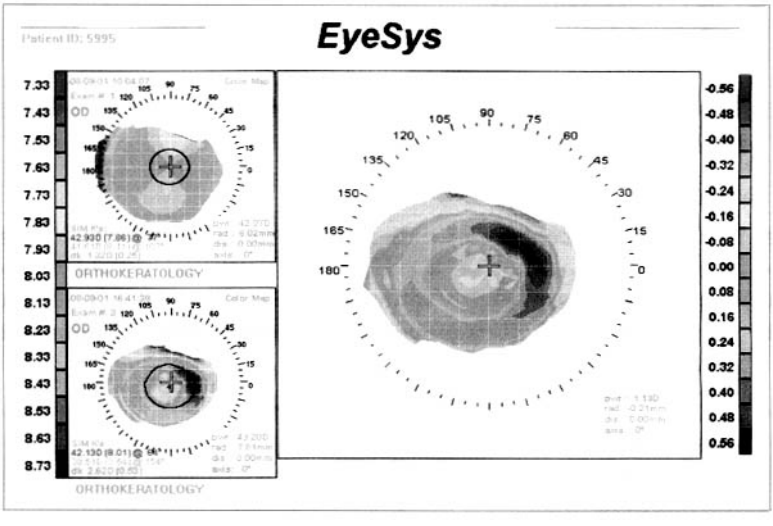

Figure 14.5 Difference map showing central islands with a steep fitting (Plate 21)

Smiley faces

Smiley faces are usually found inferior to the central treatment zone (Figure 14.6). They represent areas of localized corneal steepening caused by a flat fitting with insufficient sag which in turn allows superior lens decentration. Smiley faces suggest corneal topography that over-estimates the corneal sag indicating a flatter fitting than necessary. Correction is by:

- Increasing the overall sag of the lens.
- A steeper fitting.
- A larger TD.

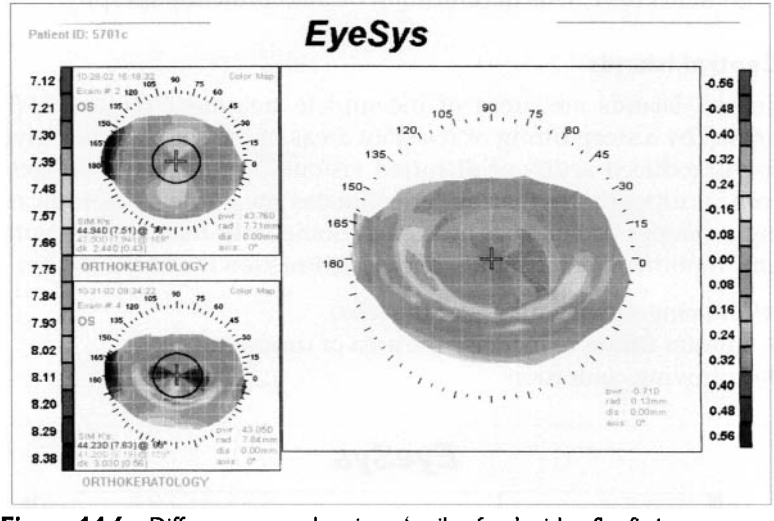

Figure 14.6 Difference map showing a 'smiley face' with a flat fitting on a toric cornea (Plate 22)

Lens adhesion

A fairly high percentage of patients experience lens adhesion on waking. This need not be a problem if there are no subjective symptoms and lens mobility returns fairly rapidly. Patients should be instructed in how to remove lenses without risk of damage to the corneal epithelium.

A lens that adheres may be improved by:

- Using a smaller TD.
- Altering the alignment fitting curve in relation to any lens decentration.
- Flattening the peripheral curve to increase edge lift.

Central corneal staining

Central corneal staining is almost invariably associated with excessive apical touch, and a steeper fitting is required.

Dimpling

Dimpling may indicate too deep a tear reservoir with a steep fitting which needs adjustment. Sometimes dimpling occurs with a perfectly satisfactory fitting where fenestrations allow the introduction of air bubbles. These may be ignored if there is no interference with vision.

14.6.5 Subsequent aftercare and follow-up

Patients should be checked at the end of the first overnight and after one or two weeks. Subsequently they should be monitored on a regular basis. It is important that examinations take place at the same time of day for each visit, to maintain a consistent record of refraction and unaided vision.

Careful attention should be paid to lens condition and the patient's cleaning regimen. Since orthokeratology works entirely on the basis of lens pressure at the corneal apex with a carefully controlled TLT, even a very small amount of deposit on the inside lens surface is sufficient to cause a central abrasion.

14.6.6 Retainer lenses

Orthokeratology is a reversible procedure. When the optimal result has been achieved, a final pair of *retainer lenses* is used to maintain the new corneal shape and stabilize the improvement in visual acuity. The lenses are usually worn overnight but possibly for limited periods during the day. The required time depends on the individual patient. Mountford[11] suggests that 60% of patients ultimately require lens wear only every second night and 10% as little as twice a week.

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CHAPTER 15

Scleral lens fitting

15.1 When scleral lenses should still be fitted

Advantages of scleral lenses

- Almost never lost because they are held in place by the eyelids; capillary attraction is to the sclera rather than the cornea.
- Robust and dimensionally stable.
- Do not deteriorate.
- Handling may be easier for less dextrous patients, e.g. aphakes.
- Dry storage is usually preferable.
- Lid sensation is much less than with corneal lenses.
- Foreign bodies are uncommon except on insertion.
- Extensive power range possible, in excess of ±40.00 D.
- It is possible to encapsulate a realistic painted iris.

Indications

Irregular corneal topography

- High astigmatism.
- Primary corneal ectasia, i.e. keratoconus and related conditions.
- Corneal transplants.
- Traumatized eyes.

High refractive errors

- High ametropia when high-power corneal lenses lead to centration difficulties.

Encapsulated iris lenses

- Unsightly blind eyes.
- Aniridia
- Microphthalmos.

Therapeutic or protective applications

The large size of a scleral lens protects the anterior eye and enables the retention of a tears reservoir in abnormal conditions, including:

- Corneal exposure.
- Dry eyes.
- Trichiasis or lid margin keratinization.

Other applications

- Ptosis.
- Intermittent use where short-term adaptation may be easier than with corneal lenses (e.g. contact sports).
- Dusty environments.
- Water sports.

15.2 Preformed fitting

15.2.1 Preformed designs

A preformed scleral lens is fitted from diagnostic sets of predetermined shape (Figure 15.1), without taking an impression of the eye.

Wide angle lenses

Introduced by Nissel in 1947.[1] The design is a combination of spherical optic and scleral portions with a conical transition designed to give a tangential junction between the optic and transition zones. Diagnostic sets are extensive because they require sufficient variables for the fitting of both major parts of the lens. Range:

BSR (back scleral radius): 12.50–14.50 mm in 0.25 mm steps
BOZR: 8.00–9.00 in 0.25 mm steps.

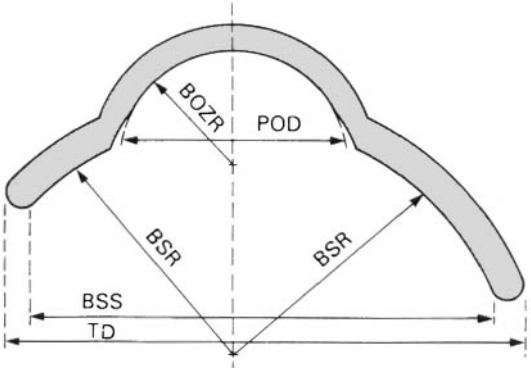

Figure 15.1 Preformed scleral lens. BOZR, back optic zone radius; BOZD, back optic zone diameter; BSR, back scleral radius; TD, total diameter (from Phillips and Speedwell, *Contact Lenses*, 4th edn, Butterworth-Heinemann, Oxford, by permission)

Transcurve lenses

Redesigned in their present form by Bier in 1948.[2] Lenses have a spherical optic and back scleral surface. The transition is 2.00 mm wide, with a spherical radius of curvature approximately halfway between the back optic and scleral zone. Usual range:

TD: 22.50–24.50 mm
BSR: 12.50–15.00 mm.

15.2.2 Traditional PMMA preformed scleral lens fitting

Four variables must be considered:

- Back optic zone radius.
- Back optic zone diameter.
- Back scleral radius.
- Total diameter.

There are two possible approaches:

- Separate fitting of the scleral and optic portions.
- Fitting both parts at the same time.

Independent optic and scleral fitting

The scleral zone is fitted using scleral fitting sets and the optic zone with a fenestrated lens for optic measurement (FLOM). The method

enables some assessment of the independent portions. The disadvantage is that the practitioner never sees the complete and final fitting until the lens is dispensed.

Scleral portion

Diagnostic sets vary both in BSR and total diameter (TD). A full set consists of 12 lenses in steps of 0.50 mm for radius and diameter, but a useful minimum range is:

TD: 22.50 mm and 24.50 mm
BSR: 12.50 mm and 14.50 mm

It is important that the scleral portion does not interfere with the optic fitting, hence the optic radius should be no flatter than 7.50 mm at a chord width of 12.50 mm to ensure that the optic portion is clear of the cornea at all times during fitting. With experience, it is possible to judge by how much to alter the size without necessarily inspecting a second lens in situ. This does not apply to the radius, where it is essential to observe the next lens.[3]

Practical advice

- Aim for a minimum clearance fitting, not more than 0.10 mm for a fenestrated scleral lens.
- An optimum fitting scleral radius minimizes conjunctival blood vessel blanching.
- A steep scleral fit bears excessively on the peripheral sclera and constricts the vessels in that area. A flat radius constricts the vessels around the limbus.
- The horizontal sclera is asymmetrical. It is not always possible to eliminate blanching completely so that a 75% 'glove fit' is acceptable.
- Avoid constricting the limbus wherever possible.
- Any modification to a scleral lens, especially the scleral zone, has an unpredictable outcome. Making a cast of the lens before proceeding is a sensible precaution.

The optic zone

The optic zone is fitted using FLOMs, first described by Bier in 1948.[4] They consist of an optic portion with a narrow scleral rim approximately 2.00 mm wide, and usually have a 13.00 mm radius. This is flatter than the limbal region it covers so that it does not interfere with the corneal fit. To assist fitting, the transition is deliberately

left sharp. This can cause discomfort, so topical anaesthetic may be used. The lenses are identified by the back optic zone radius and optic zone diameter. They are optically worked to enable refraction when the correct corneal fitting has been found. FLOMs have a 1.50 mm, peripheral fenestration. The normal range of parameters is:

Radius: 8.00–9.50 mm in 0.25 mm steps
Diameter: 13.00–14.75 mm in 0.25 mm steps
Generally, smaller lenses and optic diameters suit steep corneas

The fitting is assessed with fluorescein and is varied by altering either the radius or diameter. The optimal fit gives clearance over the whole cornea, extending 2–3 mm beyond the limbus. A crescent-shaped air bubble should remain at the limbus (Figure 15.2).

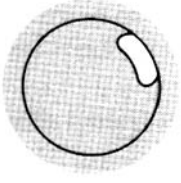

Figure 15.2 Crescent-shaped air bubble in FLOM fitting

Rule of thumb

If the BOZR is flattened by 0.25 mm, the BOZD must be increased by 0.50 mm to give the same apical clearance.

Clinical equivalents

Two lenses giving identical fitting characteristics of apical clearance with different limbal clearances are known as clinical equivalents.

Example: 8.00/13.00; 8.25/13.50

Simultaneous optic and scleral fitting

The main advantage of simultaneous fitting is that the appearance of the diagnostic lens is similar to that of the final lens. It also avoids the discomfort of a FLOM, and topical anaesthesia is unnecessary. However, a large diagnostic set is required to cover all the permutations. Wide angle lenses have been commonly used for simultaneous fitting because the design eliminates the variable of

the BOZD. The permutations are reduced, but the fitting process is simplified. Preformed fitting is ideally carried out with a combination of simultaneous and separate systems.

15.3 Moulded (impression) fitting

Fitting sclerals from eye impressions is much better for dealing with irregular anterior ocular topography. The impression gives a negative shape of the cornea, from which the scleral lens is made.

15.3.1 Impression materials

Alginates

- Orthoprint.
- The normal mixture is 2 g to 7 ml water, or equal volumes.
- Setting is faster with a higher temperature or humidity.

Polyvinyl siloxanes (recommended)

- Panasil *light body*, consisting of a base paste and hardener, is the product in most common use. Mixing equipment is included.
- Longer shelf-life if used occasionally.
- Impression does not dehydrate because no water is used.
- Retains dimensional stability after use.

15.3.2 Moulding procedure

- The eye must be anaesthetized with at least three drops of benoxinate, one instilled from above the cornea.
- One drop may also be instilled in the alternate eye to inhibit the blink if necessary.
- The eye to be moulded should look slightly down and in from the primary position. This can be achieved by dissociating the two eyes and marking the position of the cornea on the lower lid of the alternate eye.
- The moulding shell or tray is chosen as (a) small, medium or large; and (b) left or right, since nasal and temporal sizes are different (Figure 15.3).
- The impression material is mixed and spatulated to eliminate air bubbles.
- The average setting time of the impression material is about 30 seconds at normal room temperature.

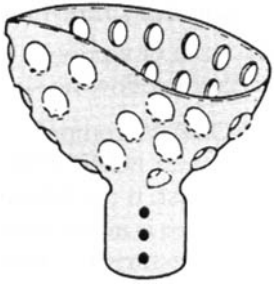

Figure 15.3 Moulding tray. The trays are colour coded (red = right; blue = left) and a system of dots denotes the size (3 dots = large; 2 dots = medium; 1 dot = small)

Injection method

- More time is available to finish mixing the impression material.
- Larger fitting trays can be used.
- The impression material is injected through a tube on the front of the moulding tray when placed on the eye.
- Care should be taken to ensure that the cornea is not distorted by the injection process.
- The tray is gently lifted at its sides to ensure complete coverage of the globe.

Insertion method

In the past, the insertion method was also used. It required a moulding tray to be filled with material before being placed on the eye with the head in a horizontal position.

15.3.3 Producing the lens or shell

The impression is cast in dental stone to give a permanent positive cast of the eye.

Manufacturing procedure

- A PMMA sheet is heat moulded over the cast, trimmed to size and edged.
- The optic zone clearance is worked using diamond-coated lapping tools.
- The substance removed from the centre to give clearance is approximately 0.10 mm, whereas 0.20 mm is taken from the limbal area.
- The optic zone is polished with wax tools or cloth-covered spherical brass tools.

Laboratory method

The cast or a polyvinyl siloxane impression is sent to a laboratory with the following specifications:

- BOZR. A competent scleral lens laboratory can decide on the optimal BOZR without specific directions and cut according to the cast. If the laboratory cannot make this judgement, the practitioner is advised to find another laboratory that can.
- If necessary to specify, 0.20 mm flatter than flattest 'K' is a guide.[5]
- Total diameter. Usually marked on the cast so that the optimal size is cut.
- Specifying centre thickness is inappropriate since it is determined from the BVP and FOZD.

15.3.4 Back vertex power

Over-refraction is carried out with a lens of known BOZR and BVP, preferably fitted slightly flat. A FLOM can be used if available, or a large diameter corneal lens. The front optic radius is calculated to give the required power and cut with a lathe. If the laboratory has determined the BOZR, an appropriate liquid lens allowance is necessary.

15.3.5 Ventilation of PMMA scleral lenses

Most patients can only wear a sealed PMMA lens for a few minutes before corneal hypoxia causes oedema. Ventilation allows fresh oxygenated tears to reach the cornea and is effected by:

- Fenestration, about 1 mm in diameter.
- Cutting a slot, usually 2 mm wide and one-quarter of the diameter of the limbus in length. It can be thinner if there is too much lid sensation.
- A channel of clearance connecting the optic zone to the edge of the lens.

15.3.6 Scleral lenses with modern hard gas-permeable lens materials

The first preformed hard gas-permeable scleral lenses were described by Ezekiel in 1983.[5] The materials are not sufficiently thermoplastic to heat mould, but two methods by which impressions can be used as a starting point for hard gas-permeable scleral lens fitting have been described, either by duplicating a fitted PMMA shape using an individualized cast moulding system,[6] or using a button

inserted into a PMMA scleral zone with adhesives.[7] Experimental trial results show that there is a distinct improvement in corneal physiology with hard gas-permeable materials compared with PMMA.[8–13] The use of hard gas-permeable sclerals has increased steadily since the introduction of modern materials and it has become evident that patient tolerance has improved considerably.[14–21] Hard gas-permeable scleral lenses can be lathe cut from large diameter blanks,[5] or produced with a range of moulded back surfaces.[3]

The improved gas permeability has enabled the use of sealed lens designs that simplify fitting processes.[14–18] Sealed lenses are simpler and more predictable to fit because they do not settle back as much as ventilated lenses, hence it is possible to control the apical clearance to a greater extent.[3] They can usually be fitted without the intrusion of an air bubble into the tears reservoir, irrespective of the corneal topography. The main limitation of hard gas-permeable sealed preformed lenses is when the sclera is excessively toric or irregular, which is the principal indication for using either of the two methods for manufacturing hard gas-permeable scleral lenses from impressions. The potential for therapeutic uses of scleral lenses to aid corneal coverage is greatly enhanced by hard gas-permeable materials because sealed lenses retain the best possible fluid reservoir where there is a tears deficiency.

15.4 Scleral lens specification

The British Standards relating to sclerals are BS 5562:1978 and BS 3521:1988 Part 3 based on ISO 8320–1986.

For spherical preformed lenses:

BOZR = Back optic zone radius
BOZD = Back optic zone diameter
BPOZR = Back peripheral optic zone radius of optic, if present
BSR = Back scleral radius
TD = Total diameter
BSS = Back scleral size where specified is preceded by the letter B; otherwise TD is assumed
L = Orientation of long axis in standard notation
D = Displacement of optic and direction

Example (mm):
R/BOZR:BOZD/BSR:BSS/L/D/transition
R/8.40: 11.00/13.00: B23.50/L10/D 1.00 in/sharp transition

Some fitting sets still use the 1962 British Standard, which gives a different specification:

Example (mm): 14.25/8.75/13.75/B23.50 D1 in

Radius of back scleral surface	= 14.25
Radius of back optic zone	= 8.75
Primary optic diameter	= 13.75
Back scleral size or total diameter	= B23.50
Displacement	= D1 in

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CHAPTER 16

Soft lens fitting and design

16.1 Fitting considerations

16.1.1 Sagittal height and corneal measurement

The curvature of the central cornea has a relatively small influence on its sagittal height compared with normal variations in shape factor and diameter. Keratometry on its own is therefore a poor predictor of the optimal soft lens radius. There is also a positive correlation between corneal diameter and corneal curvature so that flatter corneas generally have larger diameters and vice versa. A similar relationship exists for sagittal height. One of the most important influences on the optimal soft lens fitting is therefore the corneal shape factor or *p*-value, although this can generally only be obtained by using either an autokeratometer or topographer.

Atypical combinations of corneal radius and diameter should also be considered:

Large corneas with steep radii

- Have relatively large sagittal heights.
- Need soft lenses with large sagittal depths.
- Require steep lenses.

Small corneas with flat radii

- Have small sagittal heights.

- Need soft lenses with small sagittal depths.
- Require flat lenses.

16.1.2 Dynamic assessment of fitting

Soft lens fittings of all types are assessed dynamically in relation to lens movement with:

- Blinking.
- Upward and lateral gaze.
- The 'push-up test'.

The 'push-up' test

This simple test can be used to evaluate two aspects of the dynamic performance of most soft lenses on the eye.[1]

- The lens is pushed vertically upwards by digital manipulation of the lower lid margin and the resistance to decentration is assessed. An optimal fitting gives little or no resistance to movement.
- When the pressure of the lower lid is released, the speed of recovery is observed. Rapid movement, similar to that observed on blinking, indicates a satisfactory fitting whereas a slow recovery may be indicative of tightness.

A grading system has been suggested in which 100% denotes a lens that is impossible to move and 0% one that would fall off the eye: 50% represents an optimal fitting.[2] Both components of the test, however, are important so that a lens that is difficult to decentre but recovers rapidly suggests negative pressure within the tear film. This type of fitting should be particularly avoided with silicone hydrogels.

16.1.3 Design factors

The most appropriate design has to be selected from the very wide range of lens forms now available. Several factors must be taken into account:

- Size (corneal or semi-scleral).
- Water content (low, medium or high).
- Material (hydrogel or silicone hydrogel).
- *Dk*.

- Thickness (standard or thin) (*see* Section 17.4).
- Geometric and optic design (spherical or aspheric).
- Manufacturing method (lathed or moulded).
- Lens flexibility (*see* Section 17.2).
- Lens power (*see* Section 17.1).
- Disposable or conventional.

Majority of all these factors have some influence on vision, comfort and fitting characteristics but an important consideration has always been the total diameter. The two main fitting philosophies into which soft lenses have traditionally been divided are therefore *corneal* and *semi-scleral*. There has been a progressive convergence between these two approaches so that there is now considerable overlap, especially with single diameter lenses.

The majority of disposable lenses fall into this category. They are available only with a single total diameter and many offer no choice of radius. This simplifies fitting but means that if a lens proves unsatisfactory on the eye it is necessary to change to a different variety. It is therefore essential to draw on a wide range of lens types to provide an optimal fitting for the greatest number of patients.

16.2 Corneal diameter lenses

True corneal diameter lenses with TDs less than about 13.50 mm are now in the minority. They are almost invariably conventional as opposed to disposable and have traditionally been manufactured from materials of low to medium water content to give reproducible lenses of good durability. The thinner varieties, in particular, cause minimal interference with corneal metabolism and give excellent cosmetic appearance. Some patients reject the cosmetic appearance of a semi-scleral lens that overlaps onto the sclera.

Indications

- Small corneas.
- Where all disposable lenses are too large.
- Small palpebral apertures.
- Difficulty in handling larger lenses.
- Cosmetic reasons.

Contraindications

- Very large corneas.
- Shallow corneoscleral junction allowing decentration.
- Tight lids causing lens decentration.
- Sensitive lid margin.
- Sensitive limbus.

Fitting

Radius

- Radius selection is based on keratometry.
- Most radii are between 7.90 mm and 8.90 mm.
- Less flexible low water content materials may require radii that are 0.70 mm or more flatter than 'K'.
- The radius for standard HEMA lenses is usually between 0.30 mm and 0.60 mm flatter than 'K'.
- High water content lenses are fitted closer to alignment.
- Fitting steps are usually between 0.20 mm and 0.40 mm.
- Most corneal lenses have a single curve back surface.

Total diameter

- Lenses should be just slightly larger than the horizontal visible iris diameter (HVID). They should extend beyond the limbus by up to 0.50–0.75 mm to avoid irritation.
- Most corneal lenses vary in size from 12.50 to 13.50 mm, with the possible range from 12.00 to 14.00 mm.
- High water content lenses are fitted approximately 0.50 mm larger than HEMA.
- High plus and high minus lenses are fitted approximately 0.50 mm larger than low powers in order to achieve stability on the cornea.
- Fitting steps are usually 0.50 mm.

Power

After allowing for vertex distance considerations, the lens power is usually within 0.25 D of the spectacle *Rx*. Thicker designs require about 0.25 D less minus than thin lenses.

Fitting appearance

Fitting characteristics are mainly as described in Chapter 18, but it is essential for a correctly fitting lens to give complete corneal coverage

with proper centration to avoid the risk of epithelial dehydration and arcuate staining of any exposed area. The slit lamp should be used for careful observation of centration and movement, since these can be significantly influenced by factors such as:

- Corneal topography.
- Limbal topography.
- Lid pressure.
- Tear forces.
- Size of palpebral aperture.
- Position of cornea within palpebral aperture.

Figure 16.1 shows the four common ways in which a lens may position on the cornea with the eye in the primary position:

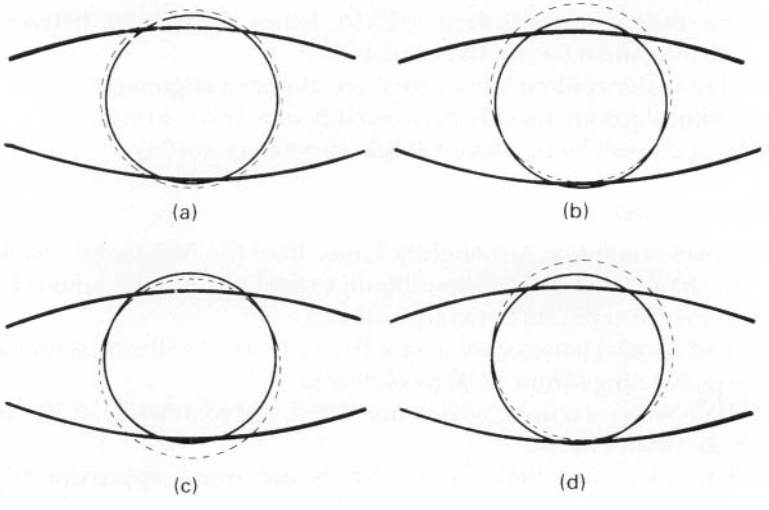

Figure 16.1 The four common positions (see text) taken up by soft lenses of corneal size, on an eye in the primary position: (a) correctly centred; (b) slightly high; (c) slightly low; (d) laterally decentred

(a) An optimal fitting is shown. The lens is perfectly centred and there should be 0.25–0.50 mm of vertical movement on blinking.
(b) The lens is riding high, influenced perhaps by a tight upper lid. This may prove acceptable, provided that the decentration is no more than about 0.50 mm. An attempt should be made to improve the fitting by selecting a larger diameter.
(c) The lens is riding in a low position. It generally represents an unsatisfactory fitting that is either too small or too flat and the

patient is likely to complain of unacceptable lid sensation. It can also occur with the downward pressure of a relatively heavy upper lid. This creates a fitting which is too tight, although initially quite comfortable. There is the possibility, after several hours of wear, of arcuate staining at the superior limbus together with oedema from insufficient tears exchange.

(d) The lens is eccentrically located. This may also be due to a fitting that is too small or too flat, or because of lid pressure with a shallow corneoscleral junction. It represents an unsatisfactory fitting and a larger total diameter should be tried. However, if the decentration is limited to 0.50 mm, it may occasionally prove acceptable. An attempt should always be made to improve the fitting characteristics of a decentred lens by selecting a larger diameter. Where this fails, it may be necessary to consider a semi-scleral lens.

Clinical equivalents

The principle of clinical equivalents applies where two lenses of the same design and material, with different but related parameters, give similar fitting characteristics on the eye.

Examples: 7.90:12.50 ≡ 8.10:13.00
8.30:13.00 ≡ 8.50:13.50

Rule of thumb

A change in diameter of 0.50 mm ≡ a change in radius of 0.20 mm.

To improve a loose fitting

- Select a larger total diameter.
- Select a steeper radius.
- Use a more rigid lens or one of lower water content material.
- Use a different lens thickness.

To improve a tight fitting

- Select a flatter radius.
- Select a smaller total diameter.
- Use a less rigid or higher water content material.
- Use a different lens thickness.

16.2.1 Examples of corneal diameter lenses

Mini (CooperVision)

A standard thickness, corneal diameter lens for daily wear; manufactured by lathing.

Material properties

Chemical nature	HEMA cross-linked polymer. Non-ionic
Water content	38.6% at 20°C
Dk	8.0×10^{-11} at 20°C
	10.0×10^{-11} at 35°C
Refractive index	1.513 (dry), 1.43 (wet)

Lens geometry

- Centre thickness is 0.12 mm at −3.00 D and 0.21 mm at +2.00 D.
- Back surface is a single curve.
- Front surface is lenticulated.

Parameters available

See Table 16.1.

Table 16.1 Parameters available for Hydron Mini lenses

Radius (mm)	7.90–8.90 in 0.20 steps	8.10–9.30 in 0.20 steps
Diameter (mm)	12.50	13.00
Power (D)	±10.00 in 0.25 steps	
	±10.50 to ± 30.00 in 0.50 steps	

Fitting technique

- Total diameter should be at least 1.00 mm larger than the HVID.
- Lenses of 13.00 mm diameter are used in about 90% of cases.
- Initial radius is selected approximately 0.70 mm flatter than 'K'.

Typical lens specification

8.70:13.00 −3.00

Lunelle ES 70 (Ocular Sciences)

A high water content, mainly corneal diameter lens manufactured by lathing. One of the few high water content lenses available in a small diameter.

Material properties

Chemical properties	Co-polymer of PMMA and polyvinyl pyrrolidone. Non-ionic
Water content	70%
Dk	36×10^{-11} at 25°C
Refractive index	1.38

Lens geometry

- Centre thickness is 0.20 mm at −3.00 D.
- Back surface is a single curve.
- Front surface is lenticulated.

Parameters available

See Table 16.2.

Table 16.2 Parameters available for Lunelle ES 70 lenses

Radius (mm)	7.70–8.30 in 0.30 steps	8.00–9.20 in 0.30 steps
Diameter (mm)	13.00	14.00
Power (D)	+8.00 to −12.00	±20.00

Fitting technique

- The 14.00 mm diameter is selected for corneas larger than 11.25 mm; the 13.00 mm diameter for corneas 11.25 mm or smaller.
- The radius is selected to be at least 0.60 mm flatter than 'K' for 14.00 mm lenses and 0.30 mm flatter than 'K' for 13.00 mm lenses.
- Lens movement should be 0.50–0.75 mm.
- The relative stiffness of the material gives an advantage in correcting low to medium degrees of astigmatism (0.75–1.25 D).
- A low rate of lens dehydration is claimed to assist or avoid dry eye problems.
- All lenses are manufactured with a UV inhibitor.

Typical lens specification

8.00:13.00 −3.00
8.90:14.00 −3.00

Related lenses

- Standard front surface toric.
- Toric *Rx* TDI, a back surface toric.
- A range of four colour enhancers.

- Lunelle Solaire, with sun filter and UV inhibitor.
- Lunelle Therapeutic, plano lenses for bandage use.
- Other special lenses are also feasible.

16.3 Semi-scleral lenses

The majority of lathed semi-sclerals are significantly larger and thicker than corneal soft lenses, giving better stability of both vision and fitting. In order to provide good physiological response, they are now mostly manufactured from medium to high water content materials with good *Dk* values.

Indications

- Most straightforward cases.
- Large corneas.
- Large palpebral apertures.
- Sensitive lid margin.
- Sensitive limbus.
- Hyperopes and high powers, if high water content.
- Moderate degrees of astigmatism (0.75–1.25 D).

Contraindications

- Very small corneas.
- Small palpebral apertures, and tight lids if handling difficult.
- Corneas prone to oedema, if low water content.
- Where cosmetic appearance is important.

Fitting

Radius

- Radius selection is based on keratometry.
- Most radii are fitted between 8.30 mm and 9.20 mm.
- High water content lenses are fitted between 0.30 mm and 1.00 mm flatter than 'K'.
- Low water content lenses are fitted flatter, between 0.70 mm and 1.30 mm flatter than 'K'.
- Fitting steps are usually 0.30 mm or 0.40 mm.
- Most semi-scleral lenses are of bicurve construction, with a relatively flat but narrow peripheral curve.

Total diameter

- Lenses are fitted significantly larger than the visible iris diameter, to give deliberate apical touch with further support beyond the limbus where they overlap onto the sclera. This type of three-point touch is shown in Figure 16.2.
- The total diameter is selected to be 2.00–3.00 mm larger than the horizontal visible iris diameter. However, many semi-scleral lenses are manufactured in only one size.
- The majority of semi-scleral lenses are fitted with total diameters of 14.20–14.80 mm; the possible range is from 13.50 to 16.00 mm.
- High and low water content lenses are both fitted with very similar diameters.
- Fitting steps are usually 0.50 mm.

Figure 16.2 Semi-scleral lens giving three-point touch

Power

Mainly because of flexure effects, the power of a correctly fitting lens often shows approximately 0.25–0.50 D less minus than the spectacle *Rx*, after allowing for any vertex distance considerations. With more rigid low water content lenses, this difference can be as great as 0.75 D, although this does not seem to apply with silicone hydrogels (*see* Chapter 20).

Fitting appearance and lens movement

Fitting characteristics are mainly as described in Chapter 18 and Table 18.1. It is essential that a correctly fitting lens should be sufficiently large to span the limbus and not interfere with the blood vessels in this region.

Figure 16.3(a–c) shows diagrammatically the limits of acceptable movement and position for semi-scleral lenses with the eye in the primary position and in lateral and upward gaze. Figure 16.4(a–c) indicates the lack of movement with a tight lens, whereas Figure 16.5(a–c) shows the excessive mobility of a loose fitting.

Clinical equivalents and altering the fitting

The principle of clinical equivalents also applies so that two lenses of different but related specification behave in the same way on the eye.

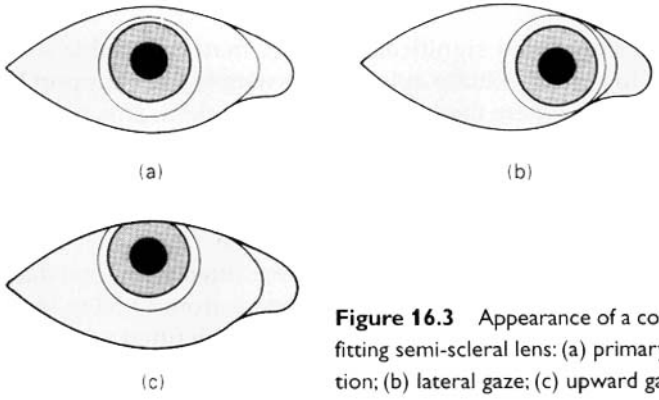

Figure 16.3 Appearance of a correctly fitting semi-scleral lens: (a) primary position; (b) lateral gaze; (c) upward gaze

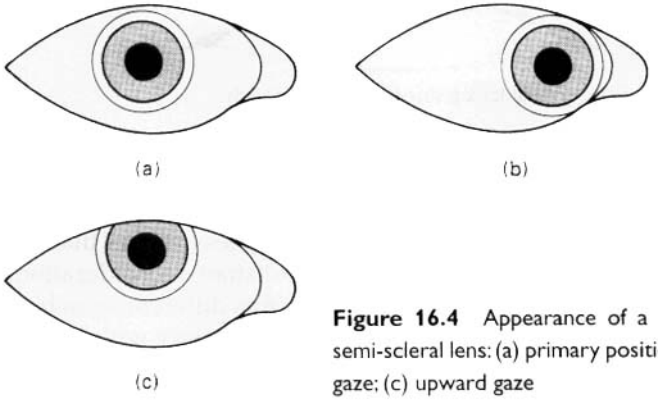

Figure 16.4 Appearance of a tightly fitting semi-scleral lens: (a) primary position; (b) lateral gaze; (c) upward gaze

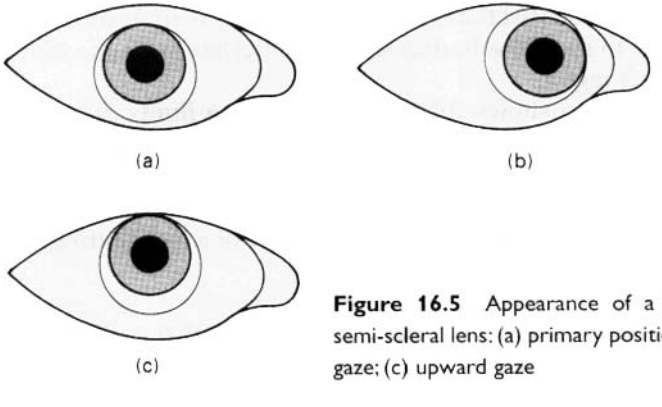

Figure 16.5 Appearance of a loose fitting semi-scleral lens: (a) primary position; (b) lateral gaze; (c) upward gaze

Examples: 8.10:13.50 ≡ 8.40:14.00
8.70:14.50 ≡ 9.00:15.00

Clinical equivalents have approximately the same ratio of sagittal depth to total diameter. They do not have the same sagittal depth.

Rule of thumb

A change in radius of 0.30 mm ≡ a change of diameter of 0.50 mm.

To improve a loose fitting

- Select a steeper radius.
- Select a larger total diameter.
- Use a more rigid or lower water content material.
- Use a different lens thickness.

A lens of specification 8.70:14.00 may be progressively tightened with the following steps: 8.70:14.50; 8.40:14.00; 8.40:14.50.

To improve a tight fitting

- Select a flatter radius.
- Select a smaller total diameter.
- Use a less rigid or higher water content material.
- Use a different lens thickness.

A lens of specification 8.70:14.50 may be progressively loosened with the following steps: 8.70:14.00; 9.00:14.50; 9.00:14.00.

16.3.1 Examples of semi-scleral lenses

Durasoft 3 Lite Tint (CIBA Vision)

A medium water content semi-scleral lens manufactured by lathing.

Material properties

Chemical nature	Co-polymer of HEMA and 2-ethoxyethyl methacrylate. Non-ionic
Water content	55%
Dk	16×10^{-11} at 35°C
Refractive index	1.412

Lens geometry

- Back surface is of monocurve construction.
- Front surface is lenticulated.
- Centre thickness is 0.05 mm for a lens of BVP –3.00 D.

Parameters available

See Table 16.3.

Table 16.3 Parameters available for Durasoft 3 Lite Tint lenses

Radius (mm)	8.30, 8.60, 9.00
Diameter (mm)	14.50
Power (D)	±20.00

Fitting method

- The 8.60 radius (designated *median*) is used in the great majority of cases and is selected first unless the cornea is very steep or flat.
- The total diameter should be 1.50–2.00 mm larger than the HVID.

Typical specification

8.60:14.50 −3.00

Related lenses

- Durasoft 3 Optifit Toric: a back surface toric stabilized with front surface thin zones.
- Durasoft 3 Colours and Durasoft 3 Complements: two separate ranges of cosmetic tinted lenses.

Omniflex (CooperVision)

A high water content, semi-scleral lens for daily wear, manufactured by lathing.

Material properties

Chemical nature	Co-polymer of methyl methacrylate and vinyl pyrrolidone. Non-ionic
Water content	70%
Dk	32×10^{-11} at 35°C
Refractive index	1.39

Geometry	Spherical bicurve back surface; spherical lenticulated front surface. Centre thickness 0.12 mm for −3.00 D and 0.23 mm for +3.00 D

Parameters available

See Table 16.4.

Table 16.4 Parameters available for Omniflex lenses

Radius (mm)	8.40, 8.80
Diameter (mm)	14.30
Power (D)	±20.00

Fitting method

- The total diameter is constant at 14.30 mm.
- The 8.40 mm radius fits approximately 80% of eyes.
- The 8.80 mm fitting is required for flat or small diameter corneas.

Typical specification

8.40:14.30 −3.00

Related lenses

- Omniflex toric: a back surface toric with prism free front optic and stabilization zones.
- Omniflex Softints: a range of four colour enhancers in 10% and 20% densities.

General advice

- Select the flatter of two possible fittings where there is a choice because:
  (a) It is easier to see the movement of a lens that is too loose rather than the relative lack of movement of a steep fitting.
  (b) A sharper end-point is obtained with over-refraction.
  (c) Soft lenses become steeper and therefore tighter after initial settling.
- Steep corneas require lens selection to be relatively much flatter than flat corneas where the optimal result is likely to be much closer to 'K'. This applies to both corneal and semi-scleral lenses. Thus a radius of 8.10 mm may be necessary for a 13.00 mm lens on a 7.40 mm cornea,

continued

whereas an 8.40 mm cornea might well require a much closer radius of 8.70 mm or perhaps 8.50 mm.

- It is better to achieve a more stable fitting by increasing the size. A steeper radius is likely to give worse acuity.
- It is essential to ensure adequate lens movement to allow proper exchange of tears and the removal of debris.
- It is also important to avoid fitting too tightly because of the risk of oedema. This can occur even with thin or high water content lenses.

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2. Young, G. (1992) How to fit soft contact lenses. *Journal of the British Contact Lens Association*, **15** (4), 179–180

CHAPTER 17

Other soft lens fitting considerations

17.1 Lens power

Power is an important consideration in deciding which type of lens to fit.

Low minus (<−2.00 D)

- Thin lenses should be avoided because of handling difficulties and the greater chance of dehydration.
- A thicker, medium or high water content lens should be selected, or a silicone hydrogel.

High minus (>−7.00 D) and medium to high plus (>+3.00 D)

- Low water content lenses should be avoided because of the greater thickness and physiological problems.

- Silicone hydrogels avoid any risk of physiological problems.
- Semi-scleral lenses usually give better stability of fitting.

Medium minus (−2.00 D to −7.00 D) and low plus (<+3.00 D)

- High water content or thin lenses are the probable choice, except where problems arise with fitting characteristics, dehydration or visual acuity.

17.2 Lens flexibility and modular of elasticity

An important influence on the fitting characteristics of all lenses is the flexibility of the material. This explains why two lenses of apparently the same specification but different material can behave in entirely different ways on the cornea.[1] Permalens, for example, which is very flexible, often requires to be fitted steeper than 'K' compared with other more rigid materials where the more usual flatter than 'K' approach is correct. Similarly, thin spun-cast lenses and moulded lenses with overall a thin cross-section and inherently greater flexibility than their lathed counterparts lend themselves better to a 'one-fit' fitting philosophy which relies on draping the cornea.

The modulus of elasticity of the material (*see* Table 17.1). This defines a material's relative stiffness, which has a strong influence on lens fit. Materials with a high modulus are generally much easier to handle but are more likely to cause arcuate staining (*see* Section 20.4 and 29.3). Materials with a low modulus, in addition to handling difficulties because of their flexibility, may well show less movement together with greater decentration on the eye. Variations in modulus of elasticity can also give a large difference in sagittal depth, which in turn affects the fitting characteristics.

Table 17.1 Modulus of elasticity

Material	Modulus
Soflens 66	25 g/mm^2
Acuvue	35 g/mm^2
Optima	130 g/mm^2
Night & Day	120 g/mm^2

Practical advice

- Because of flexibility and manufacturing considerations, the lenses from one laboratory cannot necessarily be duplicated by another, merely by ordering the same nominal specification.
- Fitting should be carried out with trial lenses of the type to be ordered to ensure optimal reliability.
- For conventional lenses, this is no longer feasible with current regulations but many laboratories will now supply prescription lenses on an exchange basis.
- With disposables, lenses can be taken from a fitting bank or diagnostics ordered from the laboratory.

17.3 Additional visual considerations

Flexure and liquid lens power

Flexure occurs when a soft lens fitted flatter or steeper than 'K' bends to follow the corneal curvature. The refractive effect with both plus and minus lenses is to add negative power.[2,3]

A liquid lens occurs if the posterior surface of the soft lens fails to conform to the front surface of the cornea.[4] This is more likely to be present with semi-scleral designs, whereas there is virtually no liquid lens with ultrathin lenses that completely drape the cornea.

Practical advice

- Any discrepancy between contact lens and spectacle *Rx* (allowing for vertex distance) is caused mainly by flexure but possibly by liquid lens power.
- This is unlikely to be greater than 0.50 D with a satisfactory fitting.
- Thin corneal lenses require more minus power than thick semi-scleral lenses.

Astigmatism

The usual limit for acceptable acuity with a thin spherical lens is about 1.00 DC, but it can be as little as 0.50 DC for critical observers. Very occasionally, acceptable vision is obtained with cylinders as

high as 4.00 D and with an amblyopic eye there may be no advantage in the additional complexity and cost of a toric lens.

Soft lenses are generally fitted flatter than 'K' so that less minus is required compared with the best vision sphere used with hard lenses.

Example:

Spectacle *Rx* $-3.50/-1.00 \times 180$
Likely BVP of spherical soft lens -3.50 D

Environmental factors

The power of a soft lens depends on its basic dimensions of radius, diameter, thickness and refractive index which can all vary with environmental factors. These include ocular effects such as temperature, pH, tonicity and volume of tears. Some of these are in turn influenced by external factors such as ambient temperature, humidity, or the degree of lens hydration when placed on the eye. Generally, high water content materials undergo larger changes and give greater variation in vision than HEMA.

17.4 Thin lenses

Lenses with a centre thickness less than 0.10 mm may be regarded as *thin* (*see* Section 6.3.2). Lenses in the range 0.05–0.07 mm are *ultrathin* and those less than 0.05 mm have been termed either *superthin* or *hyperthin*.

The fitting characteristics of thin and standard lenses differ even if they have an otherwise identical specification. Lens thickness may therefore be regarded as an additional fitting variable.

In practical terms, thin lenses generally:

- Possess greater flexibility.
- Prove easier to fit because there are fewer fitting steps.
- Drape the cornea more completely and give less mobility.
- Give less lid sensation and are more comfortable.
- Have better transmissibility (*Dk/t*).
- Possess different fitting characteristics and sometimes permit better centration.
- Give less satisfactory acuity on toric corneas.
- Dehydrate to a greater extent on the eye after settling.

Zero 6 (CooperVision)

Thin HEMA, semi-scleral lenses for daily wear; manufactured by lathing.

Material properties

HEMA 38.6% (*see* Section 16.1).

Lens geometry

- Centre thickness is 0.06 mm for all minus lenses of power −3.00 D or greater.
- The mid-periphery is deliberately thickened to make handling easier.
- Zero 6 plus lenses have an average thickness of 0.10 mm.
- The back surface is a bicurve with a constant BOZD of 13.28 mm and peripheral curve width of 0.36 mm (13.28 mm + 0.36 mm + 0.36 mm = 14.00 mm).
- The front surface is lenticulated with FOZDs of 6.70 mm at −10.00 D and 8.30 mm at +10.00 D.

Parameters available

See Table 17.2.

Table 17.2 Parameters available for Hydron Zero 6 and Z Plus lenses

Radius (mm)	8.40, 8.70, 9.00, 9.30
Diameter (mm)	14.00
Power (D)	±20.00

Fitting technique

- Approximately 70% of minus lenses are fitted with the 8.70 mm radius.
- The most common radius for plus lenses is 9.00 mm.
- There is no very firm relationship between 'K' and radius because of greater lens flexibility.
- 14.00 mm is the standard diameter. TDs of 13.5 mm, 14.50 mm and 15.00 mm, and radii of 8.10 mm and 9.60 mm are available to special order.

Typical specification

Zero 6: 8.70:14.00 −3.00

Related lenses

- Zero 6T: a front surface toric with prism-free optic zone.
- A range of five colour enhancer tints with densities of 10% and 20%.

17.5 Aspheric lenses

Back surface aspherics

A minority of soft lenses have an aspheric back surface designed to match the aspheric nature of the cornea. A correctly fitting lens behaves in the main as described in Section 18.1, but compared with spherical lenses:

- Aspherics do not have a true radius but are designated in some other way such as by 'fitting value' or posterior apical radius (PAR).
- Changing the total diameter does not necessarily alter the fitting characteristics.
- Lens mobility of between 0.25 mm and 0.75 mm can be acceptable.
- With some corneal geometries, proper centration cannot be achieved and a spherical lens is required, although the reverse is also true.

Weicon CE (60%) (CIBA Vision)

A back surface aspheric, corneal diameter lens for daily or extended wear, manufactured by CNC lathes.

Material properties

Chemical nature	Methyl methacrylate/vinyl pyrrolidone (MMA/VP) copolymer. Ionic
Water content	60%
Dk	28×10^{-11} at 35°C
Refractive index	1.4037

Lens geometry

- Centre thickness of a −3.00 D lens is 0.09 mm.
- All lenses have an elliptical back surface with a flat (FL) or steep (ST) fitting value instead of a radius.

- Radius and eccentricity are varied to give a consistent performance throughout the power range.
- Lenses feature a *tangential bevel* to give a continuous transition between back surface and ski-shaped edge.

Parameters available

See Table 17.3.

Table 17.3 Parameters available for Weicon CE lenses

Fitting value (eccentricity)	Flat (FL) or steep (ST)
Diameter (mm)	13.00, 13.80, 14.60
Power (D)	±25.00

Fitting technique

- The 13.80 mm diameter is most commonly used.
- The FL fitting value is generally selected.
- The ST fitting value is tried only if the FL is excessively mobile after complete settling.
- The 13.00 mm fitting can be used as a high water content corneal diameter lens.

Typical specification

Weicon CE: FL 13.80 −3.00

Related lenses

- The Weicon CE Toric: a high water content back surface toric stabilized by dynamic stabilization.
- The Weicon 38E. The original HEMA version of the Weicon CE.

Front surface aspherics

A front surface aspheric (e.g. Cantor + Nissel EV38, Mark'ennovy Super T) can give improved acuity in cases of low to medium astigmatism (0.75–1.50 D) by the correction of optical aberrations.

17.6 Spun-cast lenses

Spun-cast HEMA lenses from Bausch & Lomb were the first to obtain FDA approval in 1971 and have an important place in the history of soft lenses. They have largely been superseded by more

modern designs and materials, and most of the original series have now been discontinued.

Advantages of spin-casting

- Excellent surface quality and edge shape.
- Mass production ensures good reproducibility and consistency of manufacture.

Disadvantages of spin-casting

- Limitations on the variety of back surface forms that may be conveniently obtained.
- The full power range is not obtainable for each series of lens.

Soflens (Bausch & Lomb)

Corneal and semi-scleral lenses for daily wear; manufactured by spin-casting in open moulds.

Material properties

Chemical nature	HEMA cross-linked polymer. Non-ionic
Water content	38.6%
Dk	8.0×10^{-11} at 20°C
Refractive index	1.43

Lens geometry

- The front surface gives the 'series' or 'base curve', determined by the constant curvature of the mould during manufacture. This is the opposite of conventional lathed lenses.
- The back surface is aspheric and governs the power (Figure 17.1).

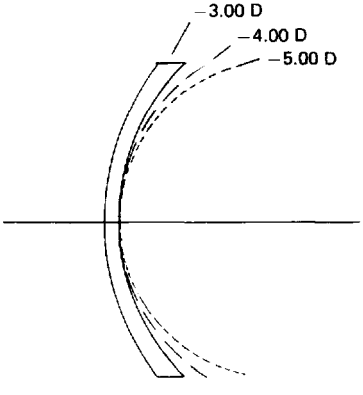

Figure 17.1 Bausch & Lomb Soflens. The front surface radius is constant. Variation in power is achieved by altering the posterior apical radius: the steeper the radius, the higher the negative power

- Minus series may have a constant sag and centre thickness.
- The higher the minus power, the tighter the fitting.
- Series are designated according to thickness and size. The suffix '4' denotes a 14.50 mm diameter; the suffix '3' a 13.50 mm diameter; and where there is no numerical suffix (e.g. the original F and U series), a 12.50 mm diameter.

Parameters available

See Table 17.4.

Table 17.4 Parameters available for Bausch & Lomb conventional lenses

Lens series	Power range (D)	Diameter (mm)	Centre thickness (mm)	Sag (mm)
B3	−9.00 to +6.00	13.50	0.12–0.30	3.10–3.90
B4	−9.00 to +6.00	14.50	0.12–0.30	3.59
H3	+10.00 to +20.00	13.50	0.48–0.61	3.40–3.47
H4	+10.00 to +20.00	14.50	0.48–0.61	3.69–3.80
HO3	−8.00 to −20.00	13.50	0.035	3.61
HO4	−8.00 to −20.00	14.50	0.035	3.67
Optima 38	−0.25 to −6.00	14.00	0.06	3.60/3.82

Fitting technique

- The constant sag and the greater flexibility of spun lenses effectively give a one-fit approach for each particular series.
- Fitting characteristics depend upon total diameter, thickness and power.
- Diameter is chosen on the basis of corneal size. 13.50 mm lenses (3 series) are used where HVID is less than 11.75 mm, and 14.50 mm (4 series) where it is greater.
- Series is chosen according to power.
- Power is based on spectacle *Rx* and vertex distance.
- If adequate centration cannot be achieved with the initial diameter, the next larger lens with the same letter series should be tried (e.g. if B3 is too small, change to B4).
- It is particularly important to achieve complete corneal coverage or there is a likelihood of arcuate staining at the limbus from corneal drying and edge abrasion.

- Lens decentration is likely to give poor vision because of the aspheric optics.
- Decentration can occur with either a loose or a tight fitting, but in the latter case there is no recovery movement on blinking.
- Movement on blinking is only about 0.25 mm (i.e. less than most other lenses).
- Other fitting characteristics are mainly as described in Chapter 18.

Optima 38 (t_c = 0.06 mm)

The Optima lens is used where greater rigidity and ease of handling are required. The back surface is lathed and there are two possible sags. Sag I (3.60 mm) gives greater movement and is fitted with flatter corneas; Sag II (3.82 mm) gives better centration and is used with steeper corneas.

Related lenses

- The Optima Toric: a 45% water content front surface toric stabilized by prism ballast.

17.7 One-fit lenses

Most one-fit lenses are semi-scleral in type. They can give a satisfactory result in a high percentage of cases because of their large diameter, thinness and flexibility.

- Because no fitting adjustment is possible, it is important to recognize early those cases for which the fitting characteristics fail to meet the criteria given in Chapter 18.
- With thinner varieties, especially spun-cast lenses, limited lens mobility of only 0.25 mm may be acceptable.
- To assess the fitting reliably, trial or diagnostic lenses should be as near as possible to the correct power.
- Particular care is required with corneas that are unusually small, large, steep or flat.
- Several disposable lenses are designed to be one-fit, to simplify fitting and reduce the number of parameters required (*see* Chapter 19).

Permaflex (CIBA Vision)

A single fitting high water content, semi-scleral lens for daily or extended wear, manufactured by cast moulding.

Material properties

Chemical nature	A cross-linked polymer of methyl methacrylate, vinyl pyrrolidone and other methacrylates. Non-ionic
Water content	74%
Dk	43×10^{-11} at 36°C
Refractive index	1.385

Lens geometry

- Centre thickness varies from 0.08 mm to 0.22 mm for minus powers; 0.14 mm for a −3.00 D lens.
- The back surface is of spherical bicurve construction.
- The front surface is lenticulated where necessary to give a minimum FOZD of 7.50 mm.

Parameters available

See Table 17.5.

Table 17.5 Parameters available for Permaflex lenses

Radius (mm)	8.70
Diameter (mm)	14.40
Power (D)	−10.00 to +8.00

Fitting technique

- Fitting is assessed with lenses as near as possible to the correct power.
- The spherical 8.70 mm radius fits a very high percentage of corneas. It is sometimes found to be too mobile and, less frequently, too tight.
- Because of the high water content, sufficient time must be allowed for lenses to settle, or an apparently correct fitting may subsequently become tight.

Typical specification

Permaflex: 8.70:14.40 −3.00

Related lenses

Precision UV: monthly disposable lenses available with additional steeper and flatter radii of 8.40 mm and 9.10 mm and an extended power range to −16.00 D. Lenses have a handling tint and UV inhibitor provided by a chromophore known as UVAM. Compared with Permaflex, the *Dk* is lower at 38×10^{-11} because of the UV inhibitor.

17.8 Unusual lens performance

Fitting sometimes gives unexpected or unreliable results. If the lens is:

Too tight

- Stored in *hypo*tonic solution, giving temporary osmotic adhesion.
- Causing initial irritation with excessive lacrimation and a hypotonic shift in the patient's tears.
- Ultrathin with a temporarily distorted shape because it has adhered to the storage vial or blister pack.
- Disinfected by heat without sufficient time to cool and revert to its proper dimensions.

Too loose

- Stored in *hyper*tonic solution.
- Inserted inside out.
- Damaged.

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CHAPTER 18

Soft lens fitting characteristics

Every make of lens has, to some extent, its own fitting characteristics. Most of the more general points, however, are summarized below, although the rather greater differences between corneal and semi-scleral lenses have been covered in Chapter 16.

18.1 Characteristics of a correct fitting

The general principles for a good fitting are complete corneal coverage, correct lens movement, good vision and comfort.

- Good centration.
- Complete corneal coverage.
- Approximately 0.50 mm of vertical movement on blinking in primary position.
- Lag of up to 1 mm on upward gaze or lateral eye movements.
- Rapid recovery on vertical displacement (push-up test).
- Comfortable in all directions of gaze.
- Good visual acuity.
- Retinoscopy reflex crisp and sharp before and after blinking.
- Vision remains stable on blinking.
- Refraction gives a precise end-point.
- Refraction correlates with spectacle BVP.

- Keratometer mires stable and undistorted.
- No irritation of limbal vessels.
- No compression of bulbar conjunctiva.

18.2 Characteristics of a tight fitting

The obvious feature of a tight lens is insufficient movement. Initial comfort is therefore good and sometimes better than a correct fitting. Centration is also usually good, although a corneal diameter lens may sometimes assume a decentred position. This is easily differentiated from a decentred flat fitting because of the lack of movement. A steep lens vaults the corneal apex, but is momentarily pressed onto the eye by blinking to give a transient improvement in vision.

- Little or no movement on blinking (less than 0.25 mm).
- Little or no movement on upward or lateral gaze (less than 0.25 mm).
- Good centration.
- Slow recovery with push-up test.
- Good initial comfort.
- Subsequent symptoms of discomfort such as heat or stinging.
- Poor visual acuity.
- Retinoscopy reflex shows irregular distortion.
- Unstable vision with temporary improvement on blinking.
- Refraction difficult with poor end-point.
- More negative power required than anticipated because of flexure or possible liquid lens.
- Keratometer mires give irregular distortion.
- Irritation of limbal or conjunctival vessels.
- Compression ring in bulbar conjunctiva (scleral indentation), often seen after the lens is removed.

18.3 Characteristics of a loose fitting

The obvious feature of a loose lens is excessive movement. On looking upwards it may catch against the top lid and cause noticeable discomfort. In the primary position, lower lid sensation is experienced if the lens sags, and the discomfort is accentuated if the fitting is so flat that the periphery buckles to give edge stand-off

(Figure 18.1). This is not uncommon on steep corneas with single fitting and disposable lenses with a limited range of parameters. More rigid silicone hydrogels are particularly prone to edge buckling.

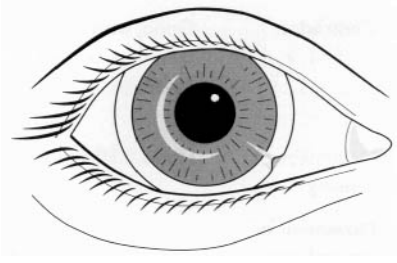

Figure 18.1 Very loose fitting showing buckling of lens edge

- Excessive movement on blinking (over 1 mm).
- Excessive lag on lateral or upward eye movements (over 2 mm).
- Poor centration.
- Poor comfort because of lid sensation.
- Visual acuity variable.
- Retinoscopy reflex clear centrally with peripheral distortion.
- Refraction variable because of lens movement.
- Keratometer mires vary with lens movement, giving peripheral distortion.
- Buckling of lens edge.

18.4 Summary of soft lens fitting characteristics

The general fitting characteristics for soft lenses are summarized overleaf in Table 18.1.

Each lens type and lens make is likely to have its own individual fitting characteristics, depending upon its water content, total diameter, method of manufacture and the various other points discussed in Chapter 16 on 'Soft lens fitting and design' and Chapter 17 on 'Other soft lens fitting considerations'. Table 18.1 is therefore intended to give a comprehensive overview of the general fitting characteristics which the contact lens practitioner may expect to be present.

Table 18.1 Fitting characteristics of soft lenses

Characteristic	Good fit	Steep fit	Flat fit
Comfort	Good	Good, initially	Poor
Centration	Good, with complete corneal coverage	Usually good, may be decentred, no recovery on blinking	Poor
Movement on blinking	Up to 0.50 mm	Less than 0.25 mm	Excessive, over 1.00 mm
Movement on upward gaze	Up to 1.00 mm	Little or none	Excessive, over 2.00 mm
Movement on lateral gaze	Up to 1.00 mm	Little or none	Excessive, over 2.00 mm
Vision	Good	Poor and variable, momentary improvement on blinking	Variable, may improve on staring after blinking
Over-refraction	Precise end-point, power correlates with BVP of spectacle *Rx*	Poorly defined end-point, positive liquid lens	Variable, negative liquid lens
Retinoscopy reflex	Clear reflex, before and after blinking	Poor and distorted, central shadow, momentarily improved on blinking	Variable, may be clear centrally with peripheral distortion
Slit lamp after settling	No limbal injection or scleral indentation	Conjunctival or limbal injection, scleral indentation	Localized limbal injection, possible edge stand-off
Keratometer mires	Sharp, stable before and after blinking	Irregular, momentary improvement on blinking	Variable and eccentric, changing on blinking
Placido disc or videokeratoscope	Regular image	Irregular image anywhere but at the edge of the lens	Irregular image, more often peripheral only but occasionally central as well

CHAPTER 19

Disposable lenses and frequent (planned) replacement

19.1 Frequent replacement lenses

Considerably fewer clinical difficulties arise when lenses are replaced on a regular basis.[1] Deposits are avoided and there are significantly reduced risks of discomfort, CLIPC, infections and red eyes. The distinction is imprecise but *disposable* is generally used to describe lenses replaced monthly or more often, and *frequent replacement* for lenses disposed of on a planned basis of over 1 month.

It has always been difficult to define the life span of a soft lens, since it depends on a variety of factors:

- Water content and material.
- Lens thickness.
- Method of disinfection and cleaning.
- Wearing time.
- Daily or extended wear.
- Tear chemistry.
- Handling ability.
- Environment.

A reasonable average time after which lenses needed either replacement or thorough professional cleaning used to be considered about 12 months. This projected life span is now reduced with the greater emphasis on high water content lenses and modern solutions, which are easier to use but less efficient at cleaning than peroxide systems. Many practitioners have therefore devised schemes that encourage patients to replace lenses on a frequent and planned basis before they reach the troublesome stage. The time interval is usually 3, 6 or, occasionally, 12 months.[2]

Conventional lenses are easily adapted for frequent replacement where laboratories supply lenses at reduced costs. Companies such as Bausch & Lomb (Fresh Vision), CIBA Vision (Continuum), CooperVision (Advantage) and Mark'ennovy have created schemes which include some or all of their lens types. Some also assist the practitioner with paperwork and computer reminders.

The advent of modern production techniques, particularly moulding, has reduced manufacturing costs so that some lenses are produced specifically for planned disposal. The replacement interval should be controlled by the practitioner but depends upon the make of lens and individual patient requirements. If new lenses are exchanged with the patient at aftercare visits, there is the additional advantage that the older lenses are removed from circulation.

19.2 Disposable lenses

The ultimate frequent replacement lens is the disposable which is discarded and replaced on a much more regular basis, usually monthly, weekly or daily.

Disposable lenses were originally recommended for weekly extended wear because they avoided most patient handling and eliminated the need for solutions and disinfection. In theory, they should have proved safer but several studies have implicated ionic materials, and in particular extended wear lenses, with a significant increase in microbial keratitis.[3,4]

Except for silicone hydrogels, disposable lenses are now used much less frequently for extended wear but they have assumed the dominant place in routine contact lens practice for daily wear. They offer several clinical advantages over their conventional counterparts.

Advantages

- Lenses rarely reach the stage where they build up deposits.
- Reduced risk of allergies and infections.
- Reduced incidence of CLIPC.
- Spare lenses are always available.
- Replacement cost is significantly less if lost or damaged.
- Less time and effort required with lens cleaning.
- Eliminate the need for professional lens cleaning.
- Cost savings on solutions.
- Patients like the regular fresh feeling of new lenses.
- Easier to fit since fitting parameters are limited.
- Ideal for children requiring soft lenses.
- Theoretically better for most extended wear (*see* Chapter 22).

Disadvantages

- Restricted range of fittings and powers.
- Restricted availability for complex lenses such as torics or bifocals.
- Increased cost on an annual basis.
- Uncertain management of patient compliance.
- Branded lenses are available by mail order so that some element of clinical control is removed from the practitioner.
- In the event of a clinical problem, patients may merely replace lenses rather than seek professional advice.
- Not feasible to check every lens.
- Administrative complexities because of the volume of lenses.

19.3 Types of disposable lens

Monthly and weekly

A wide range of disposable lenses is now available in terms of design, water content, material, fitting, power range and wearing schedule. Just some of these are shown in Table 19.1. The majority of lens systems are designed for monthly use, which represents a good compromise between life span, convenience and cost. Most are of medium to high water content and manufactured by moulding. Several have a handling tint, UV filter or both.

The most commonly used weekly lens is now Acuvue (58%), which is available in a wide range of parameters (+6.00 D to −11.00 D). Acuvue is also prescribed on a 2-weekly schedule and is the basis of a toric and bifocal design.

Table 19.1 Examples of monthly disposable lenses

Manufacturer	Lens	Water content (%)	*Dk* (Fatt)	Power range (D)	Radii (mm)	Diameter (mm)
Bausch & Lomb	Seequence	38	8.5	+4.00 to −9.00	Aspheric	14.00
Bausch & Lomb	Soflens 38	38	8.5	+4.00 to −9.00	8.40, 8.70, 9.00	14.00
Bausch & Lomb	Soflens Comfort	59	16.5	+6.00 to −9.00	8.60	14.20
Bausch & Lomb	Soflens 66	66	30	+6.00 to −9.00	8.40, 8.70	14.20
Cantor + Nissel	30 Days	55	22	+8.00 to −8.00	8.70	14.25
CIBA Vision	Focus Visitint	55	20	+6.00 to −15.00	8.60, 8.90	14.00
CIBA Vision	Precision UV	74	38	+10.00 to −16.00	8.40, 8.70, 9.10	14.50
CooperVision	Actifresh 400	73	36	+10.00 to −15.00	8.40, 8.80	14.30
CooperVision	Frequency 38	38	9	−0.25 to −8.00	8.60	14.00
CooperVision	Frequency 55	55	17	+8.00 to −10.00	8.60, 8.80, 8.90	14.20
CooperVision	Proclear Compatibles	62	27	+10.00 to −10.00	8.60	14.20
Johnson & Johnson	Surevue	58	28	+6.00 to −9.00	8.40, 8.80, 9.10	14.00
Ocular Sciences	Biomedics 38	38	10	−0.25 to −10.00	8.60	14.00
Ocular Sciences	Biomedics 55 UV	55	18	+8.00 to −10.00	8.60, 8.80, 8.90	14.20
Ocular Sciences	Promedics 60 UV	60	20	+5.00 to −6.00	8.50	14.10, 14.30
Ocular Sciences	Rythmic UV	73	45	+8.00 to −8.00	8.60, 8.90	14.20, 14.40
Ultravision International	Speciality 55	55		+6.00 to −12.00	8.60	14.20
Ultravision International	Speciality Select A.B. UV	56		+6.00 to −12.00	8.60	14.20

N.B. Fitting parameters, lens names and wearing schedules may vary in different countries.

Daily disposables

Since daily disposables should never be reused, they represent the only lens form that genuinely requires no disinfection by the patient. Saline is sometimes employed for rinsing while handling. Lenses are significantly more expensive when used on a regular basis. They tend to be thin, some are difficult to handle, and breakages in the eye are fairly common with some makes. Nevertheless, they provide several important advantages:

- No risk of solutions allergy.
- They avoid patient mistakes in using an incorrect solution.
- A lens case is not required and therefore no contamination is introduced from this source.
- No build-up of surface deposits.
- Ideal for patients who wish to use lenses intermittently.
- Can often be used while patients recover from CLIPC.

A wide choice of lenses is now available and examples are shown in Table 19.2.

Toric lenses

Toric disposables with a simplified range of parameters are produced by several manufacturers. Lenses are fitted according to the principles of stock torics, described in Section 24.4, and most laboratories provide diagnostic lenses for trial fitting. Examples are shown in Table 19.3.

Multifocals and bifocals

There is also a good range of multifocal and bifocal lens designs: these are listed in Table 19.4 (*see also* Section 25.5).

Silicone hydrogels

There are currently two varieties of monthly disposable silicone hydrogels: Bausch & Lomb Purevision and CIBA Vision Night & Day. For full details *see* Section 6.4 and Chapter 20.

19.4 Fitting disposable lenses

The selection of lens type and fitting methods follow the principles described in Chapters 16, 17 and 18. Most lenses are either one-fit or have a limited range of parameters with the TD fixed for a given

Table 19.2 Examples of daily disposable lenses (spherical single vision)

Manufacturer	Lens	Water content (%)	*Dk* (Fatt)	Power range (D)	Radii (mm)	Diameter (mm)
Bausch & Lomb	Soflens One Day	70	35	+6.50 to −9.00	8.60	14.2
CIBA Vision	Focus Dailies	69	26	+6.00 to −10.00	8.60	13.8
Johnson & Johnson	Acuvue	58	28	+6.00 to −12.00	8.50, 9.00	14.2
Ocular Sciences	Biomedics 1-Day	52	22.8	+6.00 to −10.00	8.70	14.2
Provis	Daysoft UV	7.2	38	+6.50 to −10.00	8.60	14.3

Table 19.3 Examples of toric disposable lenses

Manufacturer	Lens	Water content (%)	*Dk* (Fatt)	Power range (D)	Cylinders (D)	Radii (mm)	Diameter (mm)	Design and stabilization
Bausch & Lomb	Soflens 66 Toric	66	30	+6.00 to −9.00	−0.75, −1.25, −1.75, −2.25	8.50	14.50	BS, prism
CIBA Vision	Focus Toric	55	20	+4.00 to −6.00	−1.00, −1.75, −2.50	8.90, 9.20	14.50	BS, prism
CIBA Vision	Focus Dailies Toric	69	26	+0.50 to −6.00	−0.75	8.60	14.20	BS, Toric
Cooper Vision	Actitoric	43	12	+3.00 to −6.00	−1.00, −1.50, −2.00	8.95*	14.50	FS, prism
	Frequency 55 Toric	55	17	+6.00 to −8.00	−0.75, −1.25, −1.75, −2.25	8.40, 8.70	14.40	BS, prism
	Frequency Xcel Toric	55	17	+4.00 to −8.00	−0.75, −1.25, −1.75, −2.25	8.70	14.40	BS, prism
	Proclear Compatibles Toric	62	27	+4.00 to −6.00	−0.75, −1.25, −1.75	8.80	14.40	BS, prism
Johnson & Johnson	Acuvue Toric	58	28	+6.00 to −9.00	−0.75, −1.25, −1.75	8.70	14.40	BS, thin zones
Ocular Sciences	Biomedics Torics	55	19.6	+4.00 to −10.00	−0.75, −1.25, −1.75, −2.25	8.70	14.50	BS, prism

BS, back surface toric; FS, front surface toric.
*Equivalent radius.

Table 19.4 Examples of multifocal and bifocal disposable lenses

Manufacturer	Lens	Water content (%)	*Dk* (Fatt)	Power range (D)	Reading additions (D)	Radii (mm)	Diameter (mm)	Design
Bausch & Lomb	Multifocal	38	6.4	+6.00 to −10.00	Low to +1.50, high to 2.50	8.50, 8.80	14.50	CN
CIBA Vision	Focus Dailies Progressives	69	26	+5.00 to −6.00	Progressive up to +3.00	8.60	13.80	CN
CIBA Vision	Focus Progressives Monthly	55	16	+6.00 to −7.00	Progressive up to +3.00	8.60	14.00	CN
CooperVision	FSS Multifocal	55	17	+4.00 to −6.00	+1.50, +2.00, +2.50	8.70	14.40	CD/CN
Johnson & Johnson	Acuvue Bifocal	58	28	+6.00 to −9.00	+1.00, +1.50, +2.00, +2.50	8.50	14.20	CD
Nova	Lifestyle MV2	38	13	+4.00 to −5.00	Multifocal + enhanced monovision	8.50, 8.80	14.50	CN
Ocular Sciences	Rythmic UV Multifocal	73	45	+6.00 to −6.00	+0.75 to +2.00	8.60	14.20	CN
	Rythmic 2 UV Multifocal	73	45	+8.00 to −8.00	+2.00 to +3.00	8.6	14.20	CN

power range at approximately 14 mm or greater. The TD cannot therefore be used as a fitting variable, and disposable lenses are often too large for small corneas.

It is important to recognize when a satisfactory fitting cannot be achieved and to prescribe more than one type of disposable lens. In this way an improvement to the centration, fit or comfort can often be managed by changing from one brand to another. It is essential to avoid tight lenses if they are to be used for extended wear.

Disposables are generally fitted from a stock bank and it is a simple matter to supply patients with temporary lenses for an extended tolerance trial of a week or more. Where there is some doubt concerning the ideal fitting or water content, patients can be given either a mixed set of lenses or two different pairs and instructed to wear the more comfortable combination at the first aftercare examination.

19.5 Aftercare with disposable lenses

Lens handling

Many disposable lenses rely on a thin, flexible draping design in order to fit the widest cross-section of corneal curvatures.

Handling is often more difficult than with conventional lenses, particularly in low powers of less than −2.00 D. This applies even to experienced wearers of conventional lenses, who sometimes discontinue for this reason.

Practical advice

Where patients experience difficulty with handling, initially use disposables with high power for practice purposes. This makes insertion much easier and gives confidence to the patient.

Solutions

Except in cases of known allergy or sensitivity, the modern generation of multipurpose solutions (Section 27.4.1) is generally recommended for use with disposable lenses. Many solutions systems now include new cases, and monthly patients should be encouraged to replace the case at the same time as the lenses. Despite the simplicity of use of one-bottle systems, it is essential to stress the

importance of proper lens cleaning and disinfection. Patients often assume that disposability equals minimal lens care. Where patients use monthly disposables on an irregular basis they may not be prepared to change them every month. In these cases, the life of the lenses can be regulated according to the usage of a typical one-month bottle of soaking solution.

Aftercare

- Aftercare follows the normal principles described in Chapters 29 and 30 for both daily and extended wear.
- Careful observation is required where fittings may be marginal due to limitations in lens parameters.
- Intervals for routine aftercare visits are arranged to coincide with the dispensing of lens supplies, every 3 or 6 months.
- A full aftercare examination is required every 12 months.
- Aftercare visits represent a good opportunity to improve marginally successful fittings with newly introduced materials, parameters or a different make of lens.

19.6 Practice management

The main disadvantage of disposable lenses is the need for careful management of lens supplies.

- For patient simplicity, the replacement interval should be 1, whether this is 1 day, 1 week or 1 month.
- Where possible, supply lenses in units of 6 rather than 3 months. This means that administrative dealings with patients and laboratories occur twice instead of four times a year.
- Computer systems can be used to deal with automatic supplies from laboratories and to select patients from the practice database, but it is frequently difficult to ensure that dates coincide. There are, in fact, three time scales to correlate, determined by: (1) the laboratory, which may well work on only a 12-week quarter; (2) the practice, which should depend on the practitioner's recommendations to the patient; and (3) the patient, who may be accurate with lens usage, behind schedule by extending the lens life span, or ahead because of lens breakage or loss.
- Consider supplying lenses from a practice stock rather than relying on an inflexible laboratory computer system.
- Consider using standing orders or direct debits to control patient fees.

Practical advice

The three key pieces of information required for each patient are the mode of wear (daily or extended); the replacement interval (e.g. weekly or monthly); and the quantity of lenses to be supplied. These can be noted on the record card in the following simple fashion:

Daily/weekly/6 monthly
To indicate lenses worn daily, replaced weekly and supplied in units of 6 months.

Extended/monthly/3 monthly
To indicate extended wear lenses, replaced monthly and supplied in units of 3 months.

19.7 Other uses for disposable lenses

The low unit cost of disposables means that they have other very useful clinical applications apart from normal daily and extended wear.

As trial lenses, since most soft lenses are no longer reused (*see* Section 4.3).

- Low-cost temporary replacement in an emergency.
- Maintaining soft lens wear when CLIPC is causing rapid deposits.
- Short-term use in the hay fever season to avoid CLIPC.
- Periodic use for patients working with VDUs intensively but intermittently.
- To give a lengthy tolerance trial for contact lenses in general (e.g. can the patient cope with handling and disinfection?).
- To give an extended assessment of contact lens vision (e.g. can uncorrected astigmatism or monovision be tolerated?).
- To assess a patient's reaction to the lens material over several days in terms of dehydration and comfort prior to ordering in conventional lens form.
- Temporary lenses for patients undergoing orthokeratology (*see* Chapter 14).
- As a means of assessing children who require soft lenses.

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CHAPTER 20

Silicone hydrogels

Silicone hydrogel lenses were first introduced to the UK by Bausch & Lomb and CIBA Vision during 1999. They have the key advantage of extremely high oxygen permeability and were launched as the first of an entirely new generation of materials for 30 days extended or continuous wear. The physical properties of these two varieties are given in Table 20.1.

Table 20.1 Silicone hydrogel lenses

Proprietary name	PureVision	Night & Day
Manufacturer	Bausch & Lomb	CIBA Vision
Material name	Balafilcon A	Lotrafilcon A
Main constituents	*N*-vinyl pyrrolidone	*N,N*-dimethylacrylamide
	Tris-(trimethylsiloxysilyl) propylvinyl carbamate	Trimethylsiloxy silane
	N-carboxyvinyl ester	Siloxane macromer
	Poly[dimethysiloxyl] di[silybutanol] bis[vinyl carbamate]	
Water content (%)	36	24
Oxygen permeability (*Dk*) 10^{-11} (Fatt units)	99	140
Oxygen transmissibility (Dk/t) $\times 10^{-9}$	110	175
Surface treatment	Plasma oxidation	25 nm plasma coating
Modulus (g/mm^2)	110	120
Method of manufacture	Moulding	Moulding

Since their introduction, both lenses have proved to be very effective and much safer for extended wear with a significant reduction in serious adverse ocular responses. The advantages and disadvantages of silicone hydrogels are listed in Section 6.4 and for many patients they provide great advantages for purely daily wear.

Indications for silicone hydrogel lenses for daily wear

- To increase wearing time.
- For occasional overnight wear.
- For better comfort.
- Vascularization with existing lenses.
- To reduce conjunctival injection with existing lenses.
- For dry eye problems.
- For easier lens handling because of increased rigidity.
- To avoid lens breakage with clumsy patients.
- As bandage lenses.

Contraindications

- Where complex lenses are required (torics, bifocals).
- Patients predisposed to superior arcuate staining.
- Sensitive lids where patients have been able to tolerate only thin or high water content soft lenses.
- Additional costs.

20.1 Fitting

The range of available parameters is given in Table 20.2.

Table 20.2 Parameters available for silicone hydrogel lenses

	PureVision	Night & Day
Radius (mm)	8.60	8.60, 8.40
Diameter (mm)	14.00	13.80
Power (D)	−9.00 to +6.00	−10.00 to +6.00
Centre thickness at −3.00 D (mm)	0.09	0.08

Both makes have a back surface with a bicurve construction whilst Focus Night & Day has a tricurve front surface. Both varieties are available only as monthly disposables. Fitting and aftercare

considerations mainly relate to the greater modulus of rigidity for the materials combined with the very high oxygen permeability.

General fitting points

- Fitting characteristics should follow the principles outlined in Chapter 18 and are assessed with the slit lamp according to lens movement or push-up test.
- Mobility must remain sufficient to ensure an adequate exchange of tears behind the lens to allow the removal of debris.
- With extended wear, it is essential to recognize when lenses give unsatisfactory performance and discontinue.
- Both PureVision and Night & Day are usually very comfortable when the fitting is satisfactory.
- A small number of patients are unable to tolerate silicone hydrogels. Those who have adapted to very thin hydrogel lenses sometimes cannot support the extra rigidity and thickness, and patients with very sensitive lids may be intolerant of the surface treatments.

Radius

- With Night & Day, the 8.40 mm radius usually gives a better result unless it is obviously too tight, in which case 8.60 mm is fitted.
- PureVision currently has only the 8.60 mm lenses and no adjustment is possible.
- Both lenses fit a very wide range of corneal curvatures and successful results have been seen from 7.20 mm to 8.40 mm.
- The main cause of an unsatisfactory fitting is edge buckling. The lens is unable to conform to the corneal curvature because of its greater rigidity compared with hydrogels.
- Buckling usually occurs with steeper corneal radii and higher powers and is very uncomfortable.
- If buckling has not settled within about 15 minutes, success is unlikely.

Total diameter

- Both varieties have similar TDs which cannot be altered.
- It is important to recognize when lenses are too small with poor centration or too large and likely to give inadequate tears exchange.

Power

The rigidity of silicone hydrogels makes it less easy to correlate their powers with those of standard 'thin' hydrogel lenses. This is particularly true with plus powers. Trial lenses must be allowed to settle fully in order to assess the optimum result.

Practical advice

- In most cases, when one make proves uncomfortable for any reason, the other variety is unlikely to prove any more successful.
- Patients are usually comfortable within about 3 days. If they have not adapted by one week it is better to refit with a thin or high water content hydrogel lens.

20.2 Dispensing silicone hydrogels

Handling

- Handling considerations for silicone hydrogels also relate to their greater rigidity.
- Most patients find them much easier to handle than 'thin' or high water content hydrogels.
- Breakages are uncommon and lenses are rarely lost from the eye.
- If a lens is first placed on the sclera it is less easy to recentre.
- After initial insertion, however, trapped air bubbles from the solution are frequently observed. These tend not to resolve on their own and may cause dry spots or may be confused with mucin balls. They are best removed in the same way as a foreign body by sliding the lens onto the sclera and carefully recentring.

Wearing schedule

- Most patients can wear silicone hydrogels for several hours from the first day.
- Patients new to lenses can start at about 6 hours with 2-hour increments.
- Patients already adapted to lenses can attempt all-day wear immediately.
- Extended wear patients should first use lenses for daily wear for a few days. They should then be carefully assessed after one or two overnights.

- Most successful patients can manage 30 days of continuous wear without problems. Some, however, prefer to remove lenses on a more frequent basis, perhaps weekly or twice weekly with overnight disinfection.

Lens disinfection

- Lens disinfection can be carried out with most of the proprietary products.
- There is significantly less asymptomatic staining with polyquad based systems compared with those containing polyaminopropyl biguamide (PHMB).[1]
- Oxysept 1 Step has been reported to produce parameter changes with Purevision.
- To avoid wastage because solutions may pass their 'use by' date, unit dose vials are recommended for extended wear.

20.3 Aftercare

Aftercare considerations follow those given in Chapters 29 and 30. Although silicone hydrogels generally give much improved ocular response for extended wear, practitioners must still observe the cautions noted in Chapter 29. The uptake of standard fluorescein into the lenses is small because of their low water content. It should therefore be used at all aftercare visits, preferably in combination with some form of grading system. The peculiar physical characteristics of silicone hydrogels mean that some aspects of aftercare require particular attention.

Arcuate staining

Arcuate staining, close to the superior limbus (SEAL), is fairly common because of the shearing force of a particularly rigid material against the corneal surface. The patient may or may not be symptomatic. Staining is sometimes resolved simply by stopping lens wear for a few days. If this fails to work, the only other possibilities are to change the fitting, where feasible, or change the make of lens. Discontinuation may become necessary.

Microcysts

Microcysts have been a common problem in the past with extended wear. With silicone hydrogels, there is often an initial increase in their number as the cornea adapts to a much improved

physiological environment. Once they have migrated to the corneal surface and resolved, there is usually a marked reduction and subsequently they are rarely a problem. Microcysts exhibit reverse illumination and are small with diameters of 15–20 μm.

Mucin balls

A more recently recorded phenomenon is the mucin ball, sometimes termed a precorneal deposit or lipid plug.[2,3] They are commonly associated with silicone hydrogels because of their surface properties and lens rigidity although they were described with hard lens materials in 1994[2] and have been observed even with thin daily disposables. They tend to form in the superior half of the cornea, beneath the upper lid, and are the result of poor tears exchange beneath the lens failing to remove cell debris and other products of corneal metabolism. Mucin balls seem quite benign and most patients are completely asymptomatic requiring no action apart from routine observation. Mucin balls should be distinguishable from microcysts because:

- They have a grey translucent or opalescent appearance.
- They are larger in size (10–50 μm).
- They do not exhibit reverse illumination.
- They leave dimples in the corneal surface from which fluorescein can be washed out by irrigation.

Dryness

Most patients find silicone hydrogels very satisfactory in respect of dryness symptoms and they may well be the first choice in these cases. Sometimes, however, the lenses exacerbate the symptoms and patients are unable to tolerate them for either daily or overnight wear.

Acute red eye

Acute red eye reactions (CLARE, *see* Section 22.4.2) are seen in a minority of cases, sometimes where they were unknown with hydrogel lenses. Reactions can sometimes occur within a few days of fitting. If they recur, silicone hydrogel lenses should be discontinued.

Contact lens peripheral ulcers (*see* Section 30.1.1)

Contact lens peripheral ulcers, on the other hand, are not uncommon and are generally associated with continuous wear. They are

sometimes found with a red eye reaction but are frequently asymptomatic. Some patients seem predisposed to CLPUs and the practitioner must use careful judgement as to whether silicone hydrogel wear should be continued.

Microbial keratitis

Microbial keratitis has proven extremely rare with silicone hydrogels, supporting the view that most of the risk factors for extended wear relate to insufficient oxygen with earlier generations of materials.

Vascularization

Vascularization is most unlikely to occur because of the extremely high oxygen permeability. In some cases where patients have discontinued extended wear with lower *Dk* materials for this reason, 30 days of continuous wear has proved perfectly feasible with blood vessels 'ghosting' within a few weeks.

Papillary conjunctivitis

CLIPC is occasionally seen. Papillae may be atypically dome shaped and close to the lid margin. With extended wear, patients may notice a reduction in vision because of deposits on the lens surface.

Lens deposits

Because of the surface treatment, silicone hydrogels are relatively unaffected by white spots and other deposits although lipid formation is sometimes encountered. Deposits are rarely a serious problem since lenses should be replaced on a regular monthly basis.

Lens power

Where extended wear lenses have been worn with earlier generations of relatively low *Dk* materials, there may well be a reduction in myopia between 0.25 D and 0.50 D after one or two weeks. The lens prescription therefore needs careful verification at aftercare check-ups.

General advice

- As with all extended or continuous wear, the importance of aftercare must be stressed to all patients.
- Patients should therefore be discouraged from obtaining lenses from postal or internet sources because they may be seen less frequently for aftercare examinations.

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CHAPTER 21

Soft lens specification and verification

21.1 International Standards and tolerances[1]

Soft lens specification is currently based on BS EN ISO 8321-2:2000 (BS 7208-24:2000) Ophthalmic optics – Specifications for materials, optical and dimensional properties of contact lenses – Part 2: Single-vision hydrogel contact lenses.

21.2 Soft lens specification (Tables 21.1, 21.2)

A typical soft lens specification takes the following abbreviated form:

8.70:14.50 −3.00 HEMA 38% water content

where: 8.70 = back optic zone radius (BOZR)
14.50 = total diameter (TD)
−3.00 = BVP

The majority of lenses are made according to predetermined laboratory designs and it is neither necessary nor feasible to specify parameters such as thickness, lenticulation and peripheral curves.

Table 21.1 Recommended tolerances for soft lenses

BOZR	±0.20 mm
Total diameter	±0.20 mm
Central optic zone diameter	±0.20 mm
Sag at specified diameter	±0.05 mm
Thickness	
≤0.10 mm	±0.01 mm + 10%
>0.10 mm	±0.015 mm + 5%
BVP in weaker meridian	
Plano to ±10.00 D	±0.25 D
±10.00 D to ±20.00 D	±0.50 D
Over ±20.00 D	±1.00 D
Cylinder power	
Plano to 2.00 D	±0.25 D
2.25 D to 4.00 D	±0.37 D
Over 4.00 D	±0.50 D
Cylinder axis	±5°

Table 21.2 Material property tolerances

Dimension	Tolerance
Refractive index	±0.005
Water content	±2%
Oxygen permeability	±20% (of nominal *Dk*)

21.3 Soft lens verification

Soft lenses require verification for the same reasons as hard (*see* Section 12.3), although checking is considerably more difficult because parameters vary with:

- Degree of hydration.
- Temperature.
- pH and tonicity of storage solution.
- Nature of the storage solution.
- Time taken if measurement is in air.
- Method of supporting lens.

21.3.1 Back optic zone radius

Spherometers

Many common methods of radius checking rely on the principle of spherometry, where the sagittal depth is measured for a given

chord diameter. The majority of instruments employ a wet cell, but this is not essential.

Wet cell instruments (e.g. Optimec)

- The lens is rinsed and placed in a wet cell containing 0.9% saline solution.
- The lens is centred on a support device.
- A probe is advanced towards the concave surface until it just touches (established by viewing lens movement or electric contact) and the radius is read from the instrument scale.

Measurement in air (e.g. Zeiss spherometer)

- The lens is rinsed in saline; surplus fluid is removed by shaking and rapid superficial drying.
- The lens is centred on a 10 mm support ring, concave side down.
- The central probe is observed from above through a magnifying lens until the first point of contact is made and the radius is read from instrument scale.

Other methods

Base curve comparator

A simple device consisting of a series of spheres of known radius on which the contact lens is placed and compared by straightforward observation in air.

A much more sophisticated wet cell instrument by Söhnges allowed the profile of the lens to be matched with known radii on a projection screen.

Keratometer

This can be used in conjunction with a wet cell.[2] Measured radius, however, requires conversion to actual radius and observation is difficult because the light intensity is considerably reduced.[3]

21.3.2 Total diameter

Projection magnifiers

An optical system projects a magnified image of the lens on to a calibrated screen. Instruments may use a wet cell (e.g. Optimec) or support the lens in air on a microscope stage (e.g. Zeiss DL2).

Comparison

Comparators consisting of a series of annuli of known diameter can be used as a rapid in-air method.

21.3.3 Power

The most accurate method of measuring power is by power profile mapping (*see* Chapter 12). This is generally only employed by manufacturers because of the very high cost of the instrumentation. The most usual methods used by practitioners are as follows:

Air measurement

- Rinse the lens with saline.
- Shake off surplus fluid and dry carefully with a lint-free tissue.
- Place lens concave surface down on a reduced aperture focimeter stop.
- Read power directly from focimeter scale.

Wet cell measurement

- Place lens in wet cell.
- Mount on focimeter.
- Read power from focimeter scale.
- Convert to approximate power in air by multiplying by 4.[4]

Practical advice

- Power is more easily and more accurately measured in air.
- Any error in wet cell measurement is magnified fourfold (an error of 0.25 D ≡ 1.00 D in air).
- Power in air is reasonably constant for up to about 1 minute.
- Best results are obtained with a projection focimeter.

21.3.4 Thickness

Projection magnifiers

The easiest method of measuring thickness is by means of a millimetre scale calibrated for the screen of a projection magnifier (e.g. Optimec).

Drysdale's method

A hard lens radiuscope can be used to determine lens thickness:[5]

- Place the lens, concave surface down, on a convex sphere (this should have a curvature steeper than the lens to be measured to ensure contact at the centre).
- Focus the target on the surface of the sphere with the lens in place.
- Set the scale to zero.
- Focus the target on the front surface of the lens.
- Read the distance travelled from the scale.
- Multiply by the refractive index of the material to give the actual centre thickness.

21.3.5 Edge form

Edge form and integrity are best observed with projection magnification, but a hand loupe or the slit lamp can also be used.

21.3.6 Surface quality

Surface quality is assessed with the slit lamp or by means of projection magnification. Observation with a wet cell is more difficult because the small difference in the refractive index of the solution largely disguises any surface flaws or cracks.

21.3.7 Water content and material

Water content can be estimated with a refractometer because of its inverse relationship with refractive index. An instrument developed for contact lens measurement is the Atago CL-1 refractometer.[6]

- Rinse the hydrated lens with saline, shake off surplus moisture and blot with a lint-free tissue.
- Flatten lens against prism face, taking care not to cause damage.
- Use an external light source and read directly from the internal scale the water content at the junction between light and dark areas.

Assessing the lens material from the water content alone is far from certain, so identification may depend upon other clues such as style of engraving (*see* Section 26.1), handling tint or type of edge bevel.

Practical advice

- The easiest methods for practitioner verification are:

BOZR	Wet cell spherometer
DIAMETER	Projection magnifier
POWER	Focimeter in air
THICKNESS	Projection magnifier
CONDITION	Projection magnifier.

- The most useful instrument, which is ideally kept in the consulting room, is a projection magnifier. It is not only used for lens inspection, but also for demonstrating to the patient surface and edge flaws and deposits.
- Wet cells are a source of possible cross-infection and require regular cleaning and disinfection.
- Particular care is required when flattening high water content lenses against a glass surface (e.g. microscope stage or refractometer) because of the difficulty of removal and the risk of damage.

21.3.8 Deposits

Projection magnifiers reveal discrete areas of deposit such as white spots. Films such as protein are more easily observed by looking into the wet cell without magnification. The best method of observing deposits, however, is by dark-field illumination.[7]

High magnification can be achieved with the slit lamp by using an oblique beam and selecting a dark background. In addition, some lens deposits fluoresce with ultraviolet light.

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CHAPTER 22

Extended wear

Soft lenses have been routinely fitted for extended wear since the early 1970s with the introduction of Permalens and Sauflon PW. Improvements have since occurred not only in lens design and materials but also in understanding the physiological requirements of the cornea necessary to achieve extended wear with relative safety. More recently, high *Dk* hard lenses have been used but the introduction of silicone hydrogels in 1999 has revolutionized the concept of extended wear in practice and made them the first choice for most patients who desire overnight use.

22.1 Physiological requirements

22.1.1 Oxygen requirements of the cornea

For any lens to be successful for extended wear it must satisfy the physiological requirements of the cornea under closed eye conditions. The main effect is a reduction in the available atmospheric oxygen from 155 mmHg to the 55 mmHg derived from the palpebral conjunctival capillaries. In addition, the cornea's demand for oxygen increases along with an increase in lens temperature and

an acidic shift in the pH of the tears. The consequence of these changes in a normal eye not wearing a contact lens is overnight corneal swelling of about 4%. The effect of most contact lenses is to increase this swelling still further.

Limiting any hypoxic effect on the cornea is essential for successful long-term wear of any contact lens. In practical terms for extended wear, the following physiological requirements must be met:[1] (using Fatt units)

First day of extended wear Dk/t for zero swelling $= 24 \times 10^{-9}$
Second day of extended wear Dk/t for zero swelling $= 34 \times 10^{-9}$
For overnight swelling of only 4%, Dk/t $= 87 \times 10^{-9}$

None of the previous generation of hydrogel lenses is able to fulfil these critera, since the theoretically optimum Dk is approximately 40×10^{-11}, limited by the water content of the polymer. Extended wear with these materials, therefore, almost always risks compromising corneal health and should only be undertaken with extreme caution.

New silicone hydrogel polymers have very high transmissibility and effectively overcome the problem of corneal swelling. Examples are Bausch & Lomb's PureVision (balafilcon A, $Dk/t = 110 \times 10^{-9}$) and CIBA Vision's Night & Day (lotrafilcon A, $Dk/t = 175 \times 10^{-9}$). (*See* Chapter 20.)

Modern hard lens materials can also provide four or five times the permeability of current high water content hydrogel lenses before taking into account any tears pump effect. Lenses with a Dk in the region of 100 provide approximately 15% EOP. The tears pump adds about 2% oxygen to give a total EOP of 17% for open eye conditions and 4% for closed eye conditions. This is sufficient to avoid epithelial compromise in extended wear for most patients.[2] A Dk in the region of 150–200 provides an even better physiological performance.

22.1.2 *Effects of insufficient oxygen*

Extended wear causes chronic cumulative hypoxia to a much greater extent than daily wear because of continuous eye closure during sleep, with sometimes inadequate time for corneal deswelling during the day. Between 10% and 15% oxygen is needed to avoid oedema and measurable corneal changes.[3]

- Epithelial changes include decreased glycolysis,[4] decreased mitosis,[5] decreased cell adhesion[6] and reduced sensitivity.[7]

- The stroma shows oedema which eventually leads to stromal thinning.[4]
- Endothelial cells show distinct polymegathous changes similar to those seen in the *corneal exhaustion syndrome*.[4]

22.1.3 Tears exchange and osmolarity

There is a normal increase in corneal thickness overnight, mainly due to a change in tear osmolarity causing swelling. This rapidly disappears on eye opening. Soft lens materials may become tighter with these changes and lens adhesion may be found in the morning. Lenses usually start moving after a few blinks and this movement is very important to allow tears exchange to eliminate overnight debris from beneath the lens. This might otherwise cause a toxic effect which, when combined with lens adhesion, could precipitate an *acute red eye* response[8] (*see* Section 30.1.1).

22.1.4 Physical and chemical compatibility of lens materials

The physical aspects of materials must be considered to avoid mechanical trauma from friction or surface hardness. Weight distribution is similarly important. Materials should be chemically inert to avoid surface deposits that could irritate the ocular tissues.

22.2 Approaches to extended wear

On a practical level, extended wear lenses can be divided into three possible groups:

Flexible wear (daily plus)

Many patients requesting extended wear are prepared to accept lenses that they can use safely on an occasional overnight basis, remaining happy to remove them most evenings. This type of lens wear gives maximum flexibility and safety. On a day-to-day basis, they are taking advantage of the excellent physiological properties of either high *Dk* hard or high water content soft lenses, while at the same time incurring very little risk of adverse ocular response to occasional overnight use.

Extended wear (up to 1 month)

A maximum of 6 nights' wear followed by 1 night's rest gives a realistic schedule for many patients. Proper lens cleaning and disinfection are maintained by regular removal, and a consistent weekly routine is developed. Disposable lenses such as Acuvue fit well into such a regimen.

Silicone hydrogels have proven much safer for extended wear on a monthly disposable basis although some patients prefer to remove them more frequently.

Continuous wear (over 1 month)

Over 1 month may be regarded as continuous wear or long-term extended wear. It is suitable or even essential for many medical cases, poor lens handlers or for some vocational uses and silicone and hydrogels are now the preferred choice. For most normal eyes with traditional hydrogel lenses, wearing schedules beyond 1 week put additional stress on the cornea and must be used with great caution. Most patients in fact seem to develop a 'sixth sense' of when lenses need removal. In the past, a minority using conventional lenses encountered fewer problems with handling, breakage, solutions and infections by leaving them in the eyes for several months.

22.3 Patient selection

22.3.1 Indications and contraindications

Indications

The majority of extended wear lenses are fitted at the patient's request for purely cosmetic reasons. With proper supervision both disposable and conventional hydrogels can work well, but there is always the possibility of serious problems such as infections, oedema or vascularization (*see* Section 22.7). Even silicone hydrogels require great care not only by the practitioner but also by the patient, who must be made aware of potential hazards. The clinical needs must therefore be carefully balanced against the possible risks.

There are, however, many patients for whom extended wear is the most suitable, if not the only possible, form of visual correction:

- Aphakics, where handling and visual difficulties preclude daily wear.
- Other poor lens handlers.

- Therapeutic cases (*see* Section 32.10).
- Young children where daily handling is not feasible (*see* Section 31.1).
- Vocations where good vision is required immediately on wakening.
- Where all soft lens disinfection systems create problems and daily disposables are not feasible.
- Where soft lens patients have no facility for lens disinfection.
- As the rear component of a low vision aid system and handling is impossible.

Contraindications

- Patients known to be predisposed to corneal oedema.
- Existing corneal vascularization.
- CLIPC.
- Patients unlikely to follow practitioner advice.
- Patients unable to remove lenses.
- Diabetics, where the corneal epithelium is likely to be more fragile.
- Smokers.
- Where financial constraints may preclude aftercare and regular lens replacement.
- Where patients are known to be a long way from optometric or medical help in the event of a severe ocular emergency.

22.3.2 Advantages of soft and hard lenses in extended wear

Advantages of soft lenses

- More comfortable.
- Easier adaptation.
- Easier to fit.
- High *Dk*s with silicone hydrogels.
- No problems with foreign bodies.
- No 3 and 9 o'clock staining.

Advantages of hard lenses

- Very high *Dk*s possible.
- Tear pump on blinking.
- Avoidance of trapped debris.

- Reduced risk of infection.
- Better vision.
- Fewer corneal changes.
- Lenses do not cover the entire cornea.
- No lens dehydration.
- Fewer deposit problems.
- Easier lens maintenance.
- No solutions sensitivity.
- Longer life span.

Despite the numerous advantages of hard gas-permeable lenses, they are still fitted in only a minority of cases for extended wear because they are perceived by the patient as more difficult to wear, are more difficult to fit and give greater problems with foreign bodies.

22.4 Soft lens fitting and problems

22.4.1 Fitting

The main consideration is to provide the maximum possible oxygen supply to the cornea. Before the advent of silicone hydrogels this was achieved in one of two ways:

- By means of high water content (e.g. Precision UV, 74%). Lenses had reasonably high *Dk* values, but the potential problems were lens fragility, deposits and discolouration, and greater likelihood of solutions reaction.
- By making medium or low water content lenses extremely thin (e.g. Acuvue, 58%; Bausch & Lomb O Series, 38%; CSI-Clarity-T, 38%). These relied on good *Dk/t* values but could give problems with handling. Hyperthin lenses also give poor tears exchange on blinking.

Current fitting considerations therefore include the following:

- Patients new to extended wear should be fitted with silicone hydrogels as a first choice.
- Large refractive errors (both plus and minus) beyond the range of silicone hydrogels are better fitted with high water content lenses because of average thickness factors.
- Lenses should be as flat as possible consistent with stability of fitting and vision. The exception is the lathed Permalens, which is fitted steeper than 'K'.

- Lenses become tighter with wear, particularly overnight because of dehydration.
- Lenses become tighter with age and deposits (*see* Section 30.5).
- Examination during fitting and aftercare must be carried out with the slit lamp, otherwise small degrees of movement cannot be seen.
- Movement should ideally be about 0.50 mm, with a minimum value of 0.25 mm. This ensures proper tears exchange to remove debris from beneath the lens on blinking. It is not always possible with ultrathin lenses because of the way they drape the cornea.
- Some thicker lenses such as aphakics can cause dimpling.

Practical advice

It is generally correct to refit silicone hydrogels to existing patients with extended wear. Some, however, will be unable to tolerate the additional stiffness and thickness. If lenses have not settled within about 3 days, return to the original lens type.

22.4.2 Problems

Lens dehydration and corneal desiccation

Lens dehydration and corneal desiccation can occur with both high water content and ultrathin low water content lenses. It is usually but not invariably better with silicone hydrogels. The typical result is punctate staining in the mid-periphery of the cornea in the exposed area of the palpebral aperture. With the more rigid materials it can be associated with superior arcuate staining. Silicone hydrogels are particularly liable to cause this problem because of their greater stiffness (*see* SEALs, Chapter 29).

Where there is no obvious fault with the fitting, it is usually necessary to change to another make of lens with different dehydration characteristics.[9,10]

Contact lens acute red eye (CLARE)

The sudden, acute red eye is a serious and unpredictable complication of soft extended wear giving gross conjunctival hyperaemia. It normally occurs on wakening and is usually unilateral, associated with varying degrees of pain, photophobia, lacrimation and small limbal infiltrates. The likeliest causes are an inflammatory

response to trapped debris and toxins beneath the lens[8,11] and to deposits on the lens surface. With conventional hydrogel lenses the incidence was higher with heat disinfection and was reduced with peroxide systems.[12]

If an acute red eye reaction should occur, the courses of action are:

- Remove lenses.
- Ensure patient attends for immediate examination.
- Consider referral.
- Wait several days for the condition to resolve.
- Change to new lenses.
- Consider refitting a different type of lens.
- Ensure a peroxide disinfection system is used for conventional hydrogels.
- Consider changing to daily wear – essential if the red eye recurs.

Infections

Infections with extended wear lenses tend to be more severe and longer lasting than with daily wear lenses. Immediate removal of lenses and referral for medical treatment is absolutely essential for microbial keratitis to minimize the risk of permanent visual loss (*see* Section 30.1). Other actions are as above for red eye.

The risks of infection are reduced with:

- Silicone hydrogels.
- Frequent lens replacement.
- Maximum oxygen supply to the cornea.
- Proper lens mobility.
- Proper lens cleaning and maintenance by the patient.
- Hygienic lens handling by the patient.
- Frequent replacement of lens cases.
- Using tight-fitting goggles for swimming.

Inflammatory response and corneal infiltrates

Corneal infiltrates as an inflammatory response are seen fairly commonly in extended wear, even with silicone hydrogels[13,14] (*see* Section 30.1). They may be either symptomatic (CLPU, IK) or asymptomatic (AIK, AI) and discovered only at a routine aftercare examination. Where there are other signs or the patient experiences symptoms the practitioner must be absolutely certain that a sterile infiltrate is not actually microbial keratitis. If in doubt, the

patient should be referred for a medical opinion. Further actions are as above for an acute red eye.

Contact lens induced papillary conjunctivitis (CLIPC)

The main causes of CLIPC with soft extended wear lenses are deposits and allergic responses during the hay fever season. It still occurs with silicone hydrogels, probably due to mechanical irritation by a more rigid material. The incidence is higher with low water content lenses, or where heat disinfection is used with high water content lenses.[12] The courses of action are given in Section 29.3.5.

Oedema

Stromal oedema, virtually never seen with silicone hydrogels, is the cornea's response to insufficient oxygen under closed eye conditions (*see* Section 29.3.2) and may show in a variety of ways:

- Single stria, indicating 5–6% swelling.
- Several striae, indicating 7–10% swelling.
- Stromal folds, indicating 10–12% swelling.
- Epithelial microcysts.
- Subjective symptoms of cloudy vision.

Epithelial microcysts

Microcysts contain fluid and cellular debris, appearing as small vesicles in the corneal epithelium with diameters of 15–20 μm. They are seen with high magnification on the slit lamp and exhibit reverse illumination. They are an indication of hypoxic corneal stress, although small numbers may be considered sufficiently normal to ignore in the absence of other signs. They are generally seen after 2–3 months of extended wear, but can occur sooner.[15] They can also take several weeks to resolve.

Mucin balls

Mucin balls (pre-corneal deposits or lipid plugs) are usually associated with silicone hydrogels but can be seen with other lenses (*see* Chapter 20). They are translucent grey or opalescent in appearance and consist of cell debris and other products of corneal metabolism. There is no reverse illumination and diameters are 10–50 μm. Mucin balls are benign, most patients being completely

asymptomatic. They should, however, be distinguished from microcysts and simple dimpling with air bubbles.

Vascularization

Vascularization, practically unknown with silicone hydrogels, is a longer-term response of both daily and extended soft lens wear. Vessels may be either superficial, extending from the limbal arcades, or deeper, stromal neovascularization where there is a much greater risk that they may extend into the pupil area. The first action to consider is refitting with silicone hydrogels but it may be necessary to change from extended to daily wear, from soft to hard lenses, or even (in severe cases) to cease contact lens wear altogether.[16]

Deposits

Because lenses are not removed for cleaning, there is a general predisposition to deposits (*see* Section 30.5). These are largely avoided with disposables but are kept to a minimum with conventional lenses by peroxide and enzyme cleaning.

Breakage and loss

With the exception of silicone hydrogels, most lenses for extended wear are extremely fragile because of thinness or high water content. This is generally acceptable where handling is infrequent, but causes difficulty with more flexible wearing schedules. Loss is not a great problem, although some of the smaller, thinner lenses are occasionally rubbed out of the eye during sleep.

22.5 Hard gas-permeable fitting and problems

There are now several high *Dk* gas-permeable materials available for extended wear. These include the Bausch & Lomb Quantum 2, Menicon Z-alpha and Fluoroperm 151.

22.5.1 Fitting

The main considerations are:

- Sufficient oxygen with a high *Dk* material.
- Adequate edge lift to avoid lens adhesion.

- Avoiding excessive edge lift and 3 and 9 o'clock staining.
- Good centration, particularly avoiding low-riding lenses because of the risk of adhesion.
- Sufficient lens movement to provide a good tears pump.
- Avoiding lenses that ride on to or over the limbus.

22.5.2 Problems

Overall, there are fewer problems with hard lenses for extended wear. They do not cover the entire cornea, give a regular tears pump and are easier to remove and clean. By their nature, they avoid absorption, solutions reaction, red eye and vascularization. However, other difficulties can occur, as indicated below.

3 and 9 o'clock staining

Staining at 3 and 9 o'clock is the hard lens equivalent of soft lens dehydration. It rarely causes discomfort but, because patients continue to wear lenses, its effect may become cumulative with unacceptable conjunctival injection (*see* Section 29.3.2 for possible remedies).

Infections

Infection with hard lenses is infrequent. Care, however, is required where lens adhesion occurs because of the possibility of corneal ulceration.[17,18]

Contact lens induced papillary conjunctivitis

CLIPC can occur with silicon acrylates because of deposits, allergic response or mechanical irritation. It is less common with fluoropolymers.

Oedema

Microcysts and striae occur where materials with insufficient *Dk* have been used.[1]

Vascularization

Vascularization occasionally occurs in the horizontal meridian associated with prolonged 3 and 9 o'clock staining.

Breakage and loss

Breakage occurs with some of the more brittle high *Dk* materials and where lenses have crazed or otherwise deteriorated with time. Loss is no worse than with daily wear.

Lens adhesion (binding)

Most studies report lens adhesion to the cornea in a minimum of 10% of patients immediately on wakening.[17,18] Adhesion relates to lens design, material, lid pressure and changes in tear constituents[18] (*see* Section 29.3.6).

22.6 Other lenses for extended wear

22.6.1 Silicone lenses

Silicone lenses (*see* Section 6.6) have extremely high *Dk*s and are occasionally used for extended wear. One of their main applications is with babies to avoid the loss and damage that occur with soft lenses (*see* Section 31.4.1).

22.7 Long-term consequences of extended wear

Metabolic activity

Reduced oxygen supply to the epithelium reduces metabolic rate and therefore cell mitosis. Since the epithelium would not remain intact with decreased cell production and a constant rate of cell death and removal at the anterior epithelial surface, some compensation must occur.

Infection and inflammatory response

The chances of infection, including microbial keratitis and contact lens peripheral ulcers (sterile infiltrates), are significantly greater if the cells at the anterior epithelial surface become functionally less resistant as a result of long-term extended wear[19,20] (*see* Chapter 30).

Corneal thinning

Epithelial thinning occurs as cell production and wastage rates reach a new equilibrium. Stromal thinning results from long-term chronic oedema.[4]

Endothelial polymegathism

Polymegathism is an irregularity in the cell size of the corneal endothelium caused by a lowering of pH[21] due to increased lactic acid (resulting from lens induced hypoxia)[22] and/or increased carbonic acid (resulting from lens induced hypercapnia). There does not seem to be a change in cell density, but a size increase of 27% has been reported.[4] The chances of complications with surgery or trauma are reported to be significantly greater after extended wear.[23]

Vascularization

The extension of limbal blood vessels into the cornea is a serious indication of chronic hypoxia. The vessels may extend from any position around the limbus, but tend to be further advanced beneath the top lid. Any increase should be monitored, and if the vessels grow more than 2 mm into the cornea, extended wear should be discontinued.

Neovascularization

New vessel growth at a deep stromal level is an unacceptable response to corneal stress caused by hypoxia, limbal compression, tissue damage or an acute infection. If it is allowed to continue and encroach within the pupil area, vision may be reduced as the surrounding tissue is changed by a lipid keratopathy.

Practical advice

To minimize the risk of potential problems, both short- and long-term patients should:

- Wear lenses with maximal oxygen transmissibility.
- Return for regular aftercare visits, not only during the fitting stage but for as long as extended wear continues.
- Replace lenses on a regular basis. Conventional varieties should have a maximum life span of 12 months but preferably much less.
- Use peroxide and enzyme systems with conventional lenses.
- Receive written instructions.
- Remove lenses in case of illness, especially with upper respiratory tract infections.
- Receive advice that they *must* remove lenses if they suffer red eyes, discomfort, reduced vision, persistent lacrimation, other abnormal symptoms.
- Know where 24-hour emergency help is available in case of severe infection.

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CHAPTER 23

Toric hard lenses

Toric hard lenses are used either to improve on the fitting of a spherical lens or to give better visual acuity with an astigmatic eye.

23.1 Residual and induced astigmatism

Residual astigmatism

Residual astigmatism is the uncorrected astigmatism found by refraction when a spherical contact lens is placed on the cornea. It derives from the crystalline lens and is usually against-the-rule. It is predictable where the spectacle cylinder and 'K' readings do not correlate. The corneal astigmatism is neutralized by a spherical hard lens, leaving the lenticular astigmatism uncorrected.

Residual astigmatism = ocular astigmatism − corneal astigmatism

Example 1:

Spectacle *Rx*: $-3.00/-1.50 \times 95$ 'K' 7.90 mm × 7.85 mm
Corneal astigmatism = 0.05 mm ≡ 0.25 D
Residual astigmatism = 1.25 D

Example 2:

Spectacle *Rx*: $-2.00/-1.00 \times 180$ 'K' 7.60 mm (along 180)
7.80 mm (along 90)
Corneal astigmatism = 0.20 mm ≡ 1.00 D
Residual astigmatism = 2.00 D

Induced astigmatism

The liquid lens beneath a hard contact lens neutralizes nine-tenths of the anterior corneal astigmatism because of the difference in refractive indices.[1] Induced astigmatism is created when a toric back surface is placed on a toric cornea and is against-the-rule if the corneal and spectacle astigmatism is with-the-rule. It is a characteristic of the lens because of the different refractive indices of the lens material and the tears. Modern hard gas-permeable materials tend to give less induced astigmatism than PMMA, which has a higher refractive index.

Ocular refraction

The ocular refraction at the surface of the eye is obtained from the dioptric power of the spectacle refraction by compensating for the measured back vertex distance (BVD) in mm. The ocular refraction is required when the spectacle powers are greater than ±5.00 D in either principal meridian. It always has a value that is less minus or more plus than the spectacle prescription.

23.2 Patient selection

23.2.1 Indications and contraindications

Indications

To improve the physical fit

- The difference between principal meridians is greater than 0.60 mm.
- A spherical lens is unstable.

- A spherical lens decentres, usually along the steeper meridian.
- A spherical lens gives unacceptable bearing areas due to the corneal toricity.
- The bearing areas minimize tears exchange which may give rise to mid-peripheral corneal staining along the flatter meridian.
- A spherical lens produces corneal moulding and unacceptable spectacle blur.
- The cornea becomes significantly more toric towards the periphery.
- Poor comfort with a spherical lens due to rocking.

To give optimal visual acuity

- Residual astigmatism is greater than about 1.00 D.
- Lens flexure due to a steeply fitting spherical lens.
- Induced astigmatism.

Contraindications

- Where a spherical lens gives a satisfactory result.
- Sensitive eyes where increased thickness causes discomfort or reduces transmissibility to an unacceptable level.
- Critical visual needs where acuity may be unstable.
- With a toric cornea but spherical spectacle *Rx*; a thin spherical soft lens should be the first choice (*see* Section 5.4).
- The greater expense of toric lenses.
- A toric lens is unnecessary with an amblyopic eye.

23.3 Lens designs

There are several possible designs for the correction of astigmatism, of which not all are toroidal.

23.3.1 Non-toric lens forms

Small spherical lenses

Lenses with very small TDs are often successful. They fit only the central area of the cornea, which may be more spherical than the periphery. Fitting sets with narrow axial edge lift (typically 0.10 mm) are used to avoid excessive edge clearance or stand-off in the steeper meridian.

Practical advice

- Lenses may sometimes be as small as 7.50 mm.
- Centration is important to avoid flare.
- Use a centre thickness in the region of 0.12 mm.

Aspheric lenses

Most aspheric designs also have narrow edge lift and give reduced clearance along the steeper meridian. In some cases they can mask up to about 4.00 D of astigmatism. They are usually fitted in alignment or flatter to avoid flexure.

23.3.2 Toric lenses

Front surface toric

A spherical back surface with a front surface cylinder to correct *residual astigmatism*. Stabilization is necessary to maintain the correct cylinder axis.

Toric periphery

A spherical BOZR with toric back peripheral radii. Used to give stability and to fit corneas where peripheral toricity is significantly greater than central. The front surface is usually spherical.

Back surface toric

Both central and peripheral radii are toric with a spherical front surface. The final peripheral radius is sometimes spherical for ease of manufacture and to assist tear flow. Stabilization is unnecessary since the lens radii should correctly follow the principal meridians of the cornea. The fluorescein appearance should be identical to that of a spherical lens on a spherical eye.

Bitoric

Both central and peripheral back surface radii are toric, combined with a front surface cylinder to correct induced astigmatism. Stabilization is sometimes needed for correct orientation of the cylinder axis because its position is important.

23.4 Methods of stabilization

Prism ballast

Prism ballast usually employs 1.5$^{\Delta}$ (with an upper limit of about 3.0$^{\Delta}$). The weight differential between the top and bottom of the lens should cause it to orientate with the prism base downwards. It is usually marked to assist observation. There is a tendency for a 5–10° nasal rotation of the prism base on blinking due to lid tension and eyelid position.

Truncation

Truncation may be used either on its own or in conjunction with prism ballast and can be single or double. A chord of 0.50–1.00 mm is removed from the lens edge and the optimal effect is achieved when the truncation sits on the lower lid. It is therefore ineffective with small diameters and if the lower lid is below the limbus. To assist stability, compared with the optimal diagnostic lens diameter, the TD should be increased by 0.50 mm for single truncation and 1.00 mm for double.

23.5 Fitting front surface torics

Method 1

- Use a large spherical diagnostic lens with power as near as possible to the final *Rx* and over-refract.
- Order a lens based on this power, usually with 1.5$^{\Delta}$.
- Always have the prism base marked so that the lens orientation can be measured on the eye.
- Over-refract and record the cylinder and axis.
- Note the orientation of the prism base.
- If the lens is unstable, consider a truncation of 0.50 mm, increasing the prism, or a larger TD.
- Order the front cylinder, taking into account any rotation of the lens.
- The cylinder can be worked on the initial lens if no other changes are needed.

Method 2

- Over-refract with a spherical diagnostic lens and order the final prescription lens directly with the front surface cylinder.

- This procedure is quicker, but an estimate of the final lens rotation is required (usually 5–15° nasal).

Example:

Spectacle *Rx*:	$-2.75/-1.50 \times 80$
'K' readings:	7.55 along 80, 7.45 along 170
Lens order:	L. C3 7.55:7.50/9.50 AEL 0.12 *Dk* 60
	$-2.75/-1.00 \times 75$ 1.5^{Δ} base down (along 270)
	Single truncation: 0.50 mm along 180
	Mark dots at prism base and apex

Practical advice

- If only one eye requires a toric, there may be problems with tolerance.
- Use truncation if there is a problem with binocular vision because of prism in only one eye.

23.6 Fitting toric peripheries

- Fitted when the cornea is more astigmatic in the periphery and a small lens design fails to work.
- Normally used when the corneal astigmatism is 2.00–3.00 D.
- With a spherical diagnostic set, the fitting should be assessed for central alignment and correct peripheral clearance in the flatter meridian.
- The radius for the steeper peripheral meridian can be determined either from the 'K' readings and looking up axial edge lift tables for each meridian, or from the fluorescein pattern. A minimum toric difference of 0.60 mm is usually required.
- The secondary curves are approximately 0.80–1.20 mm flatter.
- All toric periphery lenses with a spherical BOZR give an oval optic with the smallest diameter along the flattest meridian.
- If there are manufacturing problems with the theoretically designed periphery, an additional spherical edge curve can be used.
- A toric periphery diagnostic set can be used for fitting.
- The prescription lens should give good acuity since the liquid lens neutralizes corneal astigmatism.
- A toric periphery is less expensive than a fully toroidal back surface design but represents a compromise.

Example:

'K' 7.90 mm × 7.50 mm
C3 7.90:7.00/8.90:8.20/11.30:9.00
8.30 10.70
C3 7.90:7.00/8.90:8.20/10.75:9.00
8.30

23.7 Fitting back surface torics

23.7.1 Toric fitting set

- A diagnostic lens is selected to have the flatter meridian the same as flattest 'K' and the steeper meridian 0.10 mm flatter than the steepest 'K'. The meridians are therefore not exactly matched (e.g. 'K' 8.00 × 7.40; BOZR 8.00 × 7.50).
- The ideal fluorescein pattern should look the same as an alignment spherical fit.
- Over-refraction should be carried out with minus cylinders. The spherical component is the power along the flatter meridian.
- The laboratory will produce the cylinder along the steeper meridian.
- The possibility of induced astigmatism must always be considered.

23.7.2 Spherical fitting set

- A spherical lens is fitted in alignment to establish the flatter meridian.
- The steeper radius is determined from the 'K' readings.
- The spherical power is determined by over-refraction with minus cylinders.
- The cylinder is obtained by calculation.

Example:

Ocular refraction: $-2.00/-3.00 \times 180$
Keratometry: 8.00 mm along 180, 7.45 mm along 90
The astigmatism is entirely corneal
Diagnostic lens BOZR giving alignment along 180 = 8.00 mm

By fluorescein assessment toric lens needed is:
r_1 = 8.00 mm along 180
r_2 = 7.55 mm along 90

BVP calculation:
$F = (n-1)/r$

where refractive index of tears $n = 1.336$

Along 180 BOZR of 8.00 mm gives anterior surface power to the tear lens in air of:
$336/8.00 = +42.00$

Along 90 BOZR of 7.55 mm gives anterior surface power to the tear lens in air of:
$336/7.55 = +44.50$

Along 180 BVP = −2.00 D (from over-refraction with diagnostic lens)
Along 90 BVP = −2.50 D

Final prescription:

$$\frac{8.00}{7.55}:7.00/\frac{8.60}{8.15}:8.00/\frac{10.50}{10.05}:9.00$$

$-2.00/-2.50 \times 180$

The rule-of-thumb 0.10 mm ≡ 0.50 D gives useful confirmation, since 8.00 mm −7.55 mm is 0.45 mm ≡ 2.25 D.

23.7.3 Fitting by calculation

A lens can also be ordered for the patient by theoretical calculation using the ocular refraction, 'K' readings and refractive index of the material. BOZD, TD and edge clearance are nevertheless determined from clinical assessment. The toric difference of the lens radii can be chosen to neutralize the corneal astigmatism, but the induced astigmatism must also be calculated.[2]

Explanation:
Ocular refraction: Sphere (S) Cylinder (C)

$$\text{Induced astigmatism (I)} = \frac{n-n'}{r_1} - \frac{n-n'}{r_2}$$

where:

n = refractive index of tears
n' = refractive index of the contact lens material

r_1 = steeper radius of curvature, in metres
r_2 = flatter radius of curvature, in metres

However, other factors have to be calculated.

The lens astigmatism induced by the back surface in air (A)

$$A = \frac{1-n'}{r_1} - \frac{1-n'}{r_2}$$

The BVP along the flatter meridian is S.
The BVP along the steeper meridian is S + A
To correct the induced astigmatism this becomes S + A − I along the steeper meridian.

Example:

Ocular refraction:	$-2.00/-3.00 \times 180$
Keratometry:	8.00 mm along 180, 7.60 mm along 90
Corneal astigmatism:	0.40 mm = 2.00 D
Residual astigmatism:	$(-3.00)-(-2.00) = -1.00$ D
BOZRs chosen:	$r_1 = 7.70$ mm, $r_2 = 8.00$ mm
	$n = 1.336$, $n' = 1.480$

$$\text{Induced astigmatism:} = \frac{-144}{7.70} - \frac{-144}{8.00}$$
$$= (-18.70) - (-18.00) = -0.70 \text{ D}$$

This almost exactly corrects the residual astigmatism and a front surface cylinder is unnecessary in this case.

BVP along the flatter meridian: = −2.00 D
BVP along the steeper meridian needs to be calculated:
Lens astigmatism in air (back surface lens astigmatism)

$$-1000\frac{(1-n')}{r_1} - 1000\frac{(1-n')}{r_2} = \frac{-480}{7.70} - \frac{-480}{8.00}$$
$$= (-62.33) - (-60.00)$$
$$= -2.33 \text{ D}$$

As induced astigmatism is neutralized, the final powers are:
BVP along flatter meridian: = −2.00 D
BVP along steeper meridian: = −2.00 + (−2.33) = −4.33
Equivalent to: −2.00/−2.33 along flatter meridian

23.8 Fitting bitorics

A bitoric is required when a back surface toric has created sufficient induced astigmatism (usually over 0.75 D) to warrant correction with a front surface cylinder.[3]

- If corneal and ocular astigmatism are equal, the induced astigmatism created may require correction.
- If the ocular astigmatism is less than the corneal astigmatism, lenticular astigmatism is revealed by a hard lens and requires neutralizing together with the induced astigmatism. In this case, a large front surface cylinder is needed.

Example:

Ocular refraction:	$-2.00/-3.00 \times 180$
Keratometry:	8.00 mm along 180, 7.40 mm along 90
Corneal astigmatism:	3.00 D
Residual astigmatism:	0.00 D
If we choose BOZRs of:	$r_1 = 7.50$ mm, $r_2 = 8.00$ mm
For:	$n = 1.336$, $n' = 1.480$

$$\text{Induced astigmatism:} = \frac{-144}{7.50} - \frac{-144}{8.00}$$

$$= (-19.20) - (-18.00) = -1.20\,\text{D}$$

This degree of induced astigmatism requires correction.
The astigmatism induced by the back surface in air:

$$\frac{-480}{7.50} - \frac{-480}{8.00} = (-64.00) - (-60.00) = -4.00\,\text{D}$$

BVP along flatter meridian: $= -2.00$ D
BVP along steeper meridian: $= (-2.00) + (-4.00) - (-1.20)$

$$= -4.80\,\text{D}$$

Equivalent to $-2.00/-2.80$ along flatter meridian

23.9 Compromise back surface torics

If the ocular astigmatism is greater than the corneal astigmatism, a compromise fitting option is worth considering to avoid the use of a front surface cylinder.[4] In these cases, some of the induced astigmatism will be neutralized by the residual astigmatism and the

remaining induced astigmatism can be further eliminated by reducing the difference between the flatter and steeper radii.

- Convert the spectacle prescription to an ocular prescription.
- Calculate the resultant induced astigmatism when the back surface toric lens is designed close to alignment.
- Calculate the residual astigmatism or use rule-of-thumb.
- Calculate the difference needed in BOZRs to create induced astigmatism that is equal or close to the residual astigmatism.
- Redesign the lens so that the flatter BOZR aligns with the flattest corneal meridian and the steeper BOZR satisfies the above calculation.

Rule of thumb

Choosing the lens radii to be approximately 75% of the corneal toric difference often avoids the need for a bitoric lens.

Example:

Ocular refraction: $-4.00/-5.00 \times 180$
Keratometry: 8.00 mm along 180, 7.20 mm along 90
Corneal astigmatism: 4.00 D
Residual astigmatism: $(-5.00) - (-4.00) = -1.00$ D

If the BOZRs were chosen to align $r_1 = 7.20$, $r_2 = 8.00$
For $n = 1.336$, $n' = 1.480$

$$\text{Induced astigmatism} = \frac{-144}{7.20} - \frac{-144}{8.00}$$
$$= (-20.00) - (-18.00) = -2.00\,\text{D}$$

$$\text{Front surface cylinder to compensate} = (-2.00) - (-1.00)$$
$$= -1.00\,\text{D}$$

However, by flattening the steeper BOZR to 7.40 mm

$$\text{Induced astigmatism} = \frac{-144}{7.40} - \frac{-144}{8.00}$$
$$= (-19.45) - (-18.00) = -1.45\,\text{D}$$

$$\text{Uncorrected astigmatism} = (-1.45) - (-1.00) = -0.45\,\text{D}$$

The patient would be expected to tolerate this small amount of astigmatism, therefore a bitoric is not needed with a back surface toric of 8.00 × 7.40 mm.

23.10 Computers in toric lens fitting

Computer programmes are now available to help in the design and ordering of bitoric hard gas-permeable contact lenses. The required data are keratometry readings, spectacle *Rx*, BVD, and possibly the selected BOZR, BOZD and TD. Most programmes provide the final lens specification along the flatter and steeper meridians as well as the ocular astigmatism, corneal astigmatism, residual astigmatism and induced astigmatism. From this information it becomes clear whether a front surface cylinder is necessary. Some programmes suggest the compromise fit required to avoid a front surface cylinder.

Most corneal topographers now have a contact lens module that can create lens designs for back surface torics, bitorics or front surface torics. It is then possible for the practitioner to set the level of corneal toricity at which the fitting module will begin to suggest a toric lens.

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CHAPTER 24

Toric soft lenses

24.1 Patient selection

Toric soft lenses are prescribed not to improve the physical fitting, as with hard lenses (except with very high degrees of astigmatism), but to provide good visual acuity where spherical lenses are unable to achieve this.

Indications

- Vision is unsatisfactory with a spherical soft lens.
- Astigmatism is 0.75 D or greater.
- Tolerance is poor with a hard gas-permeable lens.
- Keratometry and optical considerations indicate that a hard lens requires a much more complex, bitoric design (*see* Section 23.8).

Contraindications

- Astigmatism is purely corneal and hard lens tolerance is good.
- Existing hard lens wearers.
- Irregular astigmatism.
- Monocular patients.

24.2 Stabilization

24.2.1 Influences on lens behaviour

The main influences on lens orientation are the method of stabilization and the lids. Eyelids are important in respect of:

- Position of lower lid.
- Lid angles, whether upward or downward sloping.
- Size of vertical palpebral aperture.
- Lid tension.
- Force of blink.
- Direction of movement on blinking.

In cases of with-the-rule astigmatism, the thickest portions of the correcting toric lens lie at the top and bottom. The normal action of the lids is to rotate the lens 90° off-axis to bring the thickest parts into the horizontal meridian. The action of the lids on the lens edge has been compared to squeezing a watermelon seed, so that they control the ultimate lens position even with the head inverted.[1]

There are several other factors that have some effect on lens behaviour:[2]

- Gravity.
- Water content.
- Material elasticity.
- Lens thickness.
- Hydrostatic pressure.

24.2.2 Methods of stabilization

Various techniques are possible, either on their own or in combination.

Truncation

Truncation is now hardly ever used with soft lenses as it does not lend itself to the mass production moulding methods required by disposable lenses. At the same time, other methods of stabilization have improved. Truncation is usually single, removing a 1.00–1.50 mm chord from the lower edge of the lens (e.g. Zeiss Hydroflex-TS, Hydron *Rx* Toric). Oblique truncations (up to 20°) are feasible and sometimes used with angled lids. Some designs of front surface toric have employed double truncation.

Advantages

- Excellent stability.
- Easily observed and measured on the eye.
- Thinner lenses can be used.

Disadvantages

- Less comfortable.
- Buckling of lower edge if too flat or vertical corneal meridian very steep.
- Cosmetically more noticeable.
- Less satisfactory with oblique cylinders.
- Increased deposits along truncated edge.
- Very few lens types now available.
- Not used with disposable lenses.

Prism ballast

Prism ballast usually employs 1^{Δ} or 1.5^{Δ} base down. The upper limit is approximately 3^{Δ}. Modern refinements of lens design reduce the thickness previously associated with this method and give improved comfort and physiological response:

- Prism-free optics to incorporate the stabilizing prism only in the peripheral areas of the lens (e.g. CooperVision Omniflex toric).
- Slab-off prisms to give equal thickness at both the base and 3 and 9 o'clock positions.

Where a toric is required for only one eye, in theory the spherical lens for the other eye should also include base-down prism to prevent binocular imbalance. This is not often necessary in practice (not at all with prism-free optics) and the spherical lens is usually ordered without prism but with subsequent assessment of binocularity.

Advantages

- More comfortable than truncation.
- Better with oblique cylinders.
- Cosmetically less noticeable.
- Can be used with disposable lenses.

Disadvantages

- Careful slit lamp observation required to assess lens orientation.
- Lenses may be thicker.

- Greater risk of oedema with low water content.
- Not always successful at stabilization.

Thin zones (dynamic stabilization)

Top and bottom portions of the lens are chamfered to reduce the thickness where the stabilization zones fit beneath the lids (Figure 24.1). The optic portion is the central band which lies within the palpebral aperture. Lenses have the *DS axis* marked in the 3 and 9 o'clock positions.

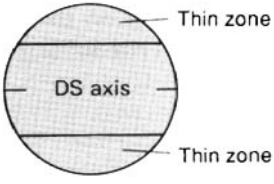

Figure 24.1 Thin zones

Advantages

- Lens remains thin overall.
- Good comfort with thin edges.
- Good cosmetic appearance.
- Unimportant if lens is upside down.
- Can be used with disposable lenses.

Disadvantages

- Careful slit lamp observation required to assess lens orientation.
- Limitation to the amount of cylinder (approximately 4.00 D).

Toric back surface

A toric back surface has a natural stabilizing effect when placed in apposition to an equivalently toroidal cornea because least elastic distortion occurs when the lens is correctly aligned. A better result, however, is achieved when used in conjunction with prism ballast or truncation. The toroidal optic zone is ellipsoidal in shape, the dimensions depending upon power and radius. It is larger with a lower cylinder and vice versa.

Other methods

- Lens elevations (orientation cams) in the 3 and 9 o'clock positions (e.g. Lunelle, Weflex 55).

- Wing ballasting to increase thickness along the horizontal meridian.
- Specially shaped, non-circular lenses.

24.2.3 Assessing lens rotation

Lens markings

In order to assess any rotation on the eye, it is essential that lenses are marked with reference points, except for truncations which are easily measurable. The following methods are commonly used:

- Radial engravings at the base of the lens. These give an assessment of rotation on the eye and are usually separated by either 15° (e.g. Z6T) or 30° (e.g. Hydrocurve III, Optima Toric) (Figure 24.2).

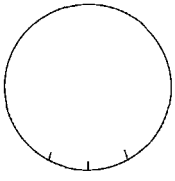

Figure 24.2 Radial engravings

- A single dot, usually at the base of the prism (e.g. Sunsoft Toric, Mark'ennovy 4T).
- Horizontal lines in the 3 and 9 o'clock positions (e.g. Focus Toric) although these sometimes distort because of lens flexure (Figure 24.3).

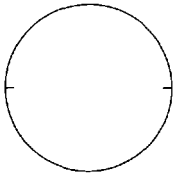

Figure 24.3 Laser lines at 3 and 9 o'clock positions

- Horizontal elevations in the 3 and 9 o'clock positions (e.g. Lunelle).
- A combination of horizontal and base markings (e.g. Proclear).

Lens orientation and measuring rotation

Whichever toric lens is used, its orientation on the eye is crucial. Compensation to the cylinder axis is frequently needed although in many patients 5° rotation (usually nasal) can be acceptable. Success is unlikely if the rotation is more than about 20°, even if consistent, and it is usually better to try a different fitting or lens type.

Apart from truncations, engravings can only be clearly observed with the slit lamp. Rotation can be measured by:

- Assessing radial markings by observation alone.
- A graticule, either internal or surrounding the slit lamp eyepiece.
- Rotating a fine slit lamp beam to align with lens engravings and reading the instrument's external protractor scale. Horizontal markings tend to be easier to assess than vertical.
- Rotating a low power cylinder in a trial frame until its axis is aligned with the markings on the toric lens.
- Using a Javal-type ophthalmometer.[3]
- By over-refraction. Mislocation of the cylinder axis gives an over-refraction in the form of a plus sphere with minus cylinder of approximately twice the power (e.g. +0.50/−1.00) at a different axis. The degree of rotation can then be calculated by computer programme or from Table 24.1.

Consistency can be evaluated by rotating the lens in either direction and observing whether the lens engravings return to the same position.

The **LARS** mnemonic is useful for lenses with the markings at 6 o'clock:

> Rotation **l**eft = **a**dd, rotation **r**ight = **s**ubtract. See example for 10° **l**eft rotation with a right eye (Figure 24.4a).

The **CAAS** mnemonic is useful for lenses with markings at 3 and 9 o'clock:

> Rotation **c**lockwise = **a**dd, rotation **a**nticlockwise = **s**ubtract. See example for 10° **c**lockwise rotation (Figure 24.4b).

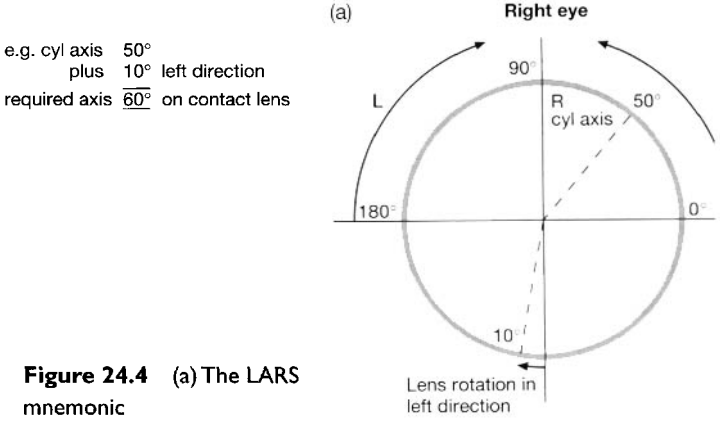

Figure 24.4 (a) The LARS mnemonic

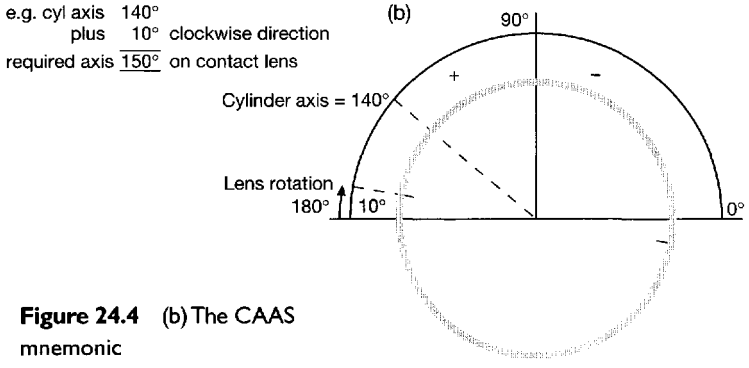

Figure 24.4 (b) The CAAS mnemonic

24.3 Lens designs

Numerous designs have evolved so that toric soft lenses, apart from stabilization with any of the methods in Section 23.2.2, may be of either corneal or semi-scleral diameter, use a variety of water contents, and have either a front or back toric surface. Several disposable torics are also available (*see* Section 19.3 and Table 19.3).

Total diameter

Advantages of corneal diameter torics

- Less risk of oedema.
- Cosmetically better.
- Less lower lid sensation.

Advantages of semi-scleral torics (e.g. Hydron Z6T, Sunsoft)

- Better stability.
- Less upper lid sensation.
- Wider range of lenses and methods of stabilization.

Water content

Advantages of low water content torics (e.g. Optima, Durasoft 2)

- Better stability on the eye.
- More reliable orientation.
- Can be made thinner.
- Longer life span.

Advantages of high water content torics (e.g. Lunelle, Proclear Compatibles, Weicon CE)

- Better comfort.
- Less risk of oedema.

Front and back surface torics

Front surface torics

Front surface torics are capable of correcting both corneal and lenticular astigmatism, up to about 4.50 D. They are successful with a wide variety of geometries, both corneal and semi-scleral (e.g. Weicon CE). Stabilization can be by means of prism ballast (e.g. Optima), truncation (e.g. Hydron *Rx* toric), or dynamic stabilization (e.g. Torisoft). The back surface may be either spherical (e.g. Weflex) or aspheric (e.g. Hydron *Rx* toric).

Back surface torics

Back surface torics have evolved logically from the fact that most of the astigmatism encountered in practice is predominantly corneal. Keratometry and spectacle *Rx* give an immediate prediction of the likelihood of visual success. The back surface of the lens is essentially designed to neutralize the toric cornea by replacing it with a spherical front surface. The radii of the principal meridians are almost always predetermined by the laboratory (e.g. Ultravision Igel 58 *Rx* toric). It is possible, however, for the practitioner to calculate the principal meridians by using a radius to surface power conversion chart (Table 24.1). The example on p. 294 shows the method for the Hydroflex-TS although this German design is no longer readily available in the UK.

Cylinders as high as 6.00 D can be corrected in this way. Lenticular astigmatism is not theoretically correctable, although in practice reasonable clinical results can usually be obtained. The back surface is sometimes stable enough on its own, but is assisted by prism ballast, truncation or front surface wing ballasting.

Practical advice

Most back surface torics include only the flatter meridian in the final lens specification (e.g. Hydrocurve 3, Mark'ennovy).

24.4 Fitting

Lenses may be either custom made to a precise *Rx* or selected from a simplified range of parameters predetermined by the laboratory (stock torics or now more commonly disposable lenses).

Custom made lenses

Custom made lenses permit the fitting of most prescriptions which it is technically feasible to manufacture, with a comprehensive range of lens parameters, water contents, spherical and cylinder powers, axis positions and methods of stabilization. The main disadvantages are the greater time required to obtain lenses to prescription and additional costs, particularly where changes to the prescription are necessary. Laboratories currently providing a full range of custom made toric lenses include Canton+Nissel, CLPL, CooperVision, Mark'ennovy and Ultravision International.

Disposable and stock torics

The simplified method enables rapid fitting from either practitioner or laboratory stock, since parameters are carefully restricted. Cylinder powers have an upper range of about 2.50 D (this will cope with 90% of prescriptions[4]), and may be limited to 0.50 D or 0.75 D steps. Axes may be restricted to 20° either side of horizontal or vertical in 10° steps, and oblique cylinders, which are generally more difficult to fit, are frequently omitted. Disposable lenses have largely assumed the role of stock torics since trial lenses are readily available and there is no waste of expensive prescription lenses.

No single make of standard design, even in the common range of astigmatism, can approach the accuracy of a properly calculated practitioner specification.[5] However, by using several makes of disposable or stock toric, a standard design can usually be found to match fairly closely the correction and fitting required. This is then the preferred method of fitting.

Laboratories currently supplying stock torics include Bausch & Lomb, CIBA Vision and Nova. For the much wider range of diposable torics see Table 19.3.

Fitting routine

Fitting conventional lenses is now hampered by the inability to use trial lenses of the preferred or anticipated type. Lenses can be

ordered empirically according to 'K' readings and spectacle *Rx*; if the laboratory offers an exchange or credit facility, the cost of wasted lenses is avoided. Alternatively, spherical or toric disposable trial lenses can be used, selecting a design which matches as closely as possible the probable type to be prescribed in terms of thickness, water content, power and method of stabilization.

- Assess spectacle *Rx* in relation to 'K' readings.
- Decide on a back or front surface toric in respect of corneal or lenticular astigmatism.
- For radius and diameter, fitting principles are in accordance with those given in Chapter 16.
- Several varieties of disposable or stock toric do not offer a choice of parameters.
- The method of stabilization is frequently determined by the choice of lens.
- Power is determined either empirically by considering the ocular refraction in both meridians or by over-refraction with a spherical lens.
- If there is a choice between two possible cylinders, it is generally correct to select the lower power, i.e. under- rather than over-correct astigmatism.
- With over-refraction, use a fully settled spherical disposable of power as near as possible to the spectacle *Rx*. Apart from any vertex distance considerations, this is always worthwhile to ensure that the results correlate, particularly in respect of cylinder power and axis. If there is any discrepancy, repeat with a different design of lens.
- Determine the lens orientation, either empirically by allowing up to 5° nasal rotation of the lens base, or from the angle at which the lens markings of a toric disposable settle or by assessing the angles of the lids.
- A lens examined on the eye establishes more accurately at the fitting stage whether compensation is required for the cylinder axis. The most common result is about 5° of nasal rotation. Success is unlikely if the rotation is more than about 20°, even if consistent, and it is usually better to try a different fitting or lens type. Oblique cylinders generally give less reliable results.
- The dynamics of a toric lens on the eye with similar cylinder to that anticipated are likely to be more reliable than a spherical lens. This is because the correcting cylinder that has been incorporated ensures comparable lens thickness.

- If axis compensation has been made because of lens rotation at the initial fitting, the prescription lens should also settle with exactly the same degree of rotation. This is particularly important when compensation has been made with the LARS method (*see* Section 24.2.3).
- There is little value in over-refracting with a toric lens on the eye, since the result will be that of obliquely crossed cylinders and only indirect information may be gained (*see* Table 24.2).
- The general nature of the over-refraction, however, may be used as a guide with the toric prescription lens, although its absolute value is not very meaningful. If cylinder is present at the original axis or at 90° to this, under- or over-correction is suggested. If it takes the form of a plus sphere with minus cylinder of approximately twice the power (e.g. +0.50/−1.00) at a different axis, it is because of cylinder axis mislocation. This may be due to lens rotation or inaccurate manufacture and may be assessed either from Table 24.2 or a suitable computer programme.

Table 24.1 Residual refractive error induced by mislocation of toric lenses of various cylindrical powers (from Holden and Frauenhofer,[4] with permission)

Convention	(1) Axes in standard axis notation (2) Anticlockwise is +ve, clockwise −ve	
Mislocation (degrees)	−1.00 D	−2.00 D (×2)
5	+0.08/−0.16 × 42.5	+0.17/−0.34 × 42.5
10	+0.17/−0.34 × 40	+0.35/−0.69 × 40
15	+0.26/−0.52 × 37.5	+0.52/−1.04 × 37.5
20	+0.34/−0.69 × 35	+0.68/−1.37 × 35
25	+0.43/−0.85 × 32.5	+0.85/−1.69 × 32.5
30	+0.50/−1.00 × 30	+1.00/−2.00 × 30
35	+0.57/−1.14 × 27.5	+1.14/−2.29 × 27.5
40	+0.64/−1.28 × 25	+1.29/−2.57 × 25
45	+0.71/−1.42 × 22.5	+1.41/−2.83 × 22.5
50	+0.76/−1.53 × 20	+1.53/−3.06 × 20
55	+0.82/−1.64 × 17.5	+1.64/−3.28 × 17.5
60	+0.87/−1.73 × 15	+1.73/−3.46 × 15
65	+0.90/−1.82 × 12.5	+1.81/−3.63 × 12.5
70	+0.94/−1.88 × 10	+1.88/−3.76 × 10
75	+0.96/−1.93 × 7.5	+1.93/−3.85 × 7.5
80	+0.98/−1.97 × 5	+1.97/−3.94 × 5
85	+0.99/−1.99 × 2.5	+1.99/−3.98 × 2.5
90	+1.00/−2.00 × 180	+2.00/−4.00 × 180

Practical advice

Depending on the type of axis markings, the position at which a lens settles on the cornea can be recorded as shown in Figure 24.5(a–c).

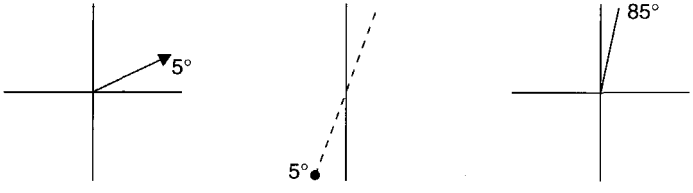

Figure 24.5 (a–c) Recording lens orientation

24.5 Fitting examples

Front surface stock toric

Example:

Spectacle *Rx*: R.E. −3.00/−1.25 × 85
Keratometry: R.E. 7.85 mm (43.00 D) spherical

The astigmatism is entirely lenticular, so a front surface toric is required.

Fitting: CIBA Vision, WCE Toric: FL (flat): 14.60–3.00 (selecting the flatter of the two options)

Cylinder refraction: −1.25 × 85 (from spectacle *Rx*)

Axis rotation: Assume 5° nasal (anticlockwise) rotation

The nearest options available for this stock design are:

Cylinders: −1.00 D or −1.75 D. It is nearly always better to under- rather than over-correct. Select −1.00 D.

Axes: 80° or 90°. Select 80° because of the assumed 5° nasal orientation. The cylinder axis should therefore rotate to the required 85°.

Lens specification: FL:14.60 −3.00/−1.00 × 80

Front surface toric with full range of parameters

Example:

Spectacle *Rx*: L.E. −2.50/−3.50 × 180
Keratometry: L.E. 8.23 mm along 180° (41.00 D)
7.72 mm along 90° (43.75 D)

The astigmatism is outside the range of a disposable or stock toric. Most is corneal but with 0.75 D lenticular. Select a front surface toric with a full range of parameters (e.g. CooperVision Z6).

Likely best fitting for Z6 Toric: 9.00:14.00 −3.00

Over-refraction: plano/−3.25 × 180 (using a thin daily disposable with power −2.50 D)

Lens specification: allowing for 5° nasal rotation (clockwise for left eye):

9.00:14.00 −2.50/−3.25 × 5

Suppose this prescription lens proved too mobile and also settled consistently with 10° temporal rotation (anticlockwise for left eye). Re-order:

Final lens specification: 8.70:14.00 −2.50/−3.25 × 170

Back surface disposable toric (e.g. Bausch & Lomb Soflens 66)

Spectacle *Rx*: R.E. −1.25 DS/−2.50 DC × 20
Keratometry: R.E. 7.96 mm along 20° (42.50 D)
7.50 mm along 110° (45.00 D)

The astigmatism is entirely corneal and possibly within the range of a stock toric or disposable.

Single fitting: 8.50:14.50

Example A:

Over-refraction: +0.25/−2.25 × 20 (using a medium water content daily disposable or Soflens 66 spherical that can be loaned to the patient for practice purposes)

Disposable toric locates with 10° nasal rotation (anti-clockwise for right eye)

Lens specification: 8.50:14.50 −1.25/−2.25 × 10

Example B:

Over-refraction: Plano/−2.75 × 25

Disposable toric locates with 20° temporal rotation (clockwise for right eye).

With 0.50 D undercorrection of the cylinder and a required axis theoretically at an oblique 45°, this example is unlikely to give a successful result. Discontinue and try another variety of toric to give better orientation on the cornea.

To calculate both meridians of a back surface toric

The example below uses the Hydroflex TS truncated design which is no longer readily available in the UK. The principles of the calculation remain valid to illustrate how the practitioner may determine the radii of both meridians.

Example:

Spectacle *Rx*: R.E. $-0.75/-3.50 \times 15$
Keratometry: R.E. 8.23 mm along 15 (41.00 D)
7.63 mm along 105 (44.25 D)

The astigmatism is almost entirely corneal and outside the range of a disposable or stock toric. Suppose non-truncated designs give unstable and excessive rotation. Select a back surface toric with truncation.

Best fitting: Hydroflex TS 9.30:14.00 –3.00
Over-refraction: $+2.50/-3.50 \times 15$
(N.B. This is required in minus cylinder form. There is also the typical +0.25 D difference in spherical power due to liquid lens and flexure effects – *see* Section 17.3.)
Trial lens: Locates with 10° nasal rotation. Prescription lens therefore requires a compensated axis at 5° (designated T5)

Calculation of radii for principal meridians

The trial lens radius is taken as the flatter meridian and, using Table 24.1, converted to surface power (N.B. minus sign).

9.30 mm	→	−47.83 D	surface power
	add	−3.50 D	correcting cylinder
8.70 mm	←	−51.33 D	

The nearest value to 51.33 D in Table 24.1 is 51.13 D (8.70 mm) and is taken as the steeper meridian.

Final lens specification: 9.30/8.70:14.00 −0.50 T5

(N.B. If the prescription lens over-corrects the astigmatism, this is possibly due to induced astigmatism, and a smaller toric difference is indicated.)

Table 24.2 Radius to surface power conversion for $n = 1.4448$

BCOR (mm)	Surface power (D)	BCOR (mm)	Surface power (D)
6.00	74.13	8.00	55.60
6.10	72.92	8.10	54.91
6.20	71.74	8.20	54.24
6.30	70.60	8.30	53.59
6.40	69.50	8.40	52.95
6.50	68.43	8.50	52.33
6.60	67.39	8.60	51.72
6.70	66.39	8.70	51.13
6.80	65.41	8.80	50.55
6.90	64.46	8.90	49.98
7.00	63.54	9.00	49.42
7.10	62.65	9.10	48.88
7.20	61.78	9.20	48.35
7.30	60.93	9.30	47.83
7.40	60.11	9.40	47.32
7.50	59.31	9.50	46.82
7.60	58.53	9.60	46.33
7.70	57.77	9.70	45.86
7.80	57.03	9.80	45.39
7.90	56.30	9.90	44.93

General advice

- A successful fitting usually returns consistently to the same orientation within one or two blinks or after rotational displacement on the eye.
- Where a lens mislocates on the eye, rather than attempt to change its orientation (e.g. by tightening the fit or adjusting the truncation), assume that the various stabilizing factors (see Section 24.2.1) will always act on the lens in a similar way. Compensate in the axis of the correcting cylinder for any lens rotation on the eye.
- Fitting is less reliable with oblique cylinders.
- Take particular care when fitting essentially monocular patients. They are much more disturbed by any instability of vision caused by temporary lens rotation on blinking.
- If no success is achieved after the second lens for a particular eye, try a different type of design.

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3. Lindsay, R.G. and Westerhout, D. (1997) Toric contact lens fitting. In: *Contact Lenses*, A.J. Phillips and L. Speedwell (eds). Butterworth-Heinemann, Oxford, pp. 464–493
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5. Cooke, G., Green, T. and Young, G. (1996) Spreadsheet calculation of oblique cylinder power. *Optician*, **211** (5540), 28–30

CHAPTER 25

Lenses for presbyopia

25.1 Patient selection

25.1.1 New patients

Indications

- Patients who fulfil the normal criteria for successful contact lens wear.
- Fairly tolerant patients who can accept some compromise in their distance and near vision.
- Patients without exacting visual requirements.

Contraindications

- Patients almost emmetropic for distance.
- Where there are basic contraindications to contact lens wear.
- Very critical patients.
- Patients who need good sustained close vision for work require particular care.
- Where the reason for fitting is obviously a spectacle dispensing problem.
- Poor handling.

Practical advice

To give prior assessment of adaptation, fit single vision distance first or try disposables if:

- The patient is uncertain about contact lenses.
- There are practitioner doubts about suitability.
- Handling may be a problem.

25.1.2 Existing lens wearers

- Early presbyopes often cope with +0.50 D added to the distance correction, usually in one eye.
- Many patients are happy to wear reading spectacles over their contact lenses to avoid both complications and expense.
- Some patients inadvertently using monovision because of refractive change are less happy when refitted with bifocals.
- If the patient is a successful hard lens wearer, soft bifocals should not be fitted.

Indications

- Long-term lens wearers who do not wish to resume wearing spectacles, even for reading.
- Physical problems with spectacles.
- Nuisance value of spectacles for one specific task.

Contraindications

- Poor volume or quality of tears, common with presbyopes.
- Where tolerance is becoming marginal with single vision lenses.
- Patients taking systemic drugs (e.g. for arthritis or sometimes hormone replacement therapy).

25.2 Monovision

Monovision is a technique for correcting presbyopia in which reading power is incorporated into a single vision contact lens, worn usually on the non-dominant eye.

25.2.1 Advantages and disadvantages of monovision

Advantages

- The least complicated method of dealing with presbyopia.
- It is unnecessary to make any compromise in the fitting.
- Patient acceptability is high, provided that the concept has been explained.
- Stability of vision.
- Patients usually decide rapidly that they can or cannot accept the technique.
- Significantly less expensive than other modalities.
- Maintains peripheral fusion.
- Refractive balancing not an issue.

Disadvantages

- Reduced stereopsis, but at optical infinity this is negligible.
- Some loss of contrast sensitivity, although this is also true of most bifocal and multifocal contact lenses.
- Unacceptable blurring may reduce tolerance.
- Cannot be used with monocular patients.
- Requires fairly strong eye dominance.
- Care is required with driving, particularly at night.

Practical advice

There is a natural limit to how much reading power can be tolerated. This is the limit of disparity beyond which monovision ceases to provide effective or comfortable vision. For most patients, once the addition reaches +2.50 D, the disparity between the two eyes may be difficult to accept.

The addition can be reduced and supplementary readers used as necessary.

25.2.2 Fitting for monovision

- Lenses, hard or soft, are fitted according to normal criteria.
- The non-dominant eye is generally used for near vision.
- The left is more often the non-dominant eye; in the UK, this is more practicable for driving.
- The least minus or most plus is found for distance in the dominant eye.

- The minimum plus power for adequate near vision is included for the non-dominant eye.

Eye dominance

Correct determination of eye dominance is essential for successful monovision. Crossed dominance (i.e. right handed and left eyed, or vice versa) is not uncommon. The methods used are:

- Determine which eye gives better corrected acuity.
- Point with the forefingers of both hands touching.
- Use a +1.25 D lens in front of each eye to see which gives less change in binocular acuity or subjective blur.
- Fixate through a cardboard tube or hole in a sheet of paper.

There is, however, frequent ambiguity between these various methods and the practitioner must decide the technique upon which to place greatest reliance.

Practical advice

- If right and left eyes are similar in prescription, the patient can experiment with which eye to use for near vision.
- If near vision is the main use, try changing the dominance and adapting the method to the patient's needs – crossed monovision.
- For occasional optimal distance vision (e.g. prolonged driving), consider prescribing either a third distance lens for the non-dominant eye or spectacles to wear over the lenses.

Partial monovision

A low add of +0.50 D or +0.75 D often gives sufficient convenience for intermittent near vision (e.g. price tags, menus, headlines) and patients are then happy to use reading spectacles for prolonged close work. This technique can sometimes be particularly effective with front surface aspherics.

25.3 Bifocal lens designs

25.3.1 Alternating designs (translating bifocals)

Alternating lenses contain two distinct sectors. These may be either fused or solid portions, or extend across the entire width of

the lens (Figure 25.1). Segment lenses are more common, but the concept is equally valid with concentric designs. Distance and near portions can never be used in the same direction of gaze or at the same time. Lens stability and position are controlled by either prism or truncation.

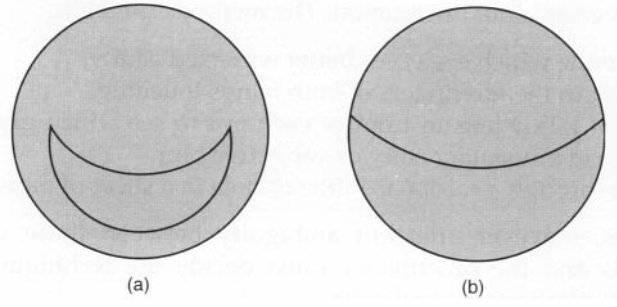

Figure 25.1 Bifocal lens design: (a) fused or solid portion; (b) solid portion extending across lens width

Factors for successful fitting

- The lens must move upwards on downward gaze to bring the near portion in front of the pupil area.
- A relatively taut lower lid is necessary; if it is too slack, the lens edge slides across the lower limbus.
- The bottom lid should be no lower than the inferior limbus in order to support the lens.
- There should be minimal disturbance of the lens on blinking or the reading portion is drawn in front of the pupil for distance and the patient complains of variable vision.

Rule of thumb

There must be sufficient movement to ensure that approximately three-quarters of the pupil area is covered by the correct section of the lens for both distance and near[1] (Figure 25.2).

25.3.2 Simultaneous designs (non-translating bifocals)

Simultaneous designs essentially provide distance and near vision together and do not rely on lens movement. They are commonly

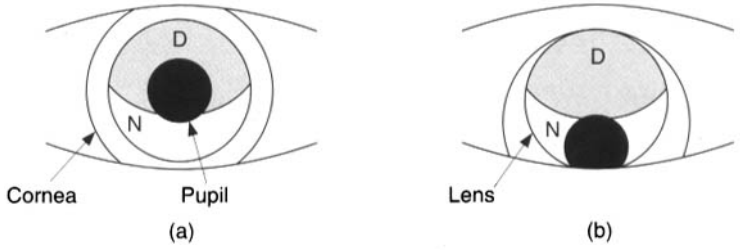

Figure 25.2 Bifocal lens movement: (a) primary gaze; (b) downgaze (D, distance portion; N, near portion)

found with concentric or aspheric lenses, where they are usually referred to as centre near (CN) and centre distance (CD), or with diffractive designs.

Factors for successful fitting

Stability of fit and the ability to discern between distance and near are important factors. Pupil size is also very significant in the performance of all simultaneous bifocals except diffractive lenses.

One of the main problems with simultaneous bifocals is a loss of contrast sensitivity of the superimposed retinal images. The problem is worse in low illumination and can give particular difficulties at near vision.

Centre near lenses

- Low illumination with CN concentric types favours distance vision because of the increase in pupil size.
- High illumination with CN concentric types favours near vision because of the decrease in pupil size; thus drivers should wear sunglasses.
- With CN aspherics, the larger the pupil the better the distance vision. Older patients with small pupils may not achieve good distance acuity.

Centre distance lenses

- Low illumination with CD concentric types favours near vision.
- High illumination with CD concentric types favours distance vision; thus sunglasses should be worn to read on a beach.
- With CD aspherics, small pupils make available less reading addition; thus, the older the patient the less suitable for near.

25.4 Fitting hard bifocals

25.4.1 Alternating types

Segmented bifocals

Segmented bifocals (e.g. Scotlens, Cantor + Nissel) exist and are fitted in the same way as fused segment designs. PMMA lenses used to be ordered with fused upcurve segments of different refractive index,[1] whilst the modern bifocal, like the now withdrawn Fluoroperm ST has a straight-top, high refractive index segment encapsulated within the lens (Figure 25.3).[2]

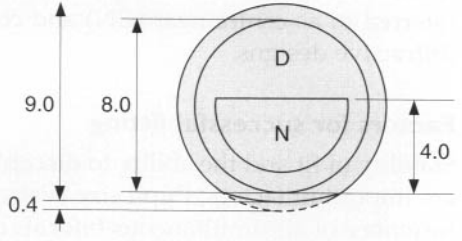

Figure 25.3 Segmented bifocal lens drawn with measurements for ordering (D, distance portion; N, near portion)

The anterior and posterior surfaces of a fused design are smooth and the segment is monocentric, i.e. the optical centre of the segment is located at the segment top to give 'step-free' vision. Despite the use of prism for stabilization, these lens designs are thinner and lighter than the solid segment Tangent Streak version. Segment size and shape are fixed at 6 mm wide and 3 mm high but all other parameters are custom designed for the patient. The amount of prism can be varied from 1.25$^{\Delta}$ to 3.00$^{\Delta}$ and depends on the BVP. It is usually greater for more negative powers.

A diagnostic lens is essential as it needs to be truncated and have prism ballast to ensure accurate assessment. With minimal astigmatism a lens is selected 0.05–0.15mm flatter than 'K'. Over 1.00DC, a steeper radius is used. The ideal fitting gives alignment or minimal apical touch with the truncation resting on the lower lid. Vertical movement should be about 1mm with rapid recovery on blinking. There should be at least 2mm between the top of the lens and the superior limbus in the primary position. On downward gaze, the lens should be lifted by at least 2mm and translate over the superior limbus.

The fused segment fluoresces and is easy to see with the Burton lamp. The segment top should be level with or slightly below the

inferior pupillary margin in normal ambient lighting. With the slit lamp and a wide beam, the segment top should be 0.40–0.70 mm below the inferior pupillary margin. Excessive lens rotation can be controlled by changing the prism power and axis, or by altering the angle of the truncation.

Typical specification:

7.80:8.00/9.40 × 9.00 −3.00 Add +2.00
Segment height: 3.60 mm; 2.00$^{\Delta}$

Practical advice

- Additions below +1.50 D are often not available.
- High-riding lenses can be improved by increasing the prism and centre thickness.
- Err on the high side for the segment top as this can subsequently be lowered by adjustment to the truncation.
- Increase the truncation if the segment is located too high.
- Avoid fitting patients with a very low lower lid as it may not be possible to control the lens position.

One-piece hard bifocal (e.g. Tangent Streak)

Consists of two wide segments meeting at a straight horizontal junction (Figure 25.4), similar to an executive-type spectacle bifocal.[3]

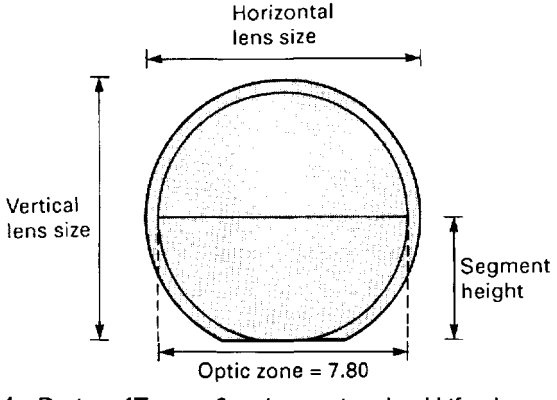

Figure 25.4 Design of Tangent Streak one-piece hard bifocal

A diagnostic set is necessary to assess movement of the lens and position of the segment line. A flat fitting is required so that the lens rides onto the lower lid between blinks. A low position is necessary to ensure sufficient clearance between the top of the lens and superior limbus for adequate translation, which is helped by truncation combined with 2^{Δ}. The range of BOZRs is 7.42 mm (45.50 D) to 8.23 mm (41.00 D) and the initial lens is selected on the basis of Table 25.1.

Corneal astigmatism (D)	Trial lens (BOZR)
0.00 D	'K' + 0.20 mm
0.50 D	'K' + 0.10 mm
>1.00 D	1/4 between flattest and steepest 'K'

The BOZD is a constant 7.80 mm, although there are two standard TDs of 9.90 × 9.40 mm and 9.40 × 9.00 mm. The position of the segment is observed with the ophthalmoscope or slit lamp. It is ideally 1.50 mm below the centre of the pupil in distance gaze. In downward gaze, the lens should translate for the segment line to rise slightly above the pupil centre. If the lens is not pushed up by the bottom lid, then more prism or a flatter BOZR should be used. Where the lower lid is below the limbus, a lens should be used with larger TD, less truncation, and higher segment.

Example:

HVID: 12.00 mm Pupil size 4.00 mm 'K' 7.80 × 7.65
BOZR: 7.90 mm; TD 9.90 × 9.40; segment height 5.20 mm

Practical advice

- Excessive lens rotation with a blink is often associated with too steep a BOZR or an upswept lower lid.
- A lens positioning superiorly requires increased prism ballast or flattening of the peripheral curves.
- Poor lens translation can be helped by increased edge clearance.
- Poor distance vision due to a high-riding lens or excessive movement can be helped by increased prism ballast or a larger TD.
- Poor near vision may require increased edge clearance to help translation.

Presbylite

Presbylite has a triangular segment reading area with an aspheric intermediate zone at the top of the triangular sector. Lenses are prism ballasted in three TDs: 9.00 mm, 9.30 mm, 9.60 mm. They are fitted empirically with a large BOZR in a full range of BVPs. The sectored near area allows up to 30° rotation without visual disturbance.

Concentric bifocals (e.g. Avision system)

The Avision lens is a CD concentric construction with alternating design principles. The optic is monocentric, so rotation is not a problem and the average lens mass is less than with many other designs. Any material can be used.

Lens position is controlled by a range of anterior bevels (designated P or M, from 1 to 4) to ensure the correct degree of lid attachment. P lenses promote more and M lenses less lid grip. Prism ballast can also be incorporated if necessary to encourage a lower lens position. A fitting set is available with the eight different edge types and a diagnostic ring to demarcate the 4.00 mm distance portion. Diagnostic lenses (with TD = 9.30 mm and AEL = 0.13 mm) allow assessment of centration, optic diameter and lens movement. The ideal lens has the size of the distance portion equal to that of the pupil diameter in ambient illumination.

The lens of first choice is selected on 'K' or 0.10 mm flatter than 'K' to give an alignment fitting with minimal mid-peripheral bearing and moderate edge clearance. The optimal edge type and fitting give a central position with 1 mm of rapid movement on blinking and a centre distance zone that provides full pupil coverage to avoid simultaneous vision effects. If the lens does not move by at least 2 mm to ensure translation for near vision, the TD should be reduced.

Practical advice

- Take advantage of loan lenses where available.
- Use lenses as near as possible to the anticipated BVP because lenses of different power behave differently on the eye.
- Err on the flat side for the initial lens.
- The larger TD is used more frequently.

continued

- If the fluorescein pattern is irregular and difficult to interpret, judge the fit according to movement and translation.
- Lenses are supplied dry and require hydration for 24 hours before dispensing.

25.4.2 *Simultaneous types*

Concentric bifocals

Concentric bifocals are especially suitable when good near vision is required above eye level, although some patients find the superimposed images difficult to ignore. The diameter of the distance portion is dependent on the pupil size and the lenses must be fitted to centre well with minimal movement. Back or front surface designs are possible (Figure 25.5), although the latter are more frequently fitted.[4]

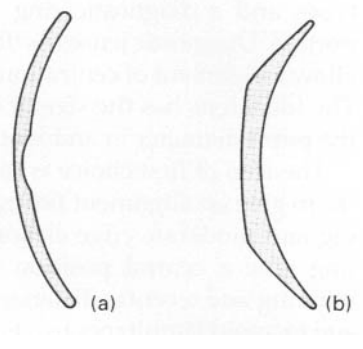

Figure 25.5 Concentric bifocals: (a) back surface design; (b) front surface design (from Phillips and Speedwell, *Contact Lenses*, 4th edn. Butterworth-Heinemann, Oxford, by permission)

Front surface

These are CD lenses made as lenticulars, with a central flatter curve giving a small optic area for distance surrounded by a steeper carrier, the radius of which is selected to give the correct power for near. The distance portion varies between 3.00 mm and 5.00 mm and should cover 50% of the pupil area. 4.00 mm is needed in 70% of cases. It is often useful to bias one eye for distance with a larger segment and the other for near with a smaller central area. A stable fit is achieved with large TDs between 9.60 mm and 9.90 mm, although some vertical movement is essential for satisfactory near vision. A low-riding lens works better than a high-riding one.

Typical specification:

R and L: 7.80:7.50/8.40:8.60/10.50:9.80 −3.00 Add +2.00
Right segment size 4.30 mm; left segment size 3.50 mm

Back surface

The de Carle lens is a CD design[5] with a very steep central back curve which relies on the partial neutralization effect of the tears. It has a typical radius of about 6.90 mm for an add of +2.50 D and a diameter between 2.00 mm and 4.00 mm. The surrounding annulus for near is used as a bearing surface (*see* Figure 25.5a and b).

Aspheric multifocals

Hard gas-permeable aspheric multifocal lenses usually have good optical quality and are relatively easy to fit. High and low eccentricities are now available.[6]

High eccentricity designs

- Are typically fitted very steep, as much as 0.60 mm steeper than flattest 'K'.
- Posterior aspheric designs can provide an effective near addition up to +2.50 D.
- The greater the near add, the smaller the distance zone.
- Good centration is essential.
- A central fluorescein pool will be seen.

Back surface aspheric (e.g. Quasar Plus)

These lenses typically have a 2 mm central spherical zone with an aspheric periphery of $e = 0.45$ to 0.60. The front surface is totally spherical. The near add point is set 3 mm from the geometric centre. They are usually fitted 0.40 mm steeper than flattest 'K' as good centration will be obtained with the help of the steep BOZR. The fluorescein pattern exhibits apical clearance with mid-peripheral alignment. Permitted movement is 1.00 mm to 1.50 mm, with 2 mm on downward gaze. An increase in the reading add is achieved by fitting a steeper BOZR. The distance zone, however, is reduced and this may compromise distance acuity. For high additions of up to +4.00 D, +2.50 D is generated on the back surface with the remaining power worked as an aspheric front surface. This design can also accommodate a back surface or front surface toric.

Practical advice

The lenticular design means that it is possible to:

- Add negative power to the distance area.
- Add positive power to the near carrier.
- Increase to a small extent the size of the distance area.

Low eccentricity designs

- Have a lower range of posterior flattening. The BOZR is chosen only 0.05 mm to 0.10 mm steeper than flattest 'K'.
- Must centre well or slightly superiorly with an alignment fluorescein pattern.
- Some translation on downward gaze helps with near vision.

Aspheric (e.g. Cantor + Nissel Aqualine MF200, Lifestyle)

These aspheric front or back surface lenses are designed to produce a progressive power curve which increases from the centre outwards. The lenses therefore give centre distance with an intermediate to near addition of up to +2.00 D within the pupil area. Plus power is further enhanced in upward or downward gaze.

Control of spherical aberration within the power gradient gives a smooth transition from distance to near vision. Some designs (e.g. Lifestyle) require a fitting 0.05 mm to 0.10 mm steeper than flattest 'K' to achieve the change in power gradient over the pupil area, whilst others (e.g. Aqualine MF) can be fitted in alignment as a standard lens.

The reading addition cannot work effectively if the lens is fitted too steep or too flat. If a higher add is required, the non-dominant eye can be over-plussed by +0.50 D but care should be taken not to over-minus distance. For best near vision while reading, the patient should hold the chin up to use the intermediate zone.

The Lifestyle lens is fitted to the mid-periphery of the cornea rather than the centre. The base curve is therefore not critical and the second aspheric curve, the equivalent base curve (EQ), is aligned with the cornea to achieve the desired fit. No corneal positioning is required and although initially it was fitted as a high-riding lens this is no longer necessary.

S-form technology

- Creates a posterior power gradient over the entire optical area.
- Ensures the desired power is constant over the whole of the specified front optic diameter.
- Gives total power control over the whole of the desired optical area.
- Excludes spherical aberration effects.
- Gives fewer problems with pupil flare in low illumination.
- Permits increased lens movement.
- Is not dependent on lens centration.

Multifocal (NOVA Essential)

Three series are available: Series I is used for adds up to +1.50 D, Series II from +1.50 D to +2.25 D, and Series III for adds greater than +2.25 D. An alignment fitting philosophy is used with upper lid attachment. The initial lens is selected on the basis of flattest 'K' and the degree of astigmatism. Success can sometimes be increased by adding more plus power to the distance BVP. This should be tried before using a series with a higher power although the stronger add may well prove helpful in the non-dominant eye.

Hard gas-permeable diffractive bifocals (e.g. Diffrax)

These diffractive bifocals were designed with a circular phase plate incorporated into the lens optic so that light could be made to interfere constructively at two focal points and to interfere destructively at other points on the optic axis.[7] The design, which was pupil independent, has been withdrawn from use with hard gas-permeable lenses.

25.5 Fitting soft bifocals

25.5.1 Alternating type

Alternating bifocals have not generally proved successful with soft lenses because of the difficulty of large lenses translating effectively. Lenses that have been produced consisted of:

- Crescent segments stabilized by truncation and prism ballast.
- Concentric designs with a high minus edge to interact with the lower lid and translate.

A more recent design is the Triton Translating Bifocal, which is manufactured with both truncation and segment.[8] Location or marker dots are used to indicate centration in order to locate the correct near power segment at a position 1.50 mm below the geometric centre.

- Marker dots must locate at the pupil centre.
- If the marker dots sit low, a larger TD is required.
- If the marker dots sit high, a smaller TD is required.
- Fitting is in relation to the vertical palpebral aperture and the position of the lower lid relative to the limbus.
- Once the correct vertical size has been determined, the BOR and BVP are calculated empirically.
- There may be problems with lid awareness because of the lens bulk and the truncation.

25.5.2 Simultaneous types

Concentric bifocals (spherical)

Both CD and CN designs have been available. CD designs tended to be more beneficial for drivers, while CN are better for VDU operators. All designs are pupil dependent, so a diagnostic lens is necessary for both fitting and power determination.

The optimal fitting should give minimal movement with good centration. The initial lens, however, should be the flattest choice that is reasonable because older, presbyopic eyes have a reduced volume of tears and less free lens movement over the conjunctiva.

The position of the central portion within the pupil area is more easily checked with either the retinoscope or ophthalmoscope than with the slit lamp. A decentred segment is unlikely to give good vision. It is often advantageous to use a different segment size in each eye, e.g. the smaller CN for the dominant distance eye and the larger CN as the reading lens.

Centre near (e.g. Simulvue)

- The diameters available for the CN portion are 2.35 mm and 2.55 mm.
- Different segment sizes should be used, choosing the smaller near diameter for the dominant eye. It may be necessary to fit very small or very large pupils respectively with the 2.35 mm or 2.55 mm segments in both eyes. Pupils that vary widely may encounter problems in extreme conditions of light or dark.

- The near add should be at least +0.50 D more than the spectacle reading addition, myopes requiring more plus for near than hyperopes.
- There is a choice of two base curves (8.70 mm and 9.00 mm); adequate but not excessive movement is required.
- The CN zone needs to cover only 50% of the pupil diameter and does not need to be exactly centred to achieve good results.
- Against-the-rule astigmatism may cause lateral decentration of the CN portion. Increasing the near zone diameter may well give better acuity.
- Monocular over-refraction should be carried out, but not using a phoropter.
- The distance over-refraction should be confirmed before checking the required reading add.

Typical specification:

R and L: 8.70:14.00 −3.00 Near add +2.50
Right segment 2.35 mm; left segment 2.55 mm

Centre distance (e.g. CIBA Vision Bisoft)

This CIBA Vision Bisoft design had 'steep' and 'flat' fittings with TDs of 13.00 mm and 13.80 mm. Distance powers ranged from −10.00 D to +7.00 D, with adds from +1.50 D to +4.00 D, both in 0.25 D steps. The diameters of the central distance portion were either 3.20 mm or 3.80 mm. This design is currently out of production.

Acuvue Bifocal

Unlike previous concentric and diffractive bifocals with a 'bull's eye' construction, the Acuvue Bifocal involves a combination of diffractive and refractive optics to achieve the bifocal correction. Using a series of concentric rings, the so-called 'pupil intelligent' lens gives different levels of near and distance correction depending on the size of the patient's pupil (Figure 25.6). The multiple ring configuration is intended to provide vision which is more specific to the available lighting conditions.

- The material is the same 58% etafilcon A used for other Acuvue lenses.
- Power range is from +6.00 D to −9.00 D.
- There are four adds: +1.00 D, +1.50 D, +2.00 D and +2.50 D.

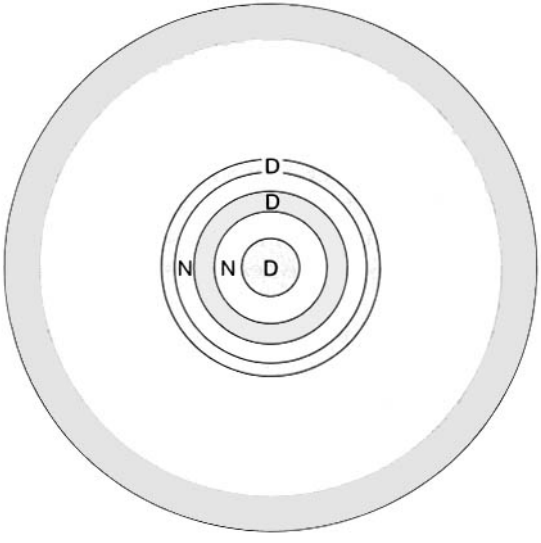

Figure 25.6 Design of Acuvue Bifocal

The concentric rings are not easily visible with the slit lamp but can be viewed using axial topography corneal mapping devices. The computer image allows centration of the lens to be compared with the corneal apex and patient's line of sight.

The distance BVP is found by converting the spectacle prescription to distance best sphere and adding up to −0.50 D for a −1.00 DC. The near add is selected by rounding up the spectacle addition. The lens has the Acuvue '123' indicator to determine that the lens is not inside out. This is particularly important as a reversed lens gives poor acuity. The distance power must not be over-minused and some adjustments may be needed to establish the optimal balance between distance and near vision. Success is increased by biasing one eye for distance and the other for near.[9]

Aspheric bifocals

Back surface aspherics (e.g. Occasions)

Progressive addition lenses of CD design with the periphery providing a near addition of up to +1.50 D. They are one-fit monthly disposables and are selected entirely on the basis of distance power. Optimal performance is achieved with good centration under conditions of average illumination and pupil size. Lenses work better

for early presbyopes because of the limited reading add and can be made more successful with over-plussing in one eye or if fitted in combination with another lens type.

Front surface aspherics (e.g. PV2000/2500, N5, Focus Progressives, Rythmic UV)

CN designs based on the over-correction of spherical aberration. The power becomes relatively less positive towards the lens periphery. Distance vision is better with large pupils, whereas near is relatively unaffected by pupil size. Distance powers for this type of lens are generally available between +7.00 D and −7.00 D. Near powers have an effective range of up to +3.00 D depending on the manufacturer. Good centration is essential to give optimal vision. Where possible, the lens of first choice is selected approximately 1.00 mm flatter than 'K'; some designs are one-fit. Lenses are essentially fitted for near vision. The initial diagnostic lens is selected on the basis of best vision sphere (spectacle sphere with half the cylinder power) plus half the near addition. It is essential to assess acuity using binocular refraction with lenses within 0.50 D of the anticipated result. Success is often increased by under-correction in the dominant eye and over-plussing in the other or by using lenses with different adds.

Example: Focus Progressives

Spectacle *Rx*:	−2.00/−0.50 × 180; near add +1.00
Best sphere:	−2.00 plus −0.25 = −2.25
	−2.25 plus +0.50 = −1.75
Diagnostic lens	−1.75 D

Multi-aspherics (Variations, Sunsoft, Polyvue)

CN simultaneous vision lenses offering a range of power profiles for near correction within a progressively corrected zone of spherical aberration. They often have two to three power profiles up to +3.00 D, depending on the design.

The greatest positive power acceptable to the patient is found. Success is increased by using the lowest addition profile in the dominant eye for distance. Hypermetropes tend to be more successful.

· Polyvue has a unique fitting aid which is the use of a white ring and black central location dot on diagnostic lenses to help easy

assessment of centration. The near addition profiles are either low (up to +2.25 D) or high (up to +3.25 D). It is a one-fit lens with central accommodation zones of either 1.50 mm or 1.90 mm.

Diffractive bifocals (e.g. Echelon)

The optical principle was similar to that of the hard Diffrax bifocal and based on Fresnel-type diffraction facets (Echelettes) less than 3 μm in depth. Chromatic aberration was reduced with virtually no pupil dependence. At distance, however, light scatter was observed around point sources and some patients had problems with sunlight and driving at night. At near, there was sometimes a ghosting or '3-D' effect. The lens was a one-fit design in 38% HEMA.

Enhanced monovision

A combination of one single vision lens and one bifocal, or two different designs of bifocal, increases the chance of success. The following combinations can be tried to give better distance vision to a dominant right eye:

Right eye	*Left eye*
Distance single vision	Centre near multifocal
Centre near bifocal (2.35)	Centre near bifocal (2.55)
Centre distance bifocal	Near single vision

Another approach is the Frequency 55 multifocal (CooperVision) which is designed to fit the dominant eye with a CD lens and the non dominant eye with a CN. The lens consists of a combination of spherical and aspheric surfaces and is termed 'an inverse geometry design'.

Quality of vision

- The use of high and low contrast visual acuity charts gives a useful idea of possible success.
- Low contrast charts will show the difference between spectacles and contact lenses and so may also give some indication of success.
- It is useful to have available in the consulting room common near vision tasks such as a VDU, different contrast papers, and needles and threads.
- A wide range of lighting in the consulting room aids assessment.
- A glare source can be utilized to illustrate potential problems.

General advice

- Have available a variety of soft bifocals in order to fit the majority of suitable patients.
- It is essential to use diagnostic lenses to obtain any idea of potential success for any particular type of bifocal.
- Try different combinations of bifocals and single vision lenses according to eye dominance.
- Avoid fitting poor lens handlers because of the potential expense with breakages.
- Monovision still has a higher success rate than multifocals.
- Do not fit patients with very small pupils of 3 mm or less. They are unable to use the area beyond the central power.
- Always use a trial frame for subjective examination as a phoropter may influence the pupil size and also make it more difficult to obtain the reading addition under normal conditions for near vision.

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CHAPTER 26

Special lens features and applications

26.1 Lens identification

26.1.1 Hard gas-permeable lenses

- A single dot engraved on the right lens used to be the standard recommendation.
- 'R' and 'L' engravings. Sometimes only the 'R' is used.
- Partial or complete lens specification is engraved by some manufacturers (e.g. CIBA Vision). This is intended for practitioner rather than patient information.
- Location of cylinder axis or prism base.
- Position of segment to assist bifocal fitting.
- Aphakics and hypermetropes, with poor unaided near vision, sometimes find it useful to have right and left lenses made in different tints. Usually the right is grey and left blue.
- A black dot is easier to see on high powered minus lenses than an engraving.

26.1.2 Soft lenses

Modern laser techniques have largely eliminated earlier problems with mechanical engravings, which could either develop fractures

or attract deposits. Information can also be imprinted onto the lens photographically and the same method was used by the practitioner to mark 'R' and 'L'.

- Numerical (123) markings to ensure the lens is not inside out.
- A manufacturer's logo.
- 'R' and 'L' engravings.
- 'R' and 'L' photographic markings.
- A code, serial or lot number.
- Details of partial or complete lens specification.
- Location of cylinder axis or prism base.
- Position of segment to assist bifocal fitting.

26.2 Tinted, cosmetic and prosthetic lenses

Lenses are tinted for a variety of reasons:

- To reduce adaptive photophobia.
- To assist handling.
- To enhance or change the natural eye colour.
- To reduce photophobia in albinism and aphakia.
- For identification.
- To improve colour vision (*see* Section 26.2.5).

The potential disadvantages of tinted lenses are:

- Change in colour values (e.g. for artists).
- Difficulty with night vision, particularly driving.
- Possible toxicity of dyes.

Tinted lenses are sometimes referred to as *enhancer tints* when they accentuate rather than change the natural eye colour.

Cosmetic lenses, in this context, may be defined as those used to change the colour of the eyes, whereas prosthetic lenses are used to conceal unsightly scarring or abnormalities of the iris.

26.2.1 Hard gas-permeable lenses

Most modern lenses are available in a fairly restricted range of tints. Many materials are made only in pale blue and do not give the option of clear lenses. Grey (and sometimes brown) is usually possible. Green is not available in several widely used materials,

and in addition the colour reproducibility tends to be unreliable. There is often poor consistency of colour between different batches of most tints and patients should be advised of the potential problem with replacement lenses.

Photochromatic lenses have also been produced but problems can occur with dimensional stability and the speed of reversal from dark to light.

Hand-painted cosmetic and prosthetic lenses are limited to stable, relatively low *Dk* materials such as XL20.

26.2.2 PMMA lenses

PMMA lenses, in contrast, have been available in a wide range of stable, consistently reproducible tints. The most common, standardly used colours are marked with an asterisk.

Grey

911 very pale grey
912* light grey (the most common)
512 medium grey/brown
999 dark grey

Brown

2285-1* light brown
2285-2 medium brown
2285 dark brown

Blue

1077-1* light blue
700 light/medium blue/violet
1077-3 medium blue
1077-2 dark blue

Green

2240-2* light green
2240-3 medium green
600 bright green
2240-1 dark green

Other tints

Yellow	200
Amber	300
Red	2241-1, 400
Pink	2241-2
Lavender	2242-2
Violet	10910

Clinical quality (CQ) materials use inert carbon particles within the monomer to avoid any possible toxic effect of dyes in commercial grade PMMA:

Clear

Very light grey/brown	9042 (previously 911 CQ)
Light grey/brown	9043 (previously 912 CQ)

Cosmetic and prosthetic lenses

Cosmetic and prosthetic corneal lenses are available with painted laminated inserts (e.g. Cantor + Nissel). These are colour-matched from photographs or sets of sample iris buttons and are usually painted by hand with the appropriate clear or black pupil. Although they give excellent cosmetic results, there are several difficulties associated with the use of corrective lenses:

- They are necessarily thick with large total diameters (about 11.50 mm) to give good corneal coverage and appearance.
- Comfort is often poor, with limited wearing time.
- There is a high risk of corneal oedema.
- The artificial pupils often give visual disturbance on blinking.
- There is a tunnel vision effect, with restricted field of view.
- It is not possible to assess the fitting of opaque lenses with fluorescein.

Some of these problems are overcome with the use of scleral lenses (*see* Section 15.1).

26.2.3 Soft lenses

There is much less clinical need for tinted soft lenses because of the low incidence of adaptive photophobia. Numerous laboratories, however, offer a range of enhancer tints for mainly cosmetic reasons.[1] Opaque and semi-opaque lenses are also available for cosmetic and prosthetic fitting. The most common variations are shown in Figure 26.1:

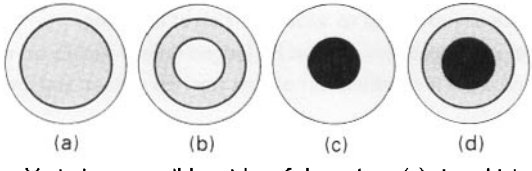

Figure 26.1 Variations possible with soft lens tints: (a) tinted iris with clear peripheral annulus; (b) tinted iris with clear peripheral annulus and clear pupil; (c) black (opaque) pupil on clear lens; (d) tinted iris with clear peripheral annulus and black (opaque) pupil

(a) Tinted iris with clear peripheral annulus. The iris diameter is usually standardized at 11.50 mm, with a clear periphery to give a natural appearance on the eye. Some laboratories (e.g. CooperVision and Ultravision International) offer a range of

both tints and colour densities. Very pale handling tints are also possible (e.g. Optima, Omniflex, Durasoft 3 Lite Tint).

(b) Tinted iris with clear pupil and clear peripheral annulus. The clear pupil partially avoids problems with changed colour values and light reduction at night. The cosmetic appearance is not as satisfactory for many patients as a completely tinted iris.

(c) Clear lens with black pupil. Used for occlusion or prosthetic reasons.

(d) Tinted iris with black pupil and clear peripheral annulus. Used for occlusion or prosthetic reasons.

General advice

- Order most hard gas-permeable lenses with a light tint to assist handling and reduce adaptive photophobia.
- Do not fit tinted soft lenses just for the sake of it. Unless a specific cosmetic effect is required or the lens type is made with a standard handling tint, the advantages may be outweighed by practical difficulties of colour matching, time delays, colour fading and constraints on which solution systems can be used.
- Avoid tints where colour values are important (e.g. artists).
- Care is required with the choice of solutions for tinted and cosmetic soft lenses. Oxidizing systems, especially those based on chlorine, can cause colour fading or laminates to peel apart.
- It is difficult to persuade many patients, particularly emmetropes, that tinted and cosmetic lenses are more than just a fashion accessory. Careful explanation is necessary that they must be fitted with the same skill and accuracy as conventional lenses and that proper care and maintenance are essential to avoid the risk of infection.
- The effect of a tinted lens cannot be judged unless placed on the eye. The final result is a combination of lens tint, iris colour and ambient lighting.
- To enhance eye colour, do not use a tint that is too saturated. The most pleasing cosmetic effect is usually achieved with a subtle colour change.
- Dark brown eyes are virtually unaffected by purely tinted lenses. Use opaque or dot matrix soft lenses to give a cosmetic colour change.
- Grey eyes respond well to blue and green tints.
- Light and medium brown eyes may sometimes respond to green tints.
- Brown eyes can sometimes be lightened with a yellow tint.
- Blue eyes may become brown with an orange tint.

Soft lenses are also produced with inhibitors, specifically to eliminate the ultraviolet part of the spectrum (e.g. Precision UV, Actifresh 400, Acuvue) and 'sun filters' (e.g. Lunelle).

Opaque painted and printed lenses

For cosmetic, prosthetic and theatrical purposes it is also possible to manufacture soft lenses with an opaque laminated backing or insert. This may be either painted or printed with clear or black pupils. Depending upon the laboratory, a limitless range of colours and cosmetic effects is possible, but the additional lens thickness of inserts can cause problems with comfort and oedema. Despite their greater stability on the eye compared with hard lenses, opaque corrective soft lenses with a clear pupil can also give visual disturbance on blinking and a reduced field of view.

Very large lenses with total diameter of up to 18.00 mm can be stabilized with prism ballast. By painting a decentred iris, they can be used cosmetically to correct squints.

Dot matrix lenses

Another successful cosmetic approach is the manufacture of lenses with coloured dot matrix patterns (e.g. CIBA Vision, Durasoft and Freshlook; CooperVision, Frequency Colours; and Johnson & Johnson, Acuvue Colours). These avoid most of the visual disturbance that occurs with opaque lenses although comfort can sometimes be a problem. A further refinement of design to overcome the restricted field of view is to have the patterns more widely spaced towards the pupil area.

26.2.4 UV inhibitors

Several varieties of soft lens are now available with a UV inhibitor (e.g. Acuvue, Johnson & Johnson; Precision UV, CIBA Vision). This provides a degree of ocular protection and considerably helps glare with some patients. The inclusion of the inhibitor, however, can adversely affect the *Dk* value. Precision UV, for example, uses a chromophore known as UVAM, and the *Dk* of the material is reduced from 43 to 38 $\times 10^{-11}$ Fatt units.

26.2.5 Lenses to enhance colour vision

The X-chrom lens

A specialized application of tinting is the monocular use of the dark red X-chrom lens. Its particular transmission characteristics are reported to enhance colour discrimination in patients with red-green deficiency.[2] Lenses are also available in soft lens form.

Chromagen

The Chromagen system also claims to achieve enhancement to colour vision and is available in a selection of soft lens tints.[3] It is also used in the management of dyslexia.

26.3 Fenestration

Uses of fenestration

PMMA lenses were fenestrated quite commonly to resolve corneal oedema, reduce the risk of the overwear syndrome (*see* Section 30.1.2), reduce spectacle blur, lengthen wearing time, improve comfort in hot, stuffy atmospheres, and permit faster adaptation. The same technique may occasionally still be used in modern gas-permeable lenses to:

- Improve tear flow beneath the lens.
- Improve frothing and dimpling, although this could be made worse.
- Prevent adhesion, commonly found with lenses for orthokeratology.

Problems with fenestration

- Discomfort in some cases.
- Visual disturbance on blinking in about 20% of patients.
- Lenses are weakened mechanically with the risk of cracking.
- The holes can become blocked with secretions from the tears.

Practical advice

- Use single holes for lenses smaller than 9.00 mm; two or more for larger total diameters.
- The size is usually 0.25–0.40 mm, but can vary from 0.10 mm to as large as 1 mm.

continued

- Position fenestrations 1–2 m off-centre with a minus lens to reduce the risk of cracking and allow the holes to cover a greater area of the cornea as the lens rotates on blinking.
- Avoid placing a peripheral hole on a transitional bearing area.
- If there is some doubt as to how the patient will react to the fenestrations, modify one lens at a time.
- Err slightly on the small side, as the ventilation holes can subsequently be enlarged.
- Instruct the patient to maintain the patency of the holes with the careful use of a soft, boxwood cocktail stick.
- Despite the obvious, always instruct the laboratory 'countersunk and very well polished'.

26.4 Overseas prescriptions

Most soft lens specifications are international. Some differences may be found with hard gas-permeable lenses. Prescriptions from continental Europe may be written in the order of radius (R_o), power (D), diameter (Ø).

Example: 7.80 –3.00 9.40

Prescriptions in the United States often give the BOZR (base curve or BCR) derived from keratometry fitting in dioptres. This is converted to millimetres using $n = 1.3375$. Peripheral (intermediate or secondary) curves are usually followed by their width and the overall diameter (OAD) in millimetres. The final back peripheral curve is usually called a *bevel*. A convex, front peripheral curve to reduce the edge thickness of minus lenses is sometimes called a *CN bevel*.

Example:

BCR 45.00 DO Z 7.80 mm OAD 9.60 mm
SCR 39.25 D (0.60 mm)
Bevel 32.12 D (0.30 mm)
is equivalent to 7.50:7.80/8.60:9.00/10.50:9.60

26.5 Contact lenses and sport

26.5.1 Advantages and disadvantages

Contact lenses offer considerable advantages over spectacles for sport.

Advantages

- Larger field of view.
- Unaffected by bad weather.
- With contact sports, both player and opponents are safer with no spectacle frame.

Disadvantages

Disadvantages relate mainly to hard lenses:

- Loss or displacement.
- Increased photophobia.
- Foreign bodies.

Because of these potential disadvantages, the governing bodies of certain sports may disallow the use of some types of contact lens (e.g. rally driving, horse racing).

26.5.2 Lens types

Soft lenses

Stability is the prime consideration with sport. The lens must give virtually no risk of loss from the eye, even with contact sports; must avoid the intrusion of foreign bodies; and must give consistent vision despite rapid eye movements. Soft lenses are therefore the first choice in most cases. For serious sporting use where optimal acuity is required (e.g. cricket), toric soft lenses are often preferable to hard, even to correct quite small degrees of astigmatism. The main disadvantage is lens dehydration.

Hard gas-permeable lenses

For less serious sport, hard lens wearers may well find that they can continue with existing lenses. Lenses can also be fitted deliberately larger and tighter than PMMA. They are specifically indicated where optimal acuity is required (e.g. pistol shooting), and in the case of flying the authorities may insist on their use to the exclusion of soft lenses.

Scleral lenses

Scleral lenses (*see* Chapter 15) give maximal stability of vision with no risk of loss. Their disadvantages are difficulty of fitting and limited wearing time. They are therefore used only rarely, but

have occasional application for aquatic sports such as water polo or canoeing where the head may be under water for a relatively long period.

26.5.3 Specific applications

Swimming

Contact lenses, on balance, are not recommended for swimming unless well-fitted goggles are worn.[4] Hard lenses, unless large and tight with a small palpebral aperture, are usually contraindicated because of the high risk of loss. Soft lenses, if used carefully, have been worn fairly successfully. Some patients are very sensitive to chlorine absorbed by the lenses and may show conjunctival injection for several hours after exposure. This can even occur when lenses have been removed during swimming, but replaced before the chlorine has been eliminated from the eyes.

Another factor is the saline concentration of sea water, since soft lenses fit more loosely in hypertonic solution. This could be used to advantage by rinsing lenses with hypotonic solution to tighten the fitting prior to swimming.

Practical advice

- It should also be remembered that swimming pools and jacuzzis are a frequent source of ocular infection, and micro-organisms such as *Acanthamoeba* may be unaffected by chlorine disinfection.
- Tightly fitted swimming goggles are likely to reduce the risk of infection.

Diving

Good results have been obtained with various water content soft lenses when used for scuba diving, with little risk of displacement. Air bubbles tend to form beneath lenses at depths of about 150 feet (45 m), but less with soft than with hard lenses, which are generally contraindicated for this reason.[5]

Water replacing air in front of the cornea reduces its refracting power by about 40.00 D. Scleral lenses have therefore been designed either with a flat-fronted air cell or with a high index glass anterior surface.[6]

Skiing

Most forms of contact lens prove very successful for skiing. It is essential to use either goggles or large sunglasses to give protection from wind and cold and prevent soft lens dehydration. Lenses with UV inhibitors are particularly indicated.[7]

Climbing at high altitude

High *Dk* hard gas-permeable or silicone hydrogel lenses should be used because of the reduced level of oxygen in the atmosphere at high altitude.[8] Extended wear may well be preferred to avoid cold weather difficulties with both handling and solutions.

Shooting

Competition shooting usually requires the precision and stability of hard lens acuity. The binocular balance is important. Depending upon the type of weapon, it is sometimes necessary either to fog the alternate eye or under-correct the fixating eye to assist focusing on the front sight.

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CHAPTER 27

Care systems

27.1 Components of solutions and disinfection standards

27.1.1 Components of solutions

All contact lens solutions are produced according to general principles of formulation and good manufacturing practice.

Buffers

Buffers (e.g. sodium phosphate, borate or tromethamine) are included where there is a need to keep the pH within the narrow limits necessary for contact lens wear (pH 6–8). The Antimicrobial Buffer System (ABS) patented by CIBA Vision combines three borate buffers (boric acid, sodium borate and sodium perborate) in bottled saline. These constituents yield 0.006% hydrogen peroxide, which acts as an antimicrobial agent.[1] Other unpreserved salines are buffered with borate or bicarbonate; phosphate is used in only a minority of preparations.

Preservatives

Preservatives restrict the growth of micro-organisms and maintain the sterility of the solution remaining in the bottle and in the contact lens case. Typical examples are given below.

Benzalkonium chloride (BAK)

Was frequently used with PMMA lenses. It destabilizes the tear film in concentrations over 0.004%, so wetting solutions or rewetting drops do not exceed this concentration. The majority of soaking and cleaning solutions can use 0.004–0.01% because they do not come into contact with the eye. Its use with modern hard gas-permeable lenses has been questioned because of surface adsorption.[2]

Chlorhexidine digluconate (CHX)

Usually included with other preservative systems in a concentration of 0.006% for hard lens solutions. If it is used alone, the kill time is slow and lenses must be stored for a minimum of 10 hours. Soft lens solutions employ a reduced concentration of 0.002–0.005%.

Thiomersal

A mercurial derivative used in concentrations of 0.001–0.002% with both hard and soft lens solutions, more often found with the latter. Thiomersal is effective against fungi, but toxic reactions are fairly common. It is slow acting as a preservative and so is usually incorporated with chlorhexidine or EDTA.

Polyquats

The collective name for the two main antimicrobials found in the current generation of soft multipurpose solutions. The polyquats are from the same family as chlorhexidine, but have a greater molecular size and weight. This means they are unable to penetrate the matrix of a soft lens and each polyquat molecule causes proportionally more damage to micro-organisms because its polymeric nature makes it more effective in low concentrations. All polyquats bind negatively charged phospholipids found in the bacterial plasma membrane. Their action results in cellular lysis rather than disrupting bacterial cell walls as with other antimicrobials.

- *Polihexanide (Dymed).* Dymed is the proprietary name for polihexanide (polyaminopropyl biguanide or polyhexamethylene biguanide).[3] Dymed is found in concentrations of 0.00005–0.0001% (e.g. ReNu, ReNu MultiPlus, Complete).
- *Polyquad.* Polyquad (polyquaternium 1) is a new generation polyquat used as a high molecular weight preservative. The molecular weight is 14 times that of chlorhexidine and nearly 4 times that of Dymed. It is bactericidal but its action against

fungi is questionable. It has shown good microbial efficacy with minimal toxicity and so is used as both a preservative and a disinfectant in a concentration of 0.001% (e.g. Opti-Free, Opti-1).

Aldox

Aldox (myristamidopropyl dimethylamine) has a novel antimicrobial buffering system. Effective against fungal contamination and *Acanthamoeba* cysts, Aldox interacts with the fungal cell wall components to allow penetration (e.g. Optifree Express). It is found in a concentration of 0.0005%.

Water-soluble cationics

Water-soluble cationics such as polyxetonium chloride 0.006% have low toxicity and are used in hard lens solutions (e.g. Total Care).

Phenylmercuric nitrate and chlorbutol

Phenylmercuric nitrate is found in some multipurpose hard lens solutions in a concentration of 0.004%. Chlorbutol binds to CAB and is now uncommon due to its volatile nature. Used in concentrations of 0.4% (e.g. Sterisoak, Liquifilm Tears).

Quaternary ammonias

Alkyl triethanol ammonium chloride (ATAC) is used in soft lens soaking solutions in concentrations of 0.013–0.03%.

Sorbic acid

Used in surfactant cleaners with a concentration of 0.1% (e.g. Pliagel).

Polyvinyl alcohol

Alcohols such as isopropyl alcohol (20%) may be incorporated as a preservative in cleaning solutions.

Tonicity agents (invariably sodium or potassium chloride)

To adjust the salt concentration and ensure compatibility with the tears.

Viscosity agents (e.g. hydroxyethylcellulose)

To improve the wetting time and comfort of the solution. The agent increases the thickness of the solution and gives it a smooth feel.

Wetting agents (e.g. polyvinyl alcohol, polysorbate 80)

To help the solution spread across the lens surface. Also found in soft lens disinfection solutions, e.g. povidone (polyvinyl pyrrolidone).

Lubricating agents (e.g. hydroxypropyl methylcellulose (HMPC), Lubricare)

Added to some of the second generation soft lens solutions to reduce surface tension, improve wettability, increase viscosity and improve lens comfort.

Chelating agents (e.g. ethylenediamine tetraacetic acid (EDTA), known as sodium edetate)

Found in concentrations of 0.01–0.2%. Used to enhance the action of preservatives, especially benzalkonium chloride, with which it has a synergistic action. The main exceptions are mercurial derivatives.

Sequestering agents (e.g. citrate, Hydranate)

Negatively charged agents to give a cleaning action with second generation multipurpose soft lens solutions. They remove positively charged protein by ionic attraction and break down complex deposits by chelating calcium. These agents work whilst the lens is soaking overnight.

Surfactants (e.g. poloxamine, miranol)

The most common surfactants used in multipurpose soft lens solutions for their cleaning action are poloxamine and tyloxapol. These are supplemented in recent products with non-ionic surfactants, e.g. Lubricare (Quattro), and protein removal agents, e.g. Hydranate (Renu Multi Plus). Those solutions not containing a surfactant (e.g. Opti-Free) do require a supplementary cleaner. Other cleaners or hard lens multifunction solutions contain miranol (e.g. Total Care) and phospholipid (e.g. Boston Elite).

27.1.2 Disinfection standards

All contact lens solutions must meet standard ISO/FDIS 14729 (Performance Requirements). Tests are against bacteria (*Pseudomonas aeruginosa, Staphylococcus aureus, Serratia marcescens*) and fungi (*Candida albicans, Fusarium solani*).

The D-value is the time to reduce organism population by 90% (1 log unit)

Stand alone test

- Primary Standard: indicates a reduction by 99.9% (3 log units) of a challenge of the test bacteria and 90% (1 log unit) reduction for fungi at the minimum recommended disinfection time (MRDT).
- Secondary Standard: for products that can be used as part of a care regimen if they meet the criteria of a combined log reduction against the three bacteria of at least 5 log units with a reduction of at least 1 log unit for any single bacterium and that there is no growth of the test fungi at the MRDT.

Regimen test

Following the full recommended care regimen, no more than 10 viable organisms per lens should remain.

Acanthamoeba is not included in this standard as there are no specifically identified species type, no standard method of recovery or quantification of survivors, and no standard test methods.

27.2 Solutions for hard gas-permeable lenses

The surface of a hard gas-permeable lens is more prone to deposits and interaction with some formulations compared to the more inert PMMA.[4]

27.2.1 Wetting solutions

Wetting solutions were used on insertion to act as a cushion between the lens and cornea. They also enhanced the spread of tears across the lens surface, although the effect lasted only for a maximum of 15 minutes and sometimes for as little as 5 seconds.[5]

Formulation: tonicity agent; viscosity agent; wetting agent; preservatives; chelating agent.

27.2.2 Soaking solutions

Soaking solutions keep lenses hydrated during overnight storage in a sterile, bactericidal environment. They facilitate good surface wetting and assist the removal of deposits. Hydration is important to maintain the correct BOZR both for modern hard lens materials[6] and for PMMA over about –10.00 D.[7]

Formulation: tonicity agent; wetting agent; detergent; preservatives; chelating agent.

27.2.3 Cleaning solutions

Cleaning solutions remove surface debris including lipids and mucus (e.g. LC65) and enhance the disinfecting action of the soaking solution. With the advent of fluorosilicon acrylates, greasing of the lens surface has become a more frequent problem. Manufacturers have therefore developed alcohol-based solutions (e.g. Boston Advance, Bausch & Lomb Elite, Miraflow) or cleaners with emollient and foam stabilizers (e.g. Total Care). The inclusion of microscopic polymeric beads in suspension gives a light surface polishing effect useful for removing denatured proteins (e.g. Boston, Bausch & Lomb).

Formulation: detergent; preservatives; chelating agent.

Practical advice

- Advise patients to take care not to cause an inadvertent power change with the polishing action.
- Take care with cleaners containing only an organic solvent (e.g. isopropyl alcohol) to avoid upsetting the surface wetting properties of some hard gas-permeable lens materials, especially fluoropolymers.[6]

27.2.4 Multipurpose solutions

These combine all of the above functions, but usually with some loss of efficiency:

- Wetting, soaking and cleaning (e.g. All-In-One)
- Soaking and cleaning (e.g. Clean-N-Soak).
- Wetting and soaking (e.g. Bausch & Lomb, Total Care).

Some reformulated wetting and soaking products are now called conditioning solutions (e.g. Bausch & Lomb Elite, Boston Advance Comfort Formula).

Formulation: wetting agent; detergent; preservatives; chelating agent.

27.2.5 Rewetting solutions (comfort drops)

Comfort drops are used to rewet lenses while they are worn, especially in dry environments (e.g. Clerz, Bausch & Lomb Rewetting drops).

Formulation: wetting agent; preservatives; chelating agent. Some are now produced without preservative in unit dose form

(e.g. Refresh Contacts) or as a continuous monodose dispensing system (e.g. Hylo-Prompt).

27.2.6 *Enzyme tablets*

Proteinaceous films require enzyme removal with some hard gas-permeable lens materials, particularly silicon acrylates. 0.4% sodium hypochlorite is also used as a protein remover (Progent A), neutralized by potassium bromide (Progent B). The soaking time is 30 minutes maximum, and the solutions are supplied as a unit dose preparation. The system also has powerful antimicrobial and prion efficacy.

Formulation: see Section 27.4.4.

Practical advice

- Depending upon the active ingredient, patients find it much more convenient to leave lenses soaking overnight.
- Enzymes may not be required with fluoropolymers and rarely with CAB.
- Advise hay fever sufferers to use enzyme tablets more frequently in the spring and early summer.

27.2.7 *Tap water*

Rising mains water can be used to flush hard gas-permeable lenses after cleaning and prior to overnight storage in a disinfecting solution. Boiled water or saline is safer for cleaning the lens case, which should then be air dried.

27.3 Solutions for soft lenses

The general principles for soft lens solutions are similar to those for hard lenses but there are potentially more difficulties because of the possibility of interaction with the material. Viscosity agents are not generally employed and the pattern of use is often different, since many solutions must be partnered to ensure complete antimicrobial efficacy.

27.4 Disinfection

Disinfection may be by means of either *chemicals* (cold) or *heat*.

27.4.1 Chemical disinfection

Cold disinfection uses either preserved chemicals or unpreserved oxidative systems.

Preserved soaking solutions

Used for overnight storage (e.g. Opti-1, Optifree).

Formulation: tonicity agent; wetting agent; preservative; buffer; detergent.

Multipurpose solutions

- Combine disinfection and cleaning.
- The soaking solution can be used for rinsing.
- Ideal for disposable lenses (e.g. Renu Multi Plus, Quattro, Optil, Solocare, Complete, Optifree Express), easy to use and economical, but there is a possibility of an allergic reaction to some of the preservatives.
- The product can be kept up to 3–6 months after opening.
- 'Singles' are available for extended wear patients who need the occasional soaking solution (CIBA Vision).

Formulation: high molecular weight preservative; sequestering agents, lubricating agents.

Saline

A solution of 0.9% saline is referred to as *isotonic*, having an overall sodium chloride concentration equivalent to that of human tears. A solution with higher salt concentration is *hypertonic* and one with a lower concentration *hypotonic*.

Normal (0.9%) saline may be either buffered or unbuffered and is available in the following formats:

- Preserved in multidose bottles (e.g. CIBA Vision).
- Unpreserved in unit dose form (e.g. Amidose).
- Unpreserved in aerosol form – but no longer readily available.
- Drip-feed bags with one-way valve (not obtainable in the UK except in some hospital departments).

N.B. Home-made saline, using purified water, ceased in the UK in 1988 with the withdrawal of salt tablets. *Acanthamoeba* infection in the USA has been linked to home-made saline.[8]

Tap water

In the past, the OptimEyes tablet, containing 0.004% chlorhexidine, was dissolved in rising mains water to create a simple and inexpensive disinfection solution. This system is no longer available.

Tap water must not be used for soft lens storage and insertion, or for cleaning the lens case, because of:

- Serious risk of microbial contamination (e.g. *Acanthamoeba*).
- Trace metals and salts.
- Lens adhesion as a result of hypotonicity.

Ideally, any use of tap water should be avoided in the hygiene regimen, except for hand washing.[9]

Oxidative systems

Oxidative systems are generally unpreserved and use hydrogen peroxide or chlorine-based compounds as the disinfecting agent.

Hydrogen peroxide (H_2O_2)

Most peroxide systems use a 3% concentration. They include a sodium or phosphate stabilizer to prevent the rapid decompensation of the otherwise unstable H_2O_2.[3] The systems need neutralizing agents to convert the peroxide into a safe neutral solution. The two-step systems are seen as the 'Gold Standard'. Three per cent hydrogen peroxide has a broad antimicrobial efficacy. Although 10 minutes is effective, longer soaking times of between 1 and 4 hours are recommended to ensure adequate antifungal and antiprotozoan activity, with 6 hours required to kill all *Acanthamoeba* cysts.[10] This usually means that an overnight soak is desirable.

A tablet of enzyme cleaner can be included with the peroxide solution (e.g. Ultrazyme).

Advantages of hydrogen peroxide

- No reaction to preservatives.
- Efficient method of disinfecting, especially when used overnight.
- Enhances cleaning.
- An enzyme cleaner can sometimes be avoided.

- Prolongs lens life.
- Less risk of red eye reaction with extended wear.

Disadvantages of hydrogen peroxide

- The peroxide must be neutralized.
- The neutralizing time is sometimes lengthy.
- Complicated to use and understand.
- High water content materials may deteriorate with prolonged storage in peroxide.
- Occasional allergies.
- The peroxide may lose its efficacy if kept too long (e.g. with extended wear).
- One-Step systems offer no on-going disinfection for intermittent wearers.
- One-Step systems give no protection against *Acanthamoeba* due to fast neutralization times.
- Bulky for travel.
- Expensive.
- Possibility of patient error.

Three types of neutralization are available:

1 Catalytic.
   (a) Using catalase, a naturally occurring bovine catalyst which is highly specific for the speedy decomposition of hydrogen peroxide, either in solution (e.g. OxySept Two Step) or with a time release tablet coated in hydroxypropyl methylcellulose (e.g. OxySept One Step). Time release tablets delay neutralization for the first 20 minutes. The concentration of peroxide does not fall below 1%, and there is then almost complete neutralization by 2 hours. A pink colourant (vitamin B_{12}) is used to aid compliance in tablet use and safety of lens wear.
   (b) Using a platinum coated disc (e.g. AOSept, EasySept). There is a rapid neutralization in the first 2 minutes (from 3% to 0.9%) followed by a much slower phase than catalase because the molecules have to migrate through the buffered saline to the disc surface instead of being evenly distributed throughout the solution. This slower phase may take up to 6 hours. The disc needs replacing every 3 months (sooner with some patients). If the neutralizing solution is buffered to a high pH (e.g. AOSept), the kill time is slower. The neutralization does not depend on the concentration of the catalyst, and no by-products are formed except water and oxygen. The recent

inclusion of cleaning agents aids lens cleaning during the early neutralization phase when bubbling at the disc is at its peak (e.g. Sauflon Multi, AOSept Plus).

Warning

The short period of time for which one-step peroxides maintain the full concentration of 3% raises implications for bacterial growth in the lens case. It is essential that this is replaced regularly.[11]

2 Reactive. Chemicals such as sodium pyruvate (e.g. 10:10, Mira-Sept) or, until recently, sodium thiosulphate (Perform) initiate an oxidation–reduction reaction that causes the hydrogen peroxide to decompose. The speed and degree of neutralization depend upon concentration and temperature. By-products are formed, such as sodium acetate, carbon dioxide and water (10:10); or sodium tetrathionate and sodium hydroxide (Perform). A further method used a 22 mg sodium perborate tablet (e.g. FreeSept), which produced 0.1% hydrogen peroxide when dissolved in unpreserved saline. A soaking time of 6 hours was needed for effective disinfection and it was necessary to give lenses a saline rinse in the case before insertion.
3 Dilution. By rinsing and soaking in saline (e.g. the now discontinued Quik-Sept).

Chlorine systems

Chlorine-based systems contain active ingredients such as sodium dichloroisocyanurate (e.g. Softab), called a low chlorine system, or *para*-dichlorosulphamoyl benzoic acid (e.g. Aerotab), called a high chlorine system.

Advantages of chlorine

- One-step systems, which help compliance.
- Neutralization unnecessary.
- Unpreserved saline is the only solution used, either to dissolve the tablet or rinse the lens before use.
- Less irritation with patient error.
- Easy to understand.
- Minimal bulk and good for travel.
- Less expensive than peroxide.

Disadvantages of chlorine

- Residual traces of the disinfecting agent may be present on lens insertion.
- Slow kill time so overnight disinfection required.
- An effective surfactant cleaner is essential.
- May be confused with enzyme tablets.
- Patient may forget to add the tablet.
- Lenses have shorter life span than with H_2O_2.
- Ineffective against *Acanthamoeba*, protozoa and some fungi.
- Inactivated by organic matter.
- Tinted soft lenses may fade.

27.4.2 Heat disinfection

Heat disinfection is generally carried out using unpreserved normal saline at a pasteurization temperature of 70–80°C. The addition of sodium edetate gives calcium-removing properties. Lenses must always be allowed to cool before insertion.

Advantages of heat disinfection

- Easy to use.
- Economical.
- Efficient at killing micro-organisms – but no effect on prions.
- Suitable for some disposable lenses.

Disadvantages of heat disinfection

- Difficult for travel.
- Denatures protein onto the lens surface.
- Accelerates lens ageing.
- Routine surfactant and enzyme cleaning essential.

Methods

- Heating unit, preferably thermostatic and time-controlled.
- Vacuum flask or saucepan. The lens case is placed in boiling water for 10 minutes, after which the lenses are allowed to cool.

Microwave

Non-pressurized microwave disinfection can be carried out; past techniques include the MicroClens. The system consisted of the

disinfection unit containing MicroClens saline into which the contact lens case, filled with the same solution, was placed. The unit was microwaved for 1–2 minutes.

Disinfection is achieved by microwave irradiation producing high-frequency oscillations within the molecules. These oscillations rapidly raise the temperature and can destroy vegetative micro-organisms within 2 minutes. Turbulence of the irradiated solution also cleans the lens surface by the emulsification of lipids.[12]

27.4.3 Cleaning solutions

Formulation: surface-active agents; preservatives.

In addition to cleaners specifically formulated for soft lenses (e.g. Bausch & Lomb), hard *gas-permeable* lens cleaners which do not contain benzalkonium chloride can be used (e.g. LC65). Alcohol-based cleaners are effective against lipids (e.g. Miraflow). For denatured protein, a surfactant–polymeric bead cleaner (e.g. Opti-Clean) combines a cleaning agent with microscopic, polystyrene-like beads.[13]

Daily manual surface cleaning is important to:

- Remove lipids, inorganic deposits, some proteins and insoluble contaminants by manual action.
- Overcome the hydrophobicity of oily deposits with surface-active agents.
- Assist chemical disinfection by removing deposits that could interfere with antibacterial activity.
- Remove contaminants that supply nutrients to bacteria.
- Disperse mucus film to minimize the potential for binding of any large molecular size antimicrobial agent.

Second generation multipurpose solutions claim to achieve physical cleaning as they often contain a cleaning agent in their formulation. Although soaking in the solution gives a potential cleaning action (e.g. Optifree Express), the manual 'rub' is important to reduce the bacterial load and accumulated deposition.

The 'No-Rub' concept for 2-weekly or monthly disposable lenses requires a 6-hour soak, whilst all other lenses require a rub and rinse step followed by a 4-hour soak. It is associated with a rinsing step before and after disinfection which must stipulate the actual time required, e.g. '5 seconds per side'.[9]

Other cleaning methods

- Ultrasonic units.
- Ultraviolet units.
- Spinning devices.

Rewetting solutions

Moisture-retaining lubricants without preservative (e.g. Refresh Contacts). Multidose solutions are available containing Purite as the preservative.

For reducing surface protein with extended wear silicone hydrogels, multidose solutions are used containing tyloxapol for lipids and debris, and tromethamine to emulsify and displace protein (e.g. Complete Blink-N-Clean).

27.4.4 Periodic cleaners

Enzyme tablets

Enzyme tablets are used for the removal of protein from the lens surface. Weekly cleaning is suggested, but patients on peroxide are able to use them less frequently. Tablets are dissolved in saline or used in the actual disinfecting solution (e.g. Oxysept One Step). Some second generation multipurpose solutions incorporate a sequestering agent and so a separate system is not required (e.g. RenuMultiplus, OptiFree Express).

Liquid enzyme is also available, e.g. as a pancreatin-based product. One drop is placed in the lens case with the disinfecting solution on a nightly basis (e.g. SupraClens).

Formulation: papain (Hydrocare or Bausch & Lomb); subtilisin A (Ultrazyme); pancreatin (Clenzyme); lipase, pronase, protease, sodium edetate (Amiclair).

Practical advice

- Where papain causes an adverse reaction, especially with high water content lenses, reduce the soaking time to 15 minutes.
- Hydrogen peroxide breaks down residual papain and should be used after the enzyme cleaner.
- Advise hay fever sufferers to use enzyme tablets more frequently in the spring and early summer.

27.4.5 Professional cleaners

Strong oxidizing agents (e.g. sodium perborate) have been used by the practitioner for intensive cleaning and rejuvenation. Their action is enhanced by means of tonicity changes and they should not be used more than once on a lens because of dimensional changes. High water content lenses are more susceptible and should be treated at a lower temperature for a shorter period of time (*see* Section 4.4.1).

27.4.6 Contact lens case

The contact lens case should be air-dried whilst lenses are worn. Ideally the case should be changed on a monthly basis. Unless boiled, there should be no contact with tap water in the hygiene regimen. This will avoid possible contamination with *Acanthamoeba*.[14]

Warning

A very small number of patients can give an extreme sensitivity reaction to professional cleaners, however thoroughly lenses are rinsed and boiled out in saline after use.

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CHAPTER 28

Lens collection and patient instruction

28.1 Lens collection

Insertion of lenses

The lenses are inserted after verification and given time to settle before assessing acuities and fitting. An existing wearer needs only a few minutes, whereas a new patient requires 10–20 minutes depending upon lens type.

Assessment of vision

The visual assessment should confirm that acuities are the same as or better than those achieved during initial fitting.

Assessment of fitting

This should confirm:

- That the fitting appears as originally intended.
- That the lenses have been accurately made. Apart from the main parameters, the practitioner should consider other factors such as blending, lenticulation, thickness and edge shape.
- That the fitting appears satisfactory, even if the previous two criteria are met.
- Whether any discomfort is normal or excessive.

28.2 Insertion and removal

Patients often need to realize that handling is a hurdle to overcome, but has little to do with comfort, vision or eventual wearing time. Insertion should always be done over a flat surface or closed sink, while removal can be into the cupped hand for hard lenses. Patients should be taught initially with a mirror, but it is ultimately better for them to manage without. Soft and hard lens insertion follow the same pattern, but removal is different.

28.2.1 Hard lenses

Insertion

The lens is cleaned, rinsed and wetted. The lids are held firmly apart while the patient looks at the reflection of the eye in a mirror. The head may be either vertical or horizontal and the lens is placed on the cornea with the first or second finger of the dominant hand.

Practical advice

- The alternate eye must be kept open to prevent Bell's phenomenon.
- The lids should be held from underneath the base of the lashes to prevent reflex blinking.
- Reassure the patient that the lens does no harm on the sclera and cannot get lost 'behind the eye'.
- Show the patient how to recentre the lens with indirect finger pressure on the lid margins or by massaging through the closed lids.

Removal

The eye must be held open wide enough for the taut lids to eject the lens from behind by means of blinking and:

- One finger pulling slightly upwards from the outer canthus.
- Two fingers from the same hand pulling from the lid margins.
- Two fingers, one from each hand, pulling with a sideways scissors motion.
- Two fingers, one from each hand, positioned vertically and pushing the lid margins against the globe of the eye and towards

each other. This method, although more difficult to learn, is more consistently reliable and will work with a lens that has stuck.
- Holding the lids firmly and turning the eye nasally.

If all of these methods fail, a moistened suction holder can be applied perpendicular to the centre of the lens.

Practical advice

The patient should not be allowed to leave before being competent at lens removal (insertion can be safely practised at home).

28.2.2 Soft lenses

Insertion

The general principles are the same as for hard lenses. The key difference is that as lenses are self-centring patients need not be concerned if they are inserted out of position. Where near fixation is uncontrollable, especially with hypermetropes, lenses can be inserted onto the inferior sclera while looking upwards at a distant fixation target.

Practical advice

- To stop lens ejection at the moment of insertion because of an air bubble, advise the patient to take both hands away and look down slowly. The eyes should be gently closed and the lids squeezed together to remove the bubble.
- A dry finger helps stop the lens reversing.
- Allow ultrathin lenses to dry on the finger for about 20 seconds to help insertion.
- With ultrathins, it may be necessary to pull the upper lid over the lens to prevent the lens rolling out of the eye on lid closure.
- If the lens is uncomfortable on insertion, it should be slid onto the temporal sclera and allowed to recentre. This usually dislodges a foreign body, make-up or very small air bubble; the lens should be removed, rinsed and reinserted if discomfort persists.

With silicone hydrogels air bubbles frequently need removal by sliding the lens off the cornea and recentring.

Removal

Hard lens pulling methods do not generally work with soft lenses. Instead they are removed by:

- Sliding onto the temporal or inferior sclera and pinching out.
- Pinching directly off the cornea (this is a less satisfactory method because of the risk of scratching the cornea).
- Squeezing at the edge of the lens with the upper and lower lid margins to create an air bubble and eject the lens.

i General advice

Where patients experience difficulty with handling, especially with thin lenses, initially use disposables with high power for practice. This makes insertion much easier, gives confidence to the patient and avoids the possible breakage of complex or conventional lenses. When some proficiency has been achieved, the correct *Rx* can then be used and the wearing schedule commenced.

28.3 Suggested wearing schedules

The aim is to achieve a wearing time with hard gas-permeable lenses of 8–10 hours by the time of the first aftercare check-up at about 2 weeks. This interval may be longer with soft lenses, although all-day wear is often achieved more rapidly. The recommended schedule can be recorded as the starting time, increment and maximum.

Examples:

Hard gas-permeable lenses	3 + 1	→	8 h
Previous failure	1 + ½	→	8 h
PMMA	2 + ½	→	8 h
Low water content soft	3 + 1	→	12 h
High water content soft	4 + 2	→	all day
Refits of hard with soft	6 + 2	→	all day
Silicone hydrogels	6 + 3	→	all day (and overnight)

All-day wear is then achieved with hourly build-up if there are no contraindications at the first aftercare visit.

Practical advice

- Wearing schedules must be easy to understand and follow.
- Advise the patient that, to avoid the risk of overwear, the wearing schedule is a maximum and not a target.
- The total wearing time can be divided into two periods at different times of day, usually separated by a 4-hour gap.
- Lenses should be removed and advice sought in the event of persistent discomfort, redness or other unusual symptoms.

28.4 General patient advice

New patients should not be allowed to wear lenses home because of the risk of early loss or damage. Before leaving, they should be given further clear instructions, both verbally and in writing, to cover the following points.

Initial advice

- Lens identification.
- How to tell if a lens is inside out (a flatter shape that reverses on gentle squeezing).
- Wearing schedule.
- That lens comfort should be no worse than that already experienced on a tolerance trial and that the eyes should not become unduly red or sore.
- To bring to the first aftercare examination both their lens case and their spectacles.
- That unless there is a serious problem with comfort or vision they should come to the aftercare visit having worn lenses for as long as possible that particular day.
- The lens case, containing solution, should be carried at all times.
- To handle lenses in a well-lit area with spectacles nearby.
- To follow a routine, always dealing with the same lens first, and to handle only one lens at a time to avoid mixing them up.

Lens care

- Method of lens storage (hard) or disinfection (soft).
- Not to change the brand or type of solution without first consulting the practitioner.

- Names of solutions equivalent to the original recommendations.
- Some solutions are sold overseas with the same brand name but have a different formulation.
- The distinction between cleaning and disinfection.
- Lenses should be cleaned daily, immediately after removal from the eye.
- Never to use hard lens solutions with soft lenses and vice versa.
- That soft lenses are very fragile if they dry out but are not necessarily spoiled since they recover after rehydration.
- To avoid placing two soft lenses in the same compartment of the case since they may stick together and prove impossible to separate.
- The lens case should be changed at regular intervals.

Unusual symptoms

- Sudden acute discomfort is probably caused by foreign bodies.
- Spectacle blur should not be experienced (except with PMMA and some back surface gas-permeable multifocals).
- Difficulty with near vision may be noticed during the first few days.
- Some degree of adaptive photophobia is normal.
- Extreme environments in terms of temperature or humidity may affect both comfort and vision.
- Anything that makes the eyes feel dry may make the lenses temporarily uncomfortable. Factors include: air conditioning, central heating, using VDU screens, and some drugs (e.g. antihistamines, HRT and alcohol).
- Falling asleep with the lenses in or entering extreme environments may give temporary lens adhesion, which may be released by the application of normal saline and gentle lid pressure.

Precautions

- What to do and where to go in case of an emergency.
- Soft lenses should not be worn while eye drops or ointment are used for any reason (wait 1 hour for drops and 4 hours for ointment).
- Hard lenses could be worn with drops but not with ointment.
- Environments containing fumes, chemicals or sprays should be avoided.
- Traces of noxious chemicals must be very carefully removed from the hands before touching the lenses.

- If soft lenses have been left in their case without being worn for more than a few days, they should be disinfected again before use.
- Not to lick lenses prior to insertion.
- Not to use detergents like washing-up liquid with hard gas-permeable lenses because they may damage the surface.
- To use goggles or photochromatic glasses for activities such as cycling or skiing to protect the eyes from wind, dust and dehydration.
- To take care with driving because of altered spatial judgement, and flare at night, especially with presbyopic corrections.
- When travelling or sunbathing, to be careful not to fall asleep with lenses in unless they are for extended wear.
- To avoid wearing lenses where possible on long flights because of the dry atmosphere on aircraft and the possibility of eye infection.
- Swimming is unwise with hard lenses because of the risk of loss. Soft lenses are often better but may still be lost; they might also cause stinging and red eyes if chlorine is absorbed into the material. There is also the risk of infection if lenses are not subsequently cleaned and disinfected. Overall, it is better to use a well-fitted pair of prescription swimming goggles.

CHAPTER 29

Aftercare

29.1 First aftercare visit

The first aftercare examination should ideally take place after 2–3 weeks. If good progress has not been made by this time, success with the initial lenses is unlikely and significant changes may well need to be made. If the timing is too soon, nearly all patients complain of a multitude of genuinely adaptive symptoms; if too long after fitting, disturbing signs may have arisen or patients may have discontinued because of problems that are not adaptive.

The timing of aftercare appointments is important. Daily wear patients should be examined during the afternoon following several hours of contact lens use, whereas extended wear patients should be seen in the morning so that any overnight effects can be observed.

The results of this and subsequent visits should be recorded according to one of the grading scales outlined in Section 3.3.

29.1.1 Initial discussion

Initial discussion should cover the following points, which may require further assessment during the course of the examination:

- What progress the patient feels has been made.
- Are there any particular problems?

- Has the patient come in wearing the lenses – if not, why not?
- Maximum wearing time.
- Wearing time on the day of examination.
- Is handling satisfactory?
- Have all instructions been understood?
- Are instructions being followed?
- Are disposables being changed at the correct interval?
- Are solutions being used correctly?
- Is the wearing schedule being followed?
- Are lenses being worn in the correct eye?
- Are soft lenses inside out?
- Is the patient in a happy and positive frame of mind?

29.1.2 Visual acuity and over-refraction

Snellen acuities are recorded monocularly and binocularly in the normal way. The quality of retinoscopy reflex is particularly important during assessment of vision and over-refraction (*see* Section 29.2).

29.1.3 Assessment of fitting with white light

White light examination, either with low magnification or unaided, gives a preliminary assessment of:

- Lens centration in primary position.
- Lens movement on blinking.
- Lens position with lateral and vertical eye movements.
- Blink rate.
- Completeness of blink.
- Conjunctival injection.
- Head position.
- Eye movements.
- Palpebral aperture.

Some of these factors may well be different during slit lamp examination where the head position is unnatural and light intensity much greater.

Practical advice

- Carefully distinguish between visual and physical symptoms. Patients often complain of discomfort that really relates to vision.

Practical advice

- Some conditions, such as swelling of the bulbar conjunctiva or eyelids, are seen more easily without magnification or with diffuse illumination on the slit lamp.
- With a soft lens, movement is best seen by directing the beam from a hand-held pen torch, not necessarily from in front but from the side or below, so that the junction of the lenticular portion of the lens casts an easily observed annular light pattern and shadow onto the iris background. The movement of this is more easily discernible than that of the lens itself.

29.1.4 Assessment of fitting with fluorescein

Examination with fluorescein is mainly directed at hard lens fittings, although it can also be used with other specialized lenses such as silicone. Ultraviolet light does not give a useful assessment of fitting with hard lenses containing UV blockers (e.g. Boston 7). High molecular weight fluorescein can be used with soft lenses, but generally adds little to white light observation. Fluorescein examination should reveal:

- The central fitting in respect of touch and clearance.
- Peripheral fitting and edge clearance.
- The speed of fluorescein mixing as an indicator of tear flow.
- 3 and 9 o'clock staining.
- Other areas of gross corneal staining or desiccation.

29.1.5 Slit lamp examination with lenses in situ

The slit lamp is the major diagnostic instrument both at initial fitting and at all aftercare examinations. With lenses in situ it is used with varying degrees of magnification to check:

- Lens fit (centration and movement, including push-up test).
- Tear lens with slit beam.
- Signs of gross corneal oedema.
- The bulbar conjunctiva for signs of vessel irritation.
- The condition of lenses.
- Any air bubbles trapped under the lenses.
- Any debris or mucin balls trapped under the lenses.
- Wettability of lens surface

29.1.6 Supplementary procedures with lenses in situ

Supplementary procedures at this stage, with lenses still in situ, may include:

- Photography or digital image capture.
- Contrast sensitivity.
- Keratometry over front surface of lens (with soft lenses).
- Placido disc or Klein keratoscope (with soft lenses).

29.1.7 Slit lamp examination with lenses removed

Lenses are removed and ideally stored in the patient's own case. Fluorescein is then instilled and the eyes examined for:

- Any signs of corneal staining, noting both extent and depth.
- Any signs of corneal oedema (e.g. central clouding, microcysts, striae), with both sclerotic scatter and direct observation.
- Corneal indentation (from hard lens adhesion).
- Scleral indentation (from tight soft lenses).
- Foreign bodies.
- Corneal desiccation.
- Qualitative assessment of tear film.
- Conjunctival injection or desiccation.
- Engorgement of limbal vessels.
- Irritation of lid margins.
- Lid oedema.
- Changes to tarsal plate (seen with lid eversion).

29.1.8 Supplementary tests with lenses removed

Examination may indicate that supplementary procedures are advisable:

- Keratometry.
- Quantitative assessment of tear flow (*see* Section 5.6).
- Staining with rose bengal.
- Photography or digital image capture.
- Pachometry.
- Aesthesiometry.

29.1.9 Clinical adjustments or changes

The practitioner is now able to decide whether any symptoms are purely adaptive and can be temporarily ignored or whether some

action is needed. There are several possible changes that may be necessary:

- Alteration to power or fitting. Hard gas-permeable lenses may be either modified or exchanged, depending upon the laboratory policy. Soft lenses require replacement.
- Refitting with the same general type of lens. For example, a hard gas-permeable lens with a higher *Dk* material; a soft lens with a different water content.
- Refitting another make of disposable with either the same or a different replacement interval (e.g. daily with daily, or monthly with daily).
- Refitting with a totally different type of lens. For example: hard gas-permeable with soft; soft with hard gas-permeable; or spherical with toric.
- Different solutions, e.g. completely changing the regimen because of allergy, adding saline as an extra rinsing solution, or using a more efficient cleaner.
- Adjustment to the wearing schedule. Adaptation can often be helped with a change of wearing schedule, either slower or occasionally faster (e.g. to span a working day as soon as possible). A single period can be divided into two or vice versa.

29.1.10 Further discussion with the patient

The aftercare examination should conclude with further discussion, particularly to maintain patient enthusiasm. It should include:

- Reassurance concerning any subjective symptoms.
- Any lens changes with reasons.
- Any changes to solutions regimen.
- Recommended date of next visit.

29.2 Visual problems

29.2.1 General factors

First look for spherical errors and, if this improves acuity to a satisfactory level, small cylinders can be ignored.

- Distance acuity should be assessed separately from near and intermediate vision, since different and independent problems can arise.

- Snellen acuity is recorded in the usual way. Binocular acuity is often significantly better than that expected from monocular results, particularly with multifocals. Contrast sensitivity measurements may explain visual problems where recorded acuities appear to be satisfactory.
- Retinoscopy reflex is an important diagnostic aid. It can show optical aberrations in a lens because of poor manufacture which may not be apparent with verification.
- A retinoscopy reflex improving after a blink with a soft lens indicates a tight fitting (*see* Chapter 18).
- The ophthalmoscope can also reveal lens aberrations as well as special features such as the position of a bifocal segment.
- Spectacle blur should not be present with hard gas-permeable and soft lenses. It is almost to be expected with PMMA.

Distance vision

Adaptive problems

- Variable vision. Most patients are affected to some degree during the early stages of adaptation.
- 'Foggy' vision due to greasy lenses. Usually worse in the afternoon and frequently associated with poor blinking and VDUs.
- Asthenopia, because of minor refractive changes or while the patient gets used to a different type of vision.
- Distorted vision and spatial judgement. Myopes and hypermetropes notice, respectively, larger and smaller retinal image sizes.
- An apparently unequal change in over-refraction, with one eye requiring more minus and the other less, is a frequent indication that right and left lenses have been reversed.

Non-adaptive problems

- Blurred vision because of refractive changes. When tear flow has returned to normal, changes in refraction of 0.50 D can sometimes occur. An increase in minus may also indicate corneal oedema, so keratometry and slit lamp findings should also be assessed.
- Blurred vision because of residual astigmatism. This should be predictable at initial fitting, but is sometimes not observed until lenses have fully settled. Patients typically complain of ghosting. Consider a front surface toric.
- 'Foggy' vision because of greasy lenses. Tends to be worse immediately on insertion because of poor wetting or late in the day because of surface drying. Look for CLIPC by everting the lids;

this can sometimes occur within a few days of lens wear. Ensure solutions are being used correctly and possibly change to a different system. Hard lenses may need to be repolished and re-edged (sometimes necessary even with new lenses) or require an entirely different edge shape. Alternatively, consider a different lens material.

- Blurred vision because of oedema. Patients typically complain of 'foggy' or 'cloudy' vision. It can be differentiated from greasy deposits because if the lenses are cleaned and reinserted there is no temporary improvement in vision. It used to be much more common with PMMA, which was fenestrated or refitted. Hard gas-permeable and soft lenses can be refitted with higher *Dk* materials.
- Asthenopia may be due to residual astigmatism, over-correction, binocular imbalance or change in eye dominance (e.g. because of residual astigmatism in the dominant eye).

Near vision

Near vision problems are frequently encountered in the early stages of adaptation with all types of lens (*see* Section 5.4).

Intermediate vision

Music reading is a common problem because of the working distance, poor lighting conditions and instability of vision during adaptation. VDUs and painting can cause similar difficulties.

29.2.2 Hard gas-permeable lenses

- Flare is worse with small lenses and flat peripheries. Possible modifications are thinning the mid-periphery or edges to improve centration. Otherwise fit a lens with a larger BOZD and total diameter; use less edge lift, especially in aspheric form; or change to a soft lens.
- Variable vision on blinking because of excessively mobile lenses.
- Blurred vision because of lens flexure. Consider a flatter fitting, greater centre thickness or a more rigid material.

29.2.3 Soft lenses

- Flare is uncommon with soft lenses, but can occur with some designs of toric and with a displaced pupil. Where the patient cannot adapt, the lens should be remade with a larger FOZD or refitted with a different design.

- Blurred vision, except after a blink, suggests a tight fitting. This may be confirmed by the retinoscopy reflex.
- Variable vision, worse after a blink, suggests a loose fitting.
- Deterioration of vision during the course of the day may be due to lens dehydration.

29.3 Wearing problems

29.3.1 General factors

The practitioner must decide whether the fitting:

- Still looks as intended at the initial fitting. It is possible for either the eyes or the lenses to have altered.
- Is satisfactory in terms of position, movement, central fit, peripheral fit and centration.
- Is responsible for any subjective symptoms. Problems can arise, however satisfactory the fitting and quality of lens manufacture.
- Is causing any asymptomatic problems (e.g. oedema with an immobile lens).

29.3.2 Cornea

Oedema

Oedema is quite feasible with hard gas-permeable and soft lenses where they are low-riding, sticking, or the cornea has high oxygen requirements. Sclerotic scatter in a darkened room shows central oedema most clearly. This technique is not so successful with soft lenses, where the oedema tends to extend from limbus to limbus and may give rise to striae. Microcysts and bullae are other signs of corneal swelling. Subjectively, patients may complain of photophobia, cloudy vision or spectacle blur.

Staining

Several types of staining are observed in practice.[1]

Arcuate staining

Arcuate staining with hard lenses is usually found in the superior mid-periphery of the cornea (Figure 29.1). It is often asymptomatic

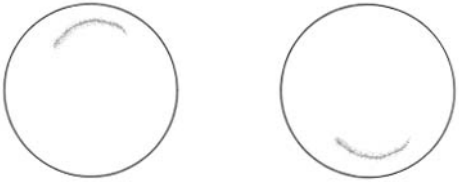

Figure 29.1 Arcuate staining

and can be caused by:

- Sharp or poorly blended transitions.
- Sharp or poorly finished edges.
- Insufficient edge lift.
- Lens adhesion.
- Overall tight fitting.
- Tight lids giving excessive force during blinking.
- Badly finished or blocked fenestrations.
- Deposits on posterior lens surface.

Pseudo-arcuate staining is sometimes observed with narrow edge lift. The lens periphery gives an arcuate pressure effect which does not actually take up fluorescein stain. It is sometimes sufficient to reveal the Fischer–Schweitzer corneal mosaic. Remedies to arcuate staining include:

- Fully blending all transitions.
- Re-edging.
- Greater edge lift.
- Smaller BOZD.
- Flatter BOZR.
- Changing to a different total diameter.

Arcuate staining is also observed with both daily and extended wear soft lenses. Although it can occur in most regions of the cornea, it is more commonly found towards the superior limbus. It occurs with thicker and higher water content lenses and with silicone hydrogels because of their greater stiffness. The staining has been referred to as superior epithelial arcuate lesions (SEALs) and usually causes discomfort with reduced wearing time, particularly when associated with corneal drying. In severe cases there is gradually advancing superior vascularization. It is usually resolved by changing the design or water content, but may occasionally necessitate refitting with hard lenses.

Arcuate staining in the lower third of the cornea is sometimes referred to as a *smile stain*. It is usually caused by lens dehydration and is often associated with poor or incomplete blinking. It may be asymptomatic but more frequently causes a gritty or burning sensation. A looser fitting lens or a material with different dehydration characteristics is required.

3 and 9 o'clock staining

3 and 9 o'clock staining is created by drying in the nasal and temporal areas of the cornea (Figure 29.2). It is almost always a problem of hard gas-permeable lenses rather than with PMMA, with several possible causes. These must be recognized before the correct remedial action can be taken:

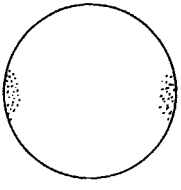

Figure 29.2 3 and 9 o'clock staining

- Poor blinking.
- Inadequate tear film.
- Wide palpebral apertures.
- Periphery too flat or edges too thick (lid held away from the corneal surface – *lid gap*).
- Periphery too tight (physical disruption of tear film).
- Total diameter too large (physical disruption of tear film).
- Total diameter too small (disincentive to proper blinking).
- The lens material (tear film disrupted by poor surface wetting properties).

3 and 9 o'clock staining may be resolved by:

- Correct blinking.
- A thinner lens.
- Refitting with a lid attachment design.
- A different total diameter.
- A different lens periphery.
- Refitting with a better wetting material.
- Refitting with soft lenses.

Central staining

Central staining is caused by the breakdown of the corneal epithelium as a result of corneal oedema (Figure 29.3). It is possible with any type of lens, but was commonly associated with PMMA.

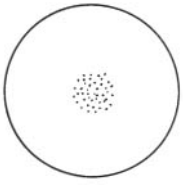

Figure 29.3 Central staining

Punctate staining (corneal stippling)

Punctate staining may be either intense or diffuse and has a variety of causes:

- Corneal desiccation between the lower periphery of a hard lens and the limbus due to exposure of the epithelium where it is not lubricated by the lids on blinking (Figure 29.4). It may be regarded as a more superficial and more diffuse type of 3 and 9 o'clock staining and responds to the same remedial actions.
- Solutions. Punctates vary from extremely fine and diffuse over the entire corneal surface with no apparent symptoms (Figure 29.5), to large coalescent areas with gross hyperaemia, lacrimation and discomfort.
- Material allergies.
- Toxic reactions (e.g. to contaminated soft lenses or unreacted monomers within the lens material).

Figure 29.4 Inferior punctate staining

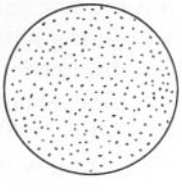

Figure 29.5 Diffuse punctate staining

Foreign body

Staining is typically superficial and linear with a curved or zig-zag shape (Figure 29.6), although sometimes a foreign body may be trapped by the lens deep into the cornea. The sudden sharp pain associated with foreign bodies is a constant minor hazard with hard gas-permeable lenses and, because the corneal sensitivity is not depressed to the same extent as with PMMA, often causes greater problems.

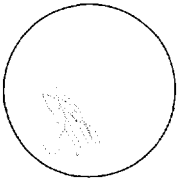

Figure 29.6 Foreign body tracks

Irregular staining

Irregular staining may have a variety of possible causes:

- A poorly fitting lens.
- A damaged lens.
- Deposits on the posterior lens surface.
- Badly finished or blocked fenestration.
- Fingernail scratch from poor insertion or removal.

Air bubbles (dimpling)

Dimpling occurs mainly with hard lenses, but is also quite possible with soft. The small air bubbles trapped in a pool of tears beneath a contact lens act as foreign bodies. They give a fairly dramatic appearance with fluorescein, but do not give true staining (Figure 29.7). If the lens is removed and the eye rinsed with saline, irregular depressions can be seen in the corneal surface, but the apparent staining disappears with no actual uptake of fluorescein by the epithelium. Dimpling causes no discomfort, but gives blurred vision if it occurs within the pupil area where it is easily detected with both the retinoscope and ophthalmoscope. As the bubbles coalesce, they can either froth or occasionally form a single large bubble that may lead to corneal desiccation. Dimpling is found:

- Centrally, with a steep fitting.
- Superiorly, under a flat periphery in a stable high-riding lens.
- With highly astigmatic corneas.
- With keratoconus and other irregular corneas.

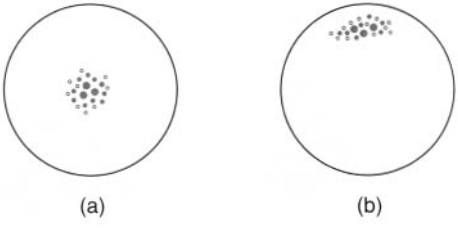

Figure 29.7
(a) Central dimpling;
(b) superior dimpling

It can be helped by:

- Loosening the fit to promote better tear flow.
- Changing the BOZD or total diameter.
- Fenestration, although this could make it worse.

Mucin balls

Corneal dimpling is also seen with mucin balls, which are most commonly associated with silicone hydrogels. *See* Section 20.3.

Practical advice

Small, discrete areas of staining (grade I) and isolated punctates can often be safely ignored with hard lenses. Much more careful assessment is necessary with soft lenses to ensure that they are not a precursor of a more serious corneal complication.

29.3.3 Limbus

Blood vessels

It is always important to examine carefully the superior corneoscleral junction, since the limbal blood vessels dilate in response to any adverse stimulus such as physical irritation, insufficient oxygen or solutions reaction. It is also possible for 'ghost' vessels from previous contact lens wear to refill within a few days if stimulated by these same factors.

Staining

Staining at the limbus can occur for various reasons:

- Solutions reaction.
- Abrasions from lens edges.

- Desiccation (3 and 9 o'clock).
- Exposure, usually inferior.
- Nasal or temporal decentration of a soft lens.
- Hypoxia beneath the upper lid.

With soft lenses, an accumulation of fluorescein rather than staining may sometimes occur around the limbus where the lens has created a pressure effect.

Dellen (Fuch's dimple)

The long-term consequence of severe 3 and 9 o'clock desiccation with hard gas-permeable and PMMA lenses is dellen formation.

This shows as marked corneal thinning at the limbus associated with severe conjunctival injection. Recovery, however, can occur within a few days of ceasing contact lens wear.

Limbal opacification

Although limbal opacification was usually a long-term response to PMMA, it can occur more rapidly with gas-permeable hard lenses. It is observed together with an advancing area of corneal drying, and on rare occasions it is observed by the time of the first aftercare examination.

Pingueculae

Pingueculae may become injected during contact lens wear, particularly where they are associated with poor blinking and dry eyes. Patients often notice them for the first time when beginning to use contact lenses and may require reassurance that they are benign and are not actually caused by the lenses.

29.3.4 Bulbar conjunctiva

Injection

Some minor degree of redness is frequently adaptive and there may be staining with either fluorescein or rose bengal. More severe conjunctival injection can be due to:

- Solutions reaction.
- Other allergies.
- Poor blinking.
- 3 and 9 o'clock staining.

- Other desiccation.
- Infections.
- Physical irritation.

29.3.5 Lids

Contact lens induced papillary conjunctivitis (CLIPC)

CLIPC is an inflammation of the papillary conjunctiva, usually of the upper lids, characterized by the presence of irregularly shaped papillae. These may appear similar to those found with vernal catarrh, but are histologically different and progress in four distinct stages:[3]

1 Preclinical stage with mild increase in mucus production.
2 Conjunctival hyperaemia and thickening with slight elevation of normal papillae. Vascular tufts can be seen in the papillae.
3 Formation of larger papillae from coalescent smaller papillae, often starting from the inner and outer canthi.
4 Formation of elevated, giant papillae with flattened heads which can stain with fluorescein.

Contact lens wearers are usually seen at stages 1 or 2. The symptoms are quite distinctive:

- Itching on lens removal.
- Discharge in the morning, typically yellow in colour.
- Severe lens deposits causing blurred vision.
- Excessive movement of the lens, which is pulled by the rough inner surface of the upper lid.
- Gradually deteriorating comfort.

The condition can be either unilateral or bilateral and, although more typically a problem of soft lens wear, can be found with all lens types.[4] There are several causative factors, working either on their own or in conjunction:

- Allergic response to the lens material.
- Autoimmune allergic response to protein deposits on the lens surface.
- Solutions sensitivity.
- Mechanical irritation.
- Environmental irritation.
- Predisposition with atopic patients (e.g. hay fever sufferers).

Resolving CLIPC may require several courses of action:

- Consider referral for medical treatment with either sodium cromoglicate 2% (e.g. Opticrom) or steroids such as Predsol-N.
- Discontinue extended wear, at least until condition is resolved.
- Fit new soft lenses or repolish hard lenses.
- Fit new soft lenses before the hay fever season.
- Ensure regular lens replacement or fit disposables.
- Eliminate all preserved solutions.
- Change to a peroxide system.
- Ensure regular use of enzyme tablets.
- With soft lenses, consider a different material or refitting with hard gas-permeable lenses.
- With hard lenses, avoid silicon acrylates and consider fluoropolymers or possibly CAB.

Ptosis

Ptosis is observed in long-term wearers of both hard gas-permeable and PMMA lenses and may be either unilateral or bilateral.[5] It appears unrelated to any particular fitting philosophy or oxygen permeability and is not usually improved by altering the fit. As long as any neurological factors have been eliminated, there may be no need to take any action but merely keep the condition under observation. If ptosis is interfering with vision or cosmetic appearance, the following may be tried:

- Change to soft lenses, which may sometimes prove effective.
- Discontinue contact lens wear.
- Surgical intervention, but this is not always successful.

Miscellaneous lid problems

There are several other possible lid problems. The majority are unconnected with contact lenses, although patients may require reassurance on this point.

- Concretions.[6]
- Make-up trapped on palpebral conjunctiva.
- Blocked meibomian glands and frothing at lid margin.
- Styes and cysts.
- Blepharitis exacerbated by contact lens wear.
- Vesicles on lid margins.
- Skin allergies, often caused by make-up but sometimes by solutions.
- Lid spasms and twitching.

29.3.6 Lens adhesion

Adhesion has been regarded as a hard lens extended wear problem (*see* Section 22.5). It is not uncommon, however, with daily wear towards the end of the day, when the impression of the lens can be seen on the cornea after removal. Patients are often asymptomatic, but the possible problems are:

- Arcuate staining.
- Redness.
- Trapped debris.
- Corneal distortion.
- Infection.

Lens adhesion can be caused by a variety of factors:

- Dry eyes.
- Tight lids.
- Periphery too narrow.
- Lens material (more common with greater flexibility).
- Lens design (more common with aspheric lenses).
- Older and worn lenses

Lens adhesion can be an intractable problem but may sometimes be helped by:

- Flattening the periphery or adding an extra edge curve with a radius of 15.00 mm or 18.00 mm.
- Steepening the central fit.
- Changing the lens design to increase the width of the periphery.
- Increasing the thickness.
- Changing to a more rigid material.
- Improved blinking.
- Lubricating drops.

29.3.7 Environmental and general factors

Some of the most difficult problems in contact lens practice are caused not by the lenses but by the environment or external factors over which the practitioner has no control:

- Central heating.
- Air conditioning.
- Low humidity.
- High altitude.

- Staring at VDU screens.
- Polluted atmospheres.
- Poor lighting.

Symptoms of discomfort are exacerbated by other factors:

- Alcohol.
- Diet.
- Systemic drugs (*see* Section 30.3).
- Oral contraceptives.
- HRT.
- Tiredness.
- Poor general health.
- Pregnancy.
- Psychological effects of tension.

29.3.8 Blinking

Infrequent or incomplete blinking is a particular difficulty with hard gas-permeable and PMMA lenses. It causes several problems:

- 3 and 9 o'clock staining.
- Other corneal and conjunctival desiccation.
- Conjunctival injection.
- Oedema because of insufficient tear pump.
- General discomfort.
- Lens deposits and blurred vision.

Incomplete blinking with soft lenses also causes problems because of dehydration. This in turn can lead to inferior or lower mid-peripheral staining (smile stain) and lens deposits.

Practical advice

Hard lenses act as a strong disincentive to correct blinking, so retraining is rarely successful. Refitting with soft lenses is often a better solution.

29.4 Aftercare at yearly intervals or longer

Examination after 12 months or a longer period is particularly concerned with the possible long-term consequences of contact lens wear and the condition of the lenses. It includes the same stages as

the first aftercare routine (*see* Sections 29.1.1 to 29.1.10) with the key additions of:

- Reassessment of contact lens refraction and fitting.
- Spectacle refraction (*see* Section 30.4).
- Ophthalmoscopy – this may be the only opportunity for fundus and ophthalmic examination.
- Assessment of contact lens condition.

29.4.1 Ocular examination

- Vascularization or neovascularization.
- Oedematous responses (microcysts, bullae, striae).
- Signs of infection (nummular or other infiltrates).
- Corneal thinning.
- Endothelial polymegathism.
- Chronic staining.

Conjunctiva

- Desiccation.
- Injection.
- Pingueculae.

Lids

- Position, including ptosis.
- CLIPC.
- Concretions.
- Patency of meibomian glands.

Tears

- Qualitative assessment.
- Break-up time.

Over-refraction

- Comparison with previously recorded acuities.
- Change in myopia or hypermetropia.
- Change in astigmatism.

29.4.2 Other factors

Reassessing contact lens refraction and fitting

Old and deposited lenses frequently give reduced acuity. Hard lenses may have distorted with repeated handling and soft lenses

become less flexible with age. Spurious refractive changes of up to 1.00 D can be found, so it is essential to reassess both refractive result and fit. Disposable trial lenses should be used routinely for soft lenses in order to obtain a reliable result.

Assessing contact lens condition

It is also important to examine the lens condition both on the eye with the slit lamp and off the eye with a projection microscope. These instruments allow easy demonstration to the patient of surface and edge defects or signs of ageing (*see* Section 30.5). Digital image capture with the slit lamp and viewing on a computer monitor is particularly useful in this respect.

Solutions

It is important to establish that the patient is using solutions correctly. Common errors are:

- Changing brands without consulting the practitioner.
- Omitting to use a daily cleaner.
- Insufficient rinsing of cleaning solution.
- Forgetting to use enzyme tablets.
- Using preserved instead of unpreserved saline.
- Thinking saline is a storage and disinfection solution.
- Forgetting to add the disinfection tablet with chlorine systems.

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CHAPTER 30

Supplementary aftercare

30.1 Emergencies and infections

Emergencies, either perceived or real, are a fairly routine occurrence in contact lens practice. It is commonly assumed by patients that the lenses are invariably the cause of any ocular problem and it may require all of the practitioner's skill to differentiate between contact lens and non-contact lens emergencies.

30.1.1 Infections and inflammatory responses

Infections may be either connected or unconnected with contact lens wear. In serious cases, immediate medical treatment is required to minimize any risk of permanent visual loss.

Microbial keratitis (suppurative keratitis)[1,2]

Microbial keratitis is a potentially sight-threatening condition and requires urgent diagnosis and referral. It is caused by bacteria such as the Gram-negative *Pseudomonas aeruginosa* or the Gram-positive *Staphylococcus aureus* or *Streptococcus pyogenes*. Patients typically

present with unilateral:

- Severe pain.
- Epithelial defect.
- Central lesion over 1 mm in diameter.
- Corneal suppuration (ulceration) which can be rapidly progressive.
- Uveitis.
- Lid oedema.

If patients are observed early, before ulceration occurs, epithelial disturbance or superficial punctate keratitis may be the only signs. Corneal ulcers associated with Gram-positive bacteria are usually smaller and less purulent. The Gram-negative Pseudomonas, in particular, is highly virulent and characteristically produces large epithelial defects with dense anterior stromal infiltrates. Treatment usually commences with a broad-spectrum antibiotic until the specific micro-organism has been identified.

Microbial keratitis in contact lens wearers is associated with soft extended wear,[3] poor patient hygiene, poor compliance and contaminated lens cases.[4]

Contact lens peripheral ulcer (CLPU)

CLPUs are also mainly unilateral and found with extended wear.[5] They are considered to be the result of an inflammatory response of the peripheral cornea. Frequently no causative micro-organism is found on culturing and they have been referred to as sterile ulcers. Compared with microbial keratitis, patients usually present with:

- Mild pain, sometimes described as being like a foreign body.
- Small peripheral lesions in the anterior stroma separated from the limbus. These focal infiltrates are dense, round and usually less than 1.2 mm in diameter.
- An overlying epithelial defect that rapidly takes up fluorescein.
- Bulbar and limbal injection, worse in the region of the infiltrate.
- Non-progressive corneal suppuration.
- No uveitis.
- Normal visual acuity.

Sterile keratitis should be treated as possibly microbial in origin until proved otherwise. The condition responds to topical steroids but frequently no medication is required and it resolves after a few days on ceasing lens wear. Normally an anterior stromal scar remains and takes a minimum of 6 months to disappear.

Practical advice

If a CLPU is suspected and the patient is not referrred for medical opinion, re-examine after 24 hours to ensure that the condition is not misdiagnosed microbial keratitis.

Contact lens acute red eye (CLARE); acute red eye reaction

The red eye reaction is an acute inflammatory response usually occurring with soft extended wear lenses on waking. There is gross unilateral hyperaemia of the bulbar conjunctiva and limbus, associated with varying degrees of pain, photophobia, lacrimation and limbal infiltrates. Corneal staining is either absent or mild punctate in character[6]. The condition has been associated with:

- Gram-negative bacterial contamination.
- A tight lens trapping endotoxins and debris.
- Upper respiratory tract infection.

The contact lens must be removed immediately, after which CLARE usually resolves without any medical intervention. There is, however, a significant possibility of recurrence, in which case extended wear should be discontinued.

Infiltrative keratitis (IK)

The term infiltrative keratitis tends to be used in respect of inflammatory infiltrative events which are not microbial keratitis, peripheral ulcers or acute red eyes. Patients have symptoms of mild pain, redness, and lacrimation. There may be signs of minor corneal trauma such as that caused by a foreign body or a poorly fitted lens. Small diffuse or focal infiltrates are usually found in the corneal periphery but may also occur more centrally. IK occurs with both daily and extended wear and may be caused by bacterial toxins trapped beneath the contact lens.[7]

In some cases patients are completely unaware of the condition, which is discovered by chance at a routine aftercare examination. It is then called asymptomatic infiltrative keratitis (AIK).

The additional term asymptomatic infiltrates (AI) is used where the cornea shows a mild infiltrative response with one or more small focal infiltrates 0.2 mm or less in size. These are also observed in asymptomatic patients at routine aftercare examination.

Practical advice

- Corneal ulceration can progress with great rapidity so that serious visual loss can occur within 12–24 hours. Immediate referral direct to an ophthalmologist is absolutely essential.
- Chloramphenicol, which is currently the only antibiotic available to optometrists as a first aid treatment, is ineffective against Gram-negative micro-organisms such as *Pseudomonas aeruginosa*.

Acanthamoeba keratitis

Acanthamoeba keratitis is an uncommon but devastating ocular condition. There are several reports that associate it with the use of contact lenses[8,9] so that the practitioner should always be open to its possibility in a patient presenting as a painful emergency.

Acanthamoeba is a non-flagellate protozoon occurring in trophozoite and cyst forms. The double-walled nature of the cyst accounts for its strong resistance to treatment. The organism is widely distributed in air and water, so tap water should never be recommended for rinsing contact lenses or their cases. Patients should also be advised to be particularly careful with cleaning and disinfection after swimming with lenses. Miraflow is specifically effective against *Acanthamoeba*.

The later, characteristic feature of *Acanthamoeba* keratitis is an extensive ring infiltrate in the cornea. There is often hypopyon and secondary glaucoma. The condition produces a high incidence of corneal scarring, requiring keratoplasty, and immediate referral is therefore essential. The earlier the diagnosis, the more successful the treatment, and a referral note should include the practitioner's suspicions.

Early features of *Acanthamoeba* infection are:

- Severe ocular pain or aching, out of all proportion to any initial signs of infection or inflammation.
- Red eye.
- Reduced acuity.
- Central punctate epithelialopathy which often breaks down to an erosion. The lesion may well be dendritiform and therefore mistaken for ocular herpes simplex.
- Perineural infiltration of corneal nerves, extending from the centre to periphery.
- Superficial nummular keratitis.

Various treatments have been developed but Brolene drops (propamidine) and ointment (dibromopropamidine) both have some efficacy. Steroids are usually contraindicated.

Viral keratitis

The contact lens practitioner may encounter two main types of viral keratitis, although there is no particular association with contact lenses. Viral infections typically produce a profuse serous discharge.

- Herpes simplex. Very painful and typically showing dendritic lesions or disciform keratitis. There is generally scarring with the risk of recurrence. Aciclovir is used in treatment.
- Adenovirus. Mildly painful, showing multiple subepithelial infiltrates which may fade very slowly. The condition is extremely infectious but self-limiting with only a small chance of visual loss.

30.1.2 Overwear syndrome (acute epithelial necrosis; 3 a.m. syndrome)

This is commonly associated with PMMA, although it is not unknown with either hard gas-permeable or soft lenses. The patient is typically awakened in the middle of the night with extreme pain ('red-hot needles' is the usual description), photophobia and lacrimation. It is an extreme response to gross corneal oedema as a result of excessive contact lens wear. Typical causes are:

- Too fast an initial wearing schedule.
- Patient forgetting to remove lenses at a specified time.
- All-day use after a gap in lens wear because of loss.
- Falling asleep with lenses in.
- Chronic oedema with longer than normal wear in a hot and stuffy atmosphere.

Examination, where feasible, shows large areas of corneal staining. Treatment may well require local anaesthetic and antibiotics to minimize the risk of secondary infection. In extreme cases, medical treatment is necessary with 'pad and bandaging' in a darkened room for 24 hours. The epithelium usually recovers within 2–3 days, although contact lens wear should not be resumed for at least a week and not until the practitioner has confirmed that the cornea is clear. A very slow wearing schedule is then indicated. Patients require considerable reassurance that they will not suffer permanent damage to their eyes.

Practical advice

- Local anaesthetics tend to retard epithelial healing and should only be used in cases of extreme pain. The preferred analgesic is aspirin with whisky.
- After recovery, to prevent recurrence the patient should be refitted with a more permeable lens.

30.1.3 Foreign bodies

These are much more common with hard lenses. The damage to the corneal epithelium, however, can sometimes be greater with soft lenses because the foreign body remains trapped behind the lens for a longer period of time. Patients complain of sudden, acute pain during the wearing day. The lens must be removed and fluorescein instilled to assess the depth of staining with slit lamp optic section. Treatment consists of antibiotics, with 'pad and bandaging' in severe cases.

30.1.4 Corneal abrasions

Severe abrasions cause symptoms similar to those resulting from foreign bodies. They may be caused by poor lens handling, typically by fingernails, inserting or wearing damaged lenses, lenses breaking in the eye, and fitting problems.

30.1.5 Solutions problems

A high proportion of soft lens emergencies relate to solutions reactions. Careful questioning is sometimes necessary to reveal either patient error or the offending solution. Typical problems are:

- Genuine allergic response.
- Thimerosal keratopathy, also known as contact lens induced superior limbic keratoconjunctivitis (CLSLK).
- Using hard lens solutions with soft lenses.
- Not neutralizing lenses stored in hydrogen peroxide.
- Confusing soaking and cleaning solutions.
- Reaction to enzyme tablets.
- Using enzyme tablets in conjunction with an incorrect solution.
- Adverse reaction after intensive cleaning.
- Using preserved comfort drops in an otherwise non-preserved regimen.
- Using preserved therapeutic drops.

- Patients changing to a brand different from that originally recommended by the practitioner.
- Patients being sold an incorrect solution.
- A solution bought overseas with the same name but a different formulation.

Practical advice

In some instances (e.g. where patients have instilled unneutralized peroxide or used hard lens solutions with soft) a very severe corneal response is seen. There may be extensive corneal staining with considerable discomfort. In these cases:

- Ensure immediate removal of the lens.
- Use copious irrigation, preferably with 0.9% saline.
- Use chloramphenicol because of the possibility of infection in a cornea with compromised epithelium.
- Consider a topical anaesthetic but only for those patients in severe pain.

30.1.6 Broken and displaced lenses

Novice patients often lose a lens in the upper fornix. It is therefore important to explain at initial collection (*see* Section 28.2) the procedure for recovering such a displaced lens, although this can happen even to experienced wearers. The problem usually occurs with gas-permeable lenses but thin soft lenses, particularly disposables, can sometimes fold up and slip off the cornea.

Most daily disposable lenses are thin and fragile. High water content varieties are therefore quite prone to breakage and this can easily happen on insertion or removal from the eye. A portion may remain which, despite discomfort, patients are unable either to locate or remove from the sclera or upper fornix and they present as an emergency. Lid eversion is frequently required and lens wear can usually be resumed immediately on removal of the broken fragment.

Practical advice

Instill fluorescein into the eye before attempting removal of a broken disposable because:

- A stained lens is more easily and quickly seen.
- Any corneal abrasion is observed at the same time.

30.1.7 Contaminated lenses

This problem mainly applies to soft lenses contaminated by products such as paint, varnish, hairspray and make-up, either by direct contact or indirectly via the hands. Hard lenses are occasionally affected.

30.2 Grief cases (drop-outs)

Not all patients adapt well to contact lenses, however carefully they are fitted. This may be due to the practitioner, the patient or limitations in available lens designs.[10]

30.2.1 Causes

The main reasons for grief cases wishing to consult another practitioner are:

- Poor vision or comfort because of fitting or refitting with an inappropriate type of lens.
- Wearing the correct type of lens but an unsatisfactory fitting.
- Poor vision or comfort because of badly manufactured lenses.
- Using inappropriate solutions.
- Recurrent deposits or greasy lenses.
- Persistent red eyes or 3 and 9 o'clock staining because of poor blinking.
- Dry eyes.
- Spectacle blur.
- Allergic response to materials or solutions.
- The patient does not understand or follow instructions.
- The presence of an eye infection, either connected or unconnected with the contact lenses.
- The patient may no longer be suitable for contact lens wear because of corneal exhaustion, dry eyes or environmental factors.
- The patient has never really been suitable for contact lenses.
- The patient may have lost confidence in the previous practitioner, although the lenses are perfectly satisfactory.

30.2.2 Courses of action

The new practitioner must decide on the main reason for previous dissatisfaction and whether successful contact lens wear is feasible.

The following are the most common courses of action:

- Modify existing lenses. This applies mainly to hard gas-permeable lenses.
- Refit lenses of the same general type (e.g. soft with soft or hard gas-permeable with hard gas-permeable), but use a different material, *Dk* or design.
- The mass of hard gas-permeable lenses can be altered by selecting a material with a high or low specific gravity, even when all other parameters remain the same. A lower specific gravity can affect the lens mass significantly and so cause alteration to the lens position, making a low-riding lens sit centrally. Similarly, a higher specific gravity can lower the position of a high-riding lens.
- Refit with lenses of an altogether different type (e.g. soft with hard gas-permeable or hard gas-permeable with soft).
- Change the solutions or disinfection system. This is often advisable, even where refitting is also carried out.
- Give advice on correct blinking.
- Give clear instructions in the correct use of solutions, even where there is no sensitivity problem.
- Give correct instructions in lens handling and maintenance.
- Refer for medical opinion.
- Advise patients that they are now unsuitable for lenses. They will be disappointed, but at the same time should accept the fact that they have at last been given unequivocal advice.

Practical advice

- Grief cases have generally been disillusioned with contact lenses and are seeking a swift and positive resolution to their problems.
- Where refitting is necessary, dispense lenses from stock where possible.
- Give a safe but rapid wearing schedule.
- Put a time limit of 2–3 weeks on any course of action to prevent an unsuccessful case dragging on interminably.
- Where only partial success is possible, advise patients to be realistic, accept a restricted wearing time or discontinue.
- Hold out the hope of possible future improvement since new lenses and materials are continually being introduced.

30.2.3 Avoiding grief cases

- Do not refit lenses just for the sake of it. If a patient is entirely happy with existing lenses and examination reveals no serious, asymptomatic problems (e.g. corneal oedema or vascularization), then leave well alone. This often applies to old-fashioned low *Dk* lenses, either hard or soft.
- Explain, nevertheless, any relevant new developments and clarify misconceptions (e.g. disposables may not be feasible for some complex lens forms).
- Do not refit PMMA wearers with soft lenses (*see* Section 13.3.3).
- If a patient has been refitted with theoretically better lenses (e.g. PMMA with hard gas-permeable or low water content soft with high) and they do not settle rapidly, then return to the previous type without delay.
- If a replacement lens does not settle rapidly with an experienced lens wearer, change it or refit.
- Use only the best possible quality lenses. Poorly made examples can waste more in practitioner time than the cost of the lenses.
- Adopt a flexible and open-minded approach to contact lens fitting and be prepared to change from one type to another if problems arise.

30.3 Side effects of systemic drugs

Many systemic drugs have side effects that give rise to symptoms of discomfort, blurred vision, dryness and lens discolouration (Table 30.1).

Practical advice

- Pathologies of the cornea due to side effects are serious and tend to be progressive as the dosage continues.
- Use the yellow card system to report any adverse response to either contact lens products or systemic drugs.

30.4 Prescribing spectacles for contact lens wearers

The factors to consider include:

- Establishing the correct *Rx*.
- Providing a correction that is visually comfortable.

Table 30.1 Systemic drugs and their side effects

Drug	Side effect
Central nervous system	
Carbamazepine (Tegretol)	Conjunctivitis and photophobia
Maprotiline (Ludiomil)	Intolerance to contact lenses and loss of tear fluid, conj oedema, lid oedema
Diazepam (Valium)	Lowered visual acuity and reduced tear production, decreased CL tolerance, tearing, burning
Amitriptyline (Tryptafen)	Reduced tear flow
Lorazepam (Ativan)	Dry eye
Blood pressure and heart condition	
Atenolol (Tenormin)	Smarting eyes and diffuse conjunctival
Amiodarone (Cordarone)	Faint striae in both corneas and yellow brown deposits
Oxprenolol (Trasidrex)	Dry eye/conjunctivitis
Cyclopenthiazide	Dry eye/conjunctivitis
Methyldopa (Aldomet)	Keratoconjunctivitis sicca
Musculoskeletal disorders (anti-inflammatory)	
Penicillamine (Distamine)	Dry eye and reduced vision
Urinary anti-infectives	
Nitrofurantoin (Furadantin)	Marked irritation with profuse lacrimation
Anti-allergic	
Sodium cromoglicate (Opticrom)	Reduced tear production
Antibiotics	
Doxycycline (Vibramycin)	Marked photophobia and contact lens sensitivity
Respiratory system	
Salbutamol (Ventolin) Rifampicin (for TB)	Increased sensitivity to contact lenses and solutions Discolours soft lenses yellow ?Reduced tear production
Oral contraceptive and oestrogen	
Microval	Decreased CL tolerance
Ovranette	Reduced tolerance to contact lenses
HRT (Premique)	Dryness and irritation

continued

Table 30.1 *continued*

Drug	Side effect
Alimentary system	
Sulfasalazine (for Crohn's disease)	Discolours soft lenses
Nasal decongestants	
Brompheniramine, Phenylephrine	Reduced tolerance to soft contact lens wear
Adrenaline (epinephrine)	Discolours soft lenses ?Corneal pigmentary deposits
Antihistamines	
Piriton, Clarityn	Dehydration Reduced tear production

- Time of examination.
- When the spectacles are likely to be worn.
- Type of contact lens worn.

Non-tolerances are a frequent problem because, irrespective of contact lens type, many patients find great difficulty in adapting to the different nature of a spectacle correction worn in front of rather than on the eye. Typical problems are:

- Visual distortion (e.g. sloping floors and bowed door frames).
- Different spatial perspective.
- Different image size.
- Restricted field of view.
- Reflections, especially at night.
- Intolerance to full correction.
- Intolerance to cylinders.

Typical causes are:

- No spectacle refraction for several years and a correction showing a very marked increase in myopia.
- Astigmatism very different in axis and power compared with any previous correction.
- Patients may literally have worn no spectacles for decades because with PMMA it was not feasible to obtain a satisfactory result.
- Contact lens monovision (deliberate or accidental) may give difficulty with either bifocals or separate distance and near spectacles.

30.4.1 PMMA

Long-term PMMA wearers are the most difficult for prescribing spectacles because:

- There is almost invariably some degree of corneal distortion or moulding.
- There is frequently some level of corneal oedema.
- Refraction often gives a poor and unreliable end-point.
- Acuity may be depressed.

The main problem, however, is that after PMMA lenses have been removed, the refraction continuously changes for several weeks while the corneal curvature is undergoing an equivalent cycle of change. Although there are wide individual differences, there is an average decrease in myopia of 1.32 D over the first 3 days, followed by an increase in myopia up to 21 days (Figure 30.1).[11] At the same time, there is a strong trend towards increased with-the-rule astigmatism.

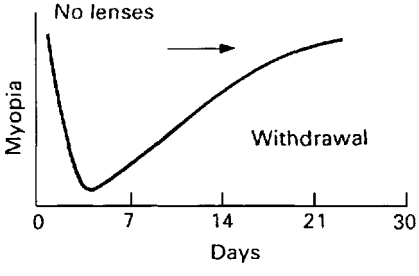

Figure 30.1 Myopia after PMMA lens removal (after Rengstorff, 1967[11])

In practical terms, therefore, there is no merit whatever in leaving out lenses for periods of several days. Not only is it extremely inconvenient for the patients, especially if they are highly myopic with no current spectacles, but it is also liable to give a wildly inaccurate result. The once common advice of removing lenses for 2 or 3 days before refraction, in fact gives an examination time at the point of maximal change.

There are two realistic times for examination, the choice of which should be discussed with the patient according to when the correction is to be used:

1 Afternoon, immediately on removal of lenses, gives the closest approximation to a correction for use in the evenings when lenses have been removed for the day.

2 Morning, prior to insertion of lenses, simulates the occasion when contact lenses will not be worn for a day.

The morning result is usually 0.50–0.75 D less. Under-correcting the evening refraction can often give a satisfactory compromise.

30.4.2 Hard gas-permeable lenses

Most modern lenses cause few problems compared with PMMA, but some degree of corneal moulding may be encountered, particularly with astigmatic eyes, where aspheric designs or back surface simultaneous vision multifocals are used. Pronounced distortion occurs in cases of lens adhesion, and refraction should be postponed.

Satisfactory refraction is usually achieved immediately on removal of lenses. If the result does not correlate with the contact lenses, keratometry and any previous spectacles, it should be repeated as a morning refraction.

Where PMMA has been refitted with hard gas-permeable lenses, wait about 2 months before refracting for spectacles, by which time most corneal changes will have resolved. This is confirmed by monitoring 'K' readings.

30.4.3 Soft lenses

Corneal curvature and refractive changes are far less common with soft lenses, although some steepening of the vertical meridian may occur. There is little mechanical moulding, and where oedema is present it generally extends from limbus to limbus without localized changes in curvature or physical distortion. Refraction on removal of soft lenses generally gives a good result, but where there is any doubt it should be repeated in the morning.

Practical advice

- Explain the potential problems to the patient.
- Take notice of any pre-contact lens spectacles, however old.
- Give maximum possible binocular addition.
- Consider under-correcting spheres by 0.25–0.50 D.
- Consider under-correcting or omitting cylinders, especially if oblique.
- Be careful not to change eye dominance.
- Repeat refraction on another occasion if it does not correlate with the contact lenses, keratometry and previous correction.

30.5 Lens ageing

30.5.1 Soft lenses

Soft lenses stored in sealed vials or blister packs have long expiry dates and remain in good condition for several years. Once they are worn regularly, however, lens deterioration occurs in a variety of ways.[12] Unlike hard lenses, ageing is a common cause of conventional lens replacement and is influenced by a variety of factors:

- Lens material. High water content ionic lenses deteriorate more rapidly than low water content and non-ionic because of deposits and discolouration (*see* Section 6.3).
- Wearing schedule. Extended wear lenses are more badly affected by deposits than those used daily.
- Tear chemistry. Some patients' lenses last only a few weeks, whereas others can remain in acceptable condition for several years. Dry eyes cause particular problems.
- Method of disinfection. Lenses had a shorter life span when sterilized by heat compared with solutions. Hydrogen peroxide is particularly good at keeping lenses in optimal condition (*see* Section 27.4.1).
- Regularity and method of cleaning.
- Patient care.
- The environment in which lenses are worn. Dry atmospheres enhance lens deposits.
- Prolonged use of VDUs also exacerbates lens deposits.

Protein film

All lenses suffer protein deposits to some extent. With HEMA in particular, there is a chemical bonding between tear protein and the polymer's hydroxyl groups. Heat disinfection exacerbates the problem by denaturing any surface protein that has not been removed by proper cleaning. It is observed as a blue-grey film by oblique illumination against a dark background (dark-field illumination). It can also be seen during slit lamp examination if the patient stares and the lens surface is allowed to dry.

Discolouration

Most high water content lenses suffer from brown discolouration to some extent. HEMA can also be affected and heat aggravates the problem. Adrenaline compounds in the tears, nicotine and

make-up have been suggested as other causes. Some lenses fluoresce with ultraviolet light. This effect may be due either to the material (with new lenses) or chlorhexidine bound to surface deposits. Acuity may be reduced and significant reductions in light transmission occur.[13] Hormonal problems and systemic drugs have also been implicated (*see* Section 30.3).

White spots

White spots almost invariably occur on the front surface of the lens. In the early stages they appear as fine punctate dots and gradually develop into discrete, elevated deposits scattered irregularly within the area of the exposed palpebral aperture. High water content lenses and those for extended wear are much more affected, particularly with dry-eyed patients and poor blinkers. In severe cases, white spots can be over 1 mm across and extremely uncomfortable. These larger deposits have also been referred to as *mulberries* and *jelly-bumps*. The composition of white spots has been variously described as a combination of mucoprotein and lipids, mucopolysaccharides, and calcium phosphate and calcium carbonate.[12]

Rust spots

Rust spots are mainly due to atmospheric pollution and are more often observed in patients from industrial areas or those who travel by train. They are a form of benign ferrous contamination affecting all types of soft lens and are occasionally found as a manufacturing fault.

Surface and edge deterioration

As lenses become older and less flexible, they become uncomfortable because of surface scratches and edge chips. Engravings can either crack or become encrusted with deposits. Uneven drying of protein film at the lens periphery can cause crenellated edges.

Fitting changes

Lenses with deposits are more influenced by the upper lid and significant changes in fitting characteristics can occur. Usually they become looser and corneal diameter lenses may become badly decentred. High-riding lenses are frequently associated with CLIPC, where the irregular tarsal plate pulls the deposited lens out of position.

Refractive changes

Old and less flexible lenses frequently give reduced acuity as well as spurious changes in over-refraction of as much as 1.00 D. The lens power, therefore, should always be rechecked with a new lens when refitting is necessary.

Practical advice

- Before undertaking professional cleaning, advise patients that it will be carried out 'at their own risk'. Unpredictable and irreversible changes can occur to lens dimensions
- A small minority of highly allergic patients can produce a severe reaction to professionally cleaned lenses.
- Use a shorter cleaning time and lower temperature with high water content lenses.
- Protein film and discolouration can usually be removed or improved by professional cleaning.
- White spots do not respond well and lenses may fail to survive intensive cleaning.
- It is sometimes beneficial to leave lenses in hydrogen peroxide for up to a week, changing the solution every 2 or 3 days, before intensive cleaning.
- Lenses with cracks and chips harbour micro-organisms and should be replaced.
- Patients should be encouraged to replace lenses on a regular basis, rather than expect an unrealistically long life span.

30.5.2 Hard gas-permeable lenses

Hard lenses do not deteriorate in the same way as soft lenses. Their life span is approximately 2–4 years but, depending upon the material, they can also deteriorate in various ways. There is usually no great merit in regular replacement under one year but some practitioners encourage annual replacement.

Deposits

Silicon acrylate materials (*see* Section 6.1.2) attract protein from the tears and most patients benefit from the use of enzyme tablets. Monthly soaking is usually sufficient, although some patients require more frequent treatment.

Fluorosilicon acrylates present less of a problem with protein and many of the materials do not require enzyme tablets.

CAB lenses do not contain silicon. Protein deposits are rarely a problem and enzyme tablets are almost always unnecessary. Lenses do attract lipids, however, so greasing is sometimes a problem.

Discolouration

Discolouration is rarely a problem with most materials. However, some (even when new) show haziness and lack of optical transparency.

Surface and edge deterioration

Some of the fluorosilicon acrylates have proved quite brittle, and edge damage or complete breakage is not uncommon. Certain of the high *Dk* silicon acrylates suffer from surface crazing. CAB lenses are more prone to surface scratching.

30.5.3 PMMA

PMMA is still the most stable and inert material. It attracts little in the way of permanent deposits, although some patients are troubled by greasing with older or scratched lenses. It can readily be repolished and frequently gives a life span in excess of 5 years.

30.6 Lens modification

Modifications may be found necessary either during initial adaptation or at annual aftercare examinations. Adjustments are usually better left to the laboratory, especially with the less stable modern hard lenses. There are some occasions, however, when it is essential for lenses to be modified on the spot, and the following equipment should be available as a minimum:

- Drum with motorized spindle.
- Velveteen pad.
- Reversible suction holder or chuck.
- Selection of convex radius tools with polishing tape.
- Polishing medium.

30.6.1 Hard gas-permeable and PMMA lenses

It is possible to make the following modifications:

- Blend and flatten peripheral radii.
- Reduce TD.
- Minor changes to BVP.
- Repolish or reshape edges.
- Repolish front surfaces.
- Fenestration.
- Truncation.

Blending and flattening of peripheral curves

- The lens is held centrally by the convex surface with a suction holder or negative chuck.
- A tape-covered convex tool of the required radius is selected.
- The lens is rotated against the tool in the opposite direction of motion to the spindle.

Changing the BVP

It is easier to add minus than plus power without upsetting the image quality. The limits for successful modification are about −0.75 D and +0.50 D for hard gas-permeable lenses; −1.00 D and +0.75 D for PMMA.

Plus power

The lens is mounted centrally by the concave surface with a suction holder or long-stemmed chuck. It is held against the centre of a velveteen pad moistened with polish and gently rocked, working from periphery to centre.

Negative power

The lens is pressed with one finger against a stationary pad, well oiled with polish. It is rotated in small circles about 10 times clockwise and then anticlockwise, working from centre to periphery. This adds about −0.25 D and is repeated for more minus.

Polishing the edges

The lens is attached to a strong suction holder or chuck and the edge rocked and rotated against a well-oiled, spinning pad.

Practical advice

- Ensure the pad or tool is wet at all times.
- All modifications tend to make the fit looser.
- It is not feasible to tighten the fit by modification.
- Do not attempt to modify surface-treated lenses.
- Modern hard lens materials require greater care to avoid distortion and far less pressure than PMMA.

Polishing the surface

The lens is mounted as if for addition of positive power, but is also drawn across the pad. This adds minus to neutralize any power change. After two passes, both the surface and the focimeter image are checked.

30.6.2 Scleral lenses (see *Chapter 15*)

Possible modifications:

- Back optic grind-out.
- Transitional grind-out.
- Fenestration.
- Channelling.
- BVP.
- Back scleral size reduction.

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CHAPTER 31

Contact lenses and children

31.1 Management

31.1.1 Parent management

Sympathetic management is essential. With infants, parents are naturally concerned about eye problems that become evident within a few weeks of birth, whether the treatment is surgery or simply optical correction. Ametropic children as young as 4 or 5 years may be brought in for contact lenses because the parents cannot accept the idea of spectacles. A contact lens trial may also help appreciation of vision where children have reacted against spectacles.

31.1.2 Child management

Babies are easy to manage as no communication is necessary, whereas infants need the stimulation of toys to help with attention. Children of 5 years and older need a great deal of patience and kindness at the initial fitting, for the essential building up of confidence. Apart from fear of the unknown, they are disturbed by the manipulation necessary for insertion and removal and can be frightened of the optical equipment. Keratometry and slit lamp examination can be performed from an early age with a co-operative child, who can

be held by the parent, kneel on a stool or stand at the instrument. A hand-held keratometer can also be useful in these cases.

31.1.3 Anaesthetics

The use of anaesthetics is dependent on the child's reaction and the practitioner's preferred method. For hard gas-permeable lens fitting there is an argument that it will help the initial reaction and aid fitting assessment. The argument against is that the child will be better for having the worst reaction at the first fitting. Then for all subsequent visits the comfort improves and the child leaves feeling positive about lenses.

31.2 Non-therapeutic fitting

If a child is happy wearing spectacles, the parents are best dissuaded from the idea of contact lenses. However, lenses can sometimes be very successful as young as 5 years old, although 10–12 years is a more usual age to consider fitting.[1] The following criteria apply:

- Visual correction is required all the time.
- The child wants lenses.
- The parents want the child to have lenses.
- The child is old enough to understand handling and maintenance.

Keratometry readings are in the same range as those for adults and the fitting technique is therefore the same. Aftercare is imperative because of the potential number of years lenses may be worn, and the material with the best physiological characteristics should be used.

The advantages and disadvantages of the various lens types are mainly as given in Section 5.3, but hard gas-permeable lenses are the probable first choice for myopes and high water content soft lenses for hypermetropes. Torics should initially be avoided because of the expense and risk of loss.

31.3 Refractive applications

31.3.1 Myopia

The correction of high myopia may improve both acuity and the field of view. Near vision develops without any optical correction. The first choice is often soft, but the thick edge of a high minus lens may lead to vascularization in the long-term.

Table 31.1 Approximate corneal dimensions for children*

	Keratometry (mm)	Corneal diameter (mm)
Baby (2 months old)	6.90	10.0
Infant (4 years old)	7.60	11.0

*Adult dimensions are reached at approximately 10 years of age.

Hard gas-permeable materials of medium *Dk* are usually the most suitable. Myopia control has been achieved with PMMA[2] and to a lesser extent with hard gas-permeable lenses,[3] which are physiologically superior. These lenses may prove more acceptable after previous soft lens wear. Orthokeratology can be carried out and may well be successful. There are, however, ethical issues in relation to children so orthokeratology has not until now been actively pursued in the UK.[4]

31.3.2 Hypermetropia

Strabismic children, especially those with accommodative esotropia, derive greatest benefit. Normal hypermetropes find vision better with spectacles, but comments at school may initiate contact lens wear.

Soft lenses are the first choice for infants under 6 years and for most older children, depending on the degree of astigmatism, the acceptance of a hard lens, and sporting and other school activities.

31.3.3 Anisometropia

Unilateral myopes or hypermetropes, whether axial or refractive, may benefit from a combination of contact lens wear and part-time occlusion. Success is often greater than with spectacles as lenses provide better stereopsis.[5] In some cases, however, lenses merely serve to keep an amblyopic eye straight.[6] If extended wear is necessary with dense amblyopia, the risks outweigh the visual benefits and contact lenses are contraindicated.

31.3.4 Amblyopic occlusion

Soft lenses provide an alternative method of occlusion to normal patching. They can be prescribed with a black occlusive pupil (*see* Section 26.2), an entirely opaque lens or, more simply, with a very high power to fog the vision.

31.4 Therapeutic applications

31.4.1 Aphakia

Early treatment and optical correction are essential for bilateral aphakic infants, so that contact lenses give significant long-term visual benefits.[7] Extended wear soft lenses are rarely used and only as a prelude to daily wear because of the risk of infection. Hard gas-permeable lenses can be fitted with confidence for children over 5 years but can also be attempted at an earlier age. Silicone rubber can be used with success where soft lens loss is a major problem.

Typical specification

Baby (1–6 months)	75% water content	7.00/12.00 + 32.00 D
	Silicone rubber	7.20/11.20 + 32.00 D
Infant (1–4 years)	60% water content	7.60/13.50 + 25.00 D
Child (5–10 years)	60% water content	7.80/14.00 + 15.00 D

Practical advice

- Overcorrect babies for arm's-length vision, which is the range of their visual world.
- Prescribe bifocal spectacles over the lenses for close work at school.

31.4.2 Albinism

Albinism is associated with nystagmus, ametropia (often with high astigmatism) and photophobia. A tinted hard gas-permeable lens is best, but often there is no visual improvement over spectacles.[8] Tinted soft lenses are more comfortable and may well help infants if cosmetically acceptable. With children, however, if astigmatism needs correction, hard gas-permeable lenses, either toric or spherical, should be used.

Practical advice

- Carefully observe any nystagmus with hard lenses because it may increase with the stress of adaptation.
- 'K' readings are more easily obtained using an autokeratometer because of speed of measurement.

31.4.3 Aniridia and iris coloboma

These conditions require an opaque iris lens to occlude the light (*see* Section 26.2) even if there is no visual improvement. Colour matching of the good eye is important for psychological reasons.

31.4.4 Microphthalmos

Microphthalmic eyes are usually fitted for cosmetic rather than visual reasons. They tend to have steep corneal radii (e.g. 6.80 mm) with high hypermetropia (e.g. +10.00 D), so that aphakic designs can be used. Unilateral amblyopic cases can be fitted with a tinted soft lens, where the plus power makes the eye look larger. This is easier to fit and more comfortable than a scleral shell.

Practical advice

- A cosmetic lens for one disfigured eye is more often the parent's idea than the child's.
- Carefully consider the long-term effects, since a child often refuses to go out without the lens.

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CHAPTER 32

Therapeutic fitting

Contact lenses are used for therapeutic reasons to:

- Correct vision in eyes with existing pathology.
- Correct irregular corneal astigmatism by providing a smooth optical surface.
- Promote healing by protecting denuded cornea and new epithelium from the lids.
- Prevent epithelial breakdown.
- Relieve pain or foreign body sensation.
- Protect the cornea and, when used in conjunction with lubricating solutions, provide a moist environment.

32.1 High myopia and hypermetropia

32.1.1 Hard gas-permeable lenses

The main problem with powers over +10.00 D is the lens mass. Stability and position may be improved by fitting:

- A TD about 0.50 mm larger than usual.
- On mean 'K' to show apical clearance with the fluorescein pattern.
- Lid attachment (hitch-up) lenses (*see* Section 7.5).
- A reduced optic and ordering the optimal design of carrier (e.g. parallel for a high minus with tight lids; negative for high plus).

32.1.2 Soft lenses

The main difficulty with myopes is the mass of material at the limbus. Even with a reduced optic, long-term problems such as oedema and vascularization can arise. The size of the optic is important: HO3 and HO4 lenses (Bausch & Lomb) have a large optic and greater average thickness, whereas CSI (CIBA Vision) have a small optic and more satisfactory thickness. The highest power normally available is −30.00 D.

Hypermetropes, on the other hand, have all the lens mass centrally. This can cause central oedema even with high water content materials. A normal cornea is under greater stress than an aphakic eye because it has higher oxygen demands.

Radii are chosen in the normal way, but larger total diameters are necessary to aid stability.

32.2 Keratoconus

Keratoconus is the classic case in which a hard contact lens provides a new refracting surface for an irregular cornea and gives good acuity where spectacles are unable to manage adequate improvement. Corneal lenses are the preferred form of correction in the early stages of the condition.

The apex of the cone is usually displaced inferiorly and nasally relative to the pupil. The common problem in all keratoconus fitting is to make the BOZD of the lens, which tends to centre at the apex of the cone, sufficiently large to cover the pupil area without the formation of either dimples or a stagnant pool of tears. Another problem is that mid-peripherally all spherical lenses are tightest where the cornea is flattest. This can cause excessive superior lens impingement.

Keratometry readings are typically steep, astigmatic and irregular, except in the early stages. As the cone advances, readings eventually fall outside the range of the instrument, although this can be

extended with a supplementary plus lens (*see* Section 2.3.4). Modern autokeratometers have a much greater range and despite corneal distortion can sometimes give readings as steep as 4–5 mm. Corneal topographers are ideal and can help with the choice of first lens.

The main problems with keratoconus fitting are:

- Decentration on an irregular cornea.
- Discomfort because of increased lid and corneal sensitivity.
- Photophobia (helped by a tint).
- Lens thickness because of the high negative power.
- Dimpling, which may necessitate fenestrations or a change in peripheral design.
- Oedema, often due to lack of lens mobility and reduced tears exchange.

32.2.1 Hard lenses

The three major techniques[1] for fitting hard lenses in keratoconus are:

1 Flat, or *two-point touch*, with primary lens support on the apex of the cornea, where the central optic zone of the lens touches or bears on the corneal apex.
2 Divided support, or *three-point touch*, with lens support and bearing shared between the corneal apex and the paracentral cornea.
3 Steep, with lens support and bearing directed off the apex and onto the paracentral cornea, with clearance or vaulting of the corneal apex.

Spherical lenses to give two-point touch

- Use the apex of the cone as a fulcrum.
- Allow the lens to be held by the top lid to achieve a high-riding fitting.
- Need to be fitted sufficiently flat to allow for lid attachment.
- Possibly change the non-affected part of the cornea by mechanical pressure.
- Are thought to be the major cause of scarring at the cone area.

Spherical lenses to give three-point touch

- The BOZR is chosen on or near the flattest 'K'.
- The BOZD is between 5.00 mm and 7.00 mm.
- The TD ranges from 8.50 mm to 9.50 mm.

- The peripheral curves are designed to flatten off rapidly to follow the topography of the cornea.
- When the patient is using the cone area, the BVP is usually much higher minus than expected because of the steep BOZR. In advanced cases, the patient may use the periconal area and require less power.

The optimal three-point touch fluorescein fit (Figure 32.1) gives the overall effect of a 'bull's-eye' pattern. There is touch on the cone surrounded by a ring of fluorescein which is in turn surrounded by an annulus of mid-peripheral bearing with peripheral edge clearance. If the central touch is too heavy, it may allow rocking of the lens and cause corneal abrasion. This can be improved either by changing the BOZR or by altering the degree of peripheral bearing.

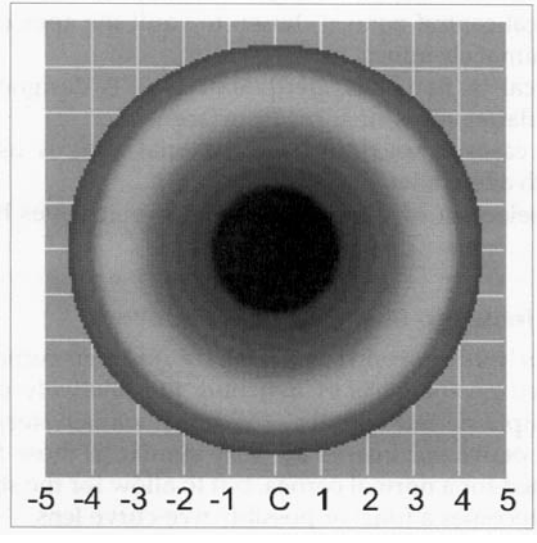

Figure 32.1 Typical 'bull's-eye' fluorescein pattern (dark shading represents corneal touch) (Plate 23)

Typical diagnostic lenses:[2]

5.50:5.60/6.50:7.60/8.50:8.60 −11.00
6.50:6.00/7.50:8.00/9.50:9.00 −5.50
7.00:6.00/8.00:8.20/10.00:9.20 −3.00

Rule of thumb

A change in radius of 0.05 mm ≡ 0.50 D with lenses steeper than 6.90 mm.

Rule of thumb

Select the initial BOZD to be approximately equal to the BOZR +0.20 mm (e.g. 7.40 mm with 7.20 mm radius; 6.20 mm with 6.00 mm radius).

The rule that a radius change of 0.05 mm ≡ 0.25 D breaks down because of the very steep curves.

Apical clearance lenses

- A spherical central zone is chosen to vault the apex of the cone with minimal clearance.
- A spherical or non-conic peripheral zone is designed to slide over the flatter superior corneal surface.
- In some cases a junctionless transitional zone is used, broad enough to allow adequate edge clearance.
- Careful selection of the peripheral curves achieves best fitting results.

Spherical lenses to fit the corneal periphery

In fairly early keratoconus, especially with large corneas, lenses can be fitted on the basis of matching the relatively unchanged corneal periphery[3] but with the addition of a much steeper BOZR. The actual peripheral curves are very similar to those found in a lens designed for a normal cornea, but to allow for the steep centre a tricurve becomes a four- or possibly five-curve lens.

Examples:

'K'	6.60 mm along 170°	× 6.10 mm along 65°
	central fitting	peripheral fitting
	6.75:7.00/	7.80:7.70/8.60:8.50/10.50:9.50
'K'	6.60 mm along 50°	other meridian off the scale
	central fitting	peripheral fitting
	6.90:7.10/7.70:7.60/	8.50:8.20/9.30:9.00/10.50:10.00

'K'	6.25 mm along 65°	other meridian off the scale
	central fitting	peripheral fitting
	6.50:6.80/7.20:7.40/	8.20:8.20/9.00:9.00/10.50:9.60/ 12.25:10.00

Offset and aspheric lenses

These designs have the advantage that, if the conical zone of the cornea lies in front of the visual axis, a small-diameter lens can be fitted.

- The BOZR is chosen on flattest 'K' to give an area of central touch.
- The BOZD varies from 2.00 mm for a true conoid to 7.70 mm for some offsets.
- The TD is typically 8.00 mm, but may be as small as 7.00 mm.
- Axial edge lift is the standard 0.10–0.15 mm and assessed by fluorescein.
- Fenestrations may be used to improve tears exchange and reduce frothing.
- A parabolic curve with edge flattening of 0.70 mm is sometimes useful when it is no longer feasible to fit spherical or aspheric lenses.
- Typical offset trial lens[4]: 6.00:5.50/AEL (ff) 0.1 at 8.50.

Elliptical 'K' (Persecon keratoconus)

The design has a bi-elliptical back surface and works well for early keratoconus, especially where patients have large pupils.[5]

- The BOZR is chosen on flattest 'K'.
- The optic zone is 8.00–8.50 mm, allowing an even pressure distribution over the lens centre.
- The TD is either 9.30 mm or 9.80 mm.
- The eccentricity of 0.39 is the same as that of the standard Persecon E (*see* Section 11.2).
- The peripheral zone flattening has an elliptical curve of the same eccentricity but flatter vertex radius.[6]

The design is predetermined by the laboratory, so that if the fluorescein pattern is unsatisfactory another type of fitting should be used.

Aspheric periphery lenses

Designed with a spherical back surface and either a flatter edge curve with an aspheric edge (e.g. Conflex/KE) or a spherical back

surface with an aspheric-type peripheral bevel for greater edge lift (Aspheri-KD, Jack Allen).

Shephard acuity lenses

Fitted from diagnostic lenses with a combined aspheric and multicurve design. Each lens is categorized according to a cone radius.

The initial lens is selected on the basis of steepest 'K'. The final fitting should give minimal touch.

Parameters available:

Radii	5.40 mm to 7.60 mm (0.20 mm steps)
Cone diameter	6.20 mm
Lens diameter	9.60 mm
Material	High *Dk* fluorocarbon

The Shephard design is useful for cases of advanced keratoconus more usually found in hospital contact lens practice.[7] There is also a soft lens version.

Rose K lens

A multicurve lens with spherical radii clearing the flat mid-peripheral and peripheral cornea. The radii are blended to form a controlled 'aspheric' peripheral lens geometry. These curves can be adjusted to give a looser or tighter peripheral fit.

- BOZRs: 4.75 mm to 8.00 mm.
- TD: 7.90 mm to 10.20 mm. Usually 8.70 mm is used; if not, then as the TD is increased or decreased the BOZD and secondary curve widths are also increased or decreased in a fixed ratio.
- To keep pooling at the base of the cone to a minimum, the back optic zone must decrease as the base curve steepens. It will vary with diameter.
- The secondary curve width will vary with diameter.
- AELs: standard, increased and decreased, increasing as the base curve is steepened.
- Choose a lens 0.20 mm steeper than average K or with a topographer choose the BOZR based on the dioptric axial radius 3.00 mm temporally.
- Initially obtain a light touch at the cone apex. A low-riding lens means the radius is too steep or the optic zone too large.
- Consider the peripheral fit and order increased or decreased edge lift as needed. It is acceptable to have lower edge stand-off and it may be needed to ensure adequate superior alignment.[8]

- Smaller TDs work well on steep corneas (8.10–8.30 mm). A large TD will tend to make the lens sit higher.
- There is often a shallow pool at the cone base, which is acceptable.
- The lower edge may give slight stand-off from the cornea because of inferior corneal steepening. This is acceptable and is often essential to ensure adequate superior alignment or clearance.

Rose K2

Essentially the same design as the original Rose K but with spherical aberration control over the back optic zone diameter. This gives an improvement in vision for the high minus powers necessary with very steep radii but might occasionally give a tighter fitting.

'Profile' design

Design based on the concept of axial profile (Jack Allen). The fitting system is designed to give equal apical profile increments of 0.10 mm of central sag across the whole range. Two peripheral designs of 'standard' (N) and 'reduced' (R) axial edge lift (by 0.10 mm) are available with three TDs of 8.70 mm (S), 9.30 mm (N) and 9.90 mm (L). Each sag has a number from 1 to 13, 1 being the smallest, and comes with the letters relating to TD and axial edge lift.[9]

'CLEK' standardized fitting set

There is debate over the possible correlation between central touch of hard lens fitting and subsequent corneal scarring. A wide-ranging study as part of the Collaborative Longitudinal Evaluation of Keratoconus (CLEK) has shown that the majority of hard lenses fitted have some degree of apical touch. In order to determine a standard fitting protocol, the study has suggested a methodology to produce apical clearance.[10] All lens parameters are uniform except the BOZR and BPZR, which are varied according to fluorescein assessment. The first lens is chosen on average 'K' and then steeper lenses are used until apical clearance is first seen.

General advice on Keratoconus

- Do not fit too steep as this may result in a large air bubble.
- The steeper the radius, the higher the minus power.

continued

- Small changes in BOZR can give larger than expected changes in refraction.
- Modifying peripheral curves can affect the lens position and the required BVP.
- Even if the first diagnostic lens is not ideal, over-refract to get an idea of the likely acuity. It is always better to assess the vision with at least two trial lenses.
- Lens design may depend on visual improvement.
- Expect to use at least two lenses per eye.
- The first lens can be made in PMMA and the final lens in a modern material.
- Sometimes a high *Dk* material is less comfortable than a low *Dk* material.
- Sometimes a lower *Dk* material gives better comfort.
- PMMA is more stable and can be made thinner.

32.2.2 *Soft lenses*

Soft lenses can sometimes be used for keratoconus, depending upon the degree of corneal distortion. Centre thickness is deliberately increased or a conical back surface is used.

Conical soft lenses

Cone curves of 5.40 mm to 7.60 mm with blended bicurve peripheral fits of extra steep (SS), steep (S), normal (N), flat (F) and extra flat (XX) are the fitting basis of the Shephard Acuity design. Lenses come with a TD of 14.50 mm. The range of BVPs is from +20.00 to −40.00 D. The peripheral and cone fit are separate entities but the result should be a lens that just traps an apical bubble that is expelled by the lightest of blinks. If it is not possible to introduce a bubble that remains until a blink, then the cone fit is probably too flat.

Spherical soft lenses

The minimum centre thickness should be 0.35 mm, but 0.60 mm is advisable. The edge is reduced to 0.18 mm by means of lenticulation. A relatively rigid +5.00 D HEMA lens masks a considerable degree of corneal distortion, and reasonable acuity may be obtained with the additional use of spectacles.

Rigidity can also be achieved with a combination of increased thickness and a proprietary series of front and back curves (Kerasoft, UltraVision International). Four BOZR values are available in Series

A, B, C and D, D being the flattest. Each is available in three TDs of 14.00 mm, 14.50 mm and 15.00 mm. The final lens power can also include a cylindrical component which may be as high as −11.00 DC.

Trapezoid lenses

The trapezoid lens is designed to vault the conical area of the cornea.[11] The back surface has a central portion between 11.00 mm and 15.00 mm in radius, with a steeper peripheral curve of 8.50 mm. The TD is 15.00 mm, and a third curve of radius 9.50 mm is introduced if the edge is too tight.

The lenses are made in HEMA for rigidity, with a centre thickness of 0.60 mm and low plus power. Some degree of corneal moulding occurs, but it is less than with a conventional lens. The fitting depends on the size and steepness of the cone and should be assessed with a diagnostic lens.

Example:

HEMA trapezoid lens:
12.00:8.50/8.00:14.00/9.00:15.00 +5.00 D t_c 0.60 mm

Scleral soft lenses

A multicurve soft scleral lens with a diameter of 23.00 mm can be designed from a mould of the eye using a shadowgraph.

32.3 Aphakia

Unilateral aphakics derive considerable visual benefit from lenses because the reduced image size and lack of distortion allow some degree of both fusion and binocular vision to be established. The field of view is also considerably improved. Visual acuity, however, is often reduced by about one line because of the absence of spectacle magnification.

The key problems with aphakic contact lens wearers are:

- Different retinal image sizes.
- Handling difficulties.
- Centration problems.
- Pupil shape and flare.

Particular care is now required with aphakia as the most straightforward cases will have received intraocular implants.

32.3.1 Hard lenses

Hard gas-permeable and PMMA lenses give excellent visual results and are therefore the ideal optical correction for those able to handle lenses.

Corneal lens fitting

- The BOZR is often fitted between mean and steepest 'K' to help stability and centration and give the preferred fluorescein pattern of apical clearance.
- The BOZD is chosen between 7.00 mm and 8.50 mm, depending on pupil size and position.
- The TD is generally larger than with the equivalent low-powered lens to help centration; it varies between 8.80 mm and 10.50 mm.
- The peripheral curves are usually spherical. The axial edge lift is greater than normal, of the order of 0.15 mm.
- Lenses are lenticular in form to reduce weight and thickness. The FOZD is often 0.50 mm larger than the BOZD. 8.00 mm to 8.50 mm is fairly standard, depending on pupil shape and position and where the lens sits. The reduced optic varies inversely with power.
- The front peripheral curve is often in the form of a negative carrier, although parallel and even positive shapes are used.
- A typical centre thickness is 0.35–0.45 mm because of the high powers required.
- Peripheral fenestrations are often used with PMMA to help tears exchange. Central fenestrations can cause flare and visual disturbance.
- Edge thickness should be at least 0.16 mm to avoid a fragile 'knife edge' and make removal easier.

Practical advice

- Some high plus lenses always assume a decentred, superior temporal position because the corneal apex has been drawn in this direction during surgery. Choose the TD and BOZD to give sufficient pupil coverage for adequate vision.
- If lenses decentre down because of gravity and lens mass, fit larger ones.
- Use a negative carrier to give a 'hitch-up' lens.

continued

- Avoid a back surface toric unless centration is a problem. Toric peripheries are sometimes necessary with high degrees of astigmatism.
- Tints reduce photophobia and assist handling; a different density or colour between right and left lenses helps identification.
- If exposed corneal sutures cause peripheral staining or are rubbed by the lens, they should be removed to enable comfortable wear. This may be necessary up to several months later.

Apex (corneoscleral) lens

The Apex is a very large, modified corneal lens with a scleral rim of about 2.00 mm and reduced optic to minimize mass.[12,13] It is a bicurve construction, with the peripheral curve at least 0.70 mm flatter than the BOZD. The lens is used where the corneal curvature is very flat in one meridian, grossly irregular, or where an eccentric pupil requires a very large optic. The lenses give stable acuity because of their limited movement on the cornea and are especially useful for uniocular senile aphakics and also for grafted aphakic eyes. The wearing times can be reasonably long because of reduced corneal sensitivity.

- The BOZR is chosen approximately 0.50 mm flatter than 'K' to give apical touch.
- The BOZD varies from 8.00 mm to 9.50 mm to allow corneal alignment over a fairly large central area.
- The TD varies between 11.50 mm and 13.00 mm, depending on the corneal diameter. The large size assists handling.
- The lens periphery usually has up to six fenestrations.

Typical specification: 8.20:8.50/10.50:12.00 BVP +17.00 Tint Blue Reduced Optic

It is important to ensure that the patient can handle the lens before ordering. Elderly aphakics often have loose lids, so removal is difficult. A suction holder is more useful if it incorporates a light source, but should only be used by patients who are aware of the lens position and can aim correctly. Bilateral aphakics can use a spectacle frame glazed on one side only. The help of a friend or relative is invaluable.

The success rate is greater with binocular cases, whereas young unilateral aphakics often find tolerance difficult with a hard lens. The cause of the aphakia is often traumatic and they find it difficult to appreciate the potential consequences of lost binocular vision,

amblyopia and divergence. A comfortable hydrophilic lens often achieves greater success.

Practical advice

- Expect some degree of corneal staining because of the fitting technique.
- The wearing time may be limited, but even a few hours of good vision is appreciated if nothing else has worked.

32.3.2 Soft lenses

Most major companies produce lenses in a range of water content, in powers of +10.00 D to +20.00 D. Fitting criteria are mainly as given in Chapter 18.

Low water content lenses

Lenses may vary in size from 12.50 mm to 14.50 mm, with BOZRs from 8.10 mm to 9.50 mm. The design is usually a bicurve construction, with FOZDs between 10.00 mm and 13.00 mm. A front surface aspheric minimizes centre thickness but makes handling more difficult.

The BOZR is chosen to be approximately 0.50 mm flatter than 'K' for corneal diameter lenses and from 0.70 mm to 1.30 mm flatter than 'K' for semi-scleral lenses.

Lens size must always be chosen to avoid the limbus and give good centration. Irregularities at the limbus such as sutures or drainage blebs influence the choice of diameter. Exposed sutures should be removed, while deformities at the limbus may need to be vaulted with a diameter as large as 16.00 mm.

Medium water content lenses

Lenses have TDs between 13.00 mm and 14.50 mm. BOZRs range from 7.80 mm to 9.30 mm and are chosen 0.50–1.00 mm flatter than 'K' for semi-scleral designs.

High water content lenses

Lenses are mainly semi-scleral bicurves, with BOZDs from 7.00 mm to 8.00 mm and TDs between 13.50 mm and 14.50 mm.

16.00 mm diameters are available from some specialist manufacturers. BOZRs range from 7.80 mm to 9.00 mm and are selected

only about 0.30 mm flatter than 'K' for diameters up to 14.00 mm. The range is steeper than with lower water content lenses because the softer materials require fitting closer to 'K' to ensure stability.

Practical advice

- Try more than one lens design, because different makes can give very different acuities.
- Always over-refract with the type of lens to be used, since the BVP may vary by at least 1.00 D between different designs.
- Centration also varies with design and lenticulation.

Continuous wear (*see also* Chapter 22)

Elderly aphakics who are unable to handle lenses may leave them in continuously. Careful practitioner management and regular aftercare visits are extremely important, since most documented infections associated with extended wear have occurred in this type of patient.[14]

Lens movement is especially important because of overnight dehydration and the need to ensure the removal of debris. A saline eyewash in the morning and evening can be recommended, ideally using minims. Deposits are a major problem and some patients need a new lens every 3–6 months.

32.4 Corneal grafts (keratoplasty)

32.4.1 Hard lenses

The main considerations are:

- The size of the graft. It is better to keep the TD within the limits of the graft tissue.
- The tilt of the graft, which may cause a problem in position and stability. Lens decentration often occurs but is acceptable if the graft is not compromised.
- Stability. Sometimes a very large lens (>12.00 mm) is necessary even to stay on the cornea with blinking.
- Staining of the grafted tissue is less acceptable than with a normal cornea and requires careful observation. Any coalescent areas are unacceptable.

Examples:

Offset 1	7.60:6.50/AEL (ff) 0.10 at 8.50
Apex	7.80:8.00/10.50:12.50

Reverse geometry lenses

It is sometimes beneficial to fit reverse geometry lenses consisting of:

- A spherical back optic zone.
- An aspheric intermediate curve, 1.00 D less steep than the equivalent intermediate curve for standard reverse geometry lenses (*see* Section 14.3).
- An aspheric peripheral curve, wider than that used for a standard reverse geometry design.

Rose K post graft keratoconus lens

- The range of BOZRs is from 6.90 mm to 9.00 mm.
- The standard TD is 10.40 mm, the range being from 9.00 mm to 12.00 mm.
- There are standard, flat and steep peripheral systems.
- The first lens is selected 0.30 mm steeper than average 'K'.
- Fitting increments should be in large steps of up to 0.20 mm.
- If a lens decentres towards the steepest part of the cornea, try either steeper or larger fittings.
- Should a toric be needed due to poor centration, select a lens 0.20 mm to 0.30 mm steeper than the 'K' readings in both meridians.
- Fenestrations are sometimes needed to aid tear circulation.

32.4.2 Soft lenses

A soft bandage lens can compress or mould a low rigidity graft or realign a partially everted graft and is often used as a protective membrane immediately the sutures have been inserted. Soft lenses are also used to treat graft rejection. The soft 'splint' is often kept in place for several weeks.

32.5 Corneal irregularity

32.5.1 Hard gas-permeable lenses

The initial lens is chosen on the basis of the best keratometry readings obtainable. The lens is fitted in the normal way, but the

fluorescein pattern nearly always shows the irregularity of the corneal surface. The fitting is decided according to visual improvement. In some cases a small amount of apical clearance gives stability and good vision, whereas in others alignment or touch is necessary. The TD may need to be larger than normal for lens stability.

Bubbles over an irregular area can cause long-term corneal desiccation and may ultimately require a scleral lens.

32.5.2 Soft lenses

Soft lenses usually conform too closely to the cornea to give any great optical benefit. Some improvement is occasionally achieved with a thick lens or rigid material (e.g. CSI).

32.6 Albinos

Hard lenses do not always give visual improvement despite frequently heavy and restrictive spectacles for bilateral hypermetropic astigmatism. Magnification is lost by fitting a contact lens and the cylinder gives unstable vision. The main benefit of contact lenses is to help photophobia by means of a tint, and occasionally soft lenses may also be used (*see* Section 26.2). Adaptation is a stressful period and any nystagmus can increase initially, although it tends to stabilize once the lenses have settled down. Nystagmus sometimes reduces where vision is improved.

Practical advice

- Use a diagnostic lens close to the anticipated power to give an accurate assessment of both BVP and fitting.
- Ensure that the back and front surface designs are consistent when replacing a lens to avoid visual and fitting difficulties.

32.7 Radial keratotomy and photo-refractive keratectomy

Radial keratotomy (RK) is a surgical technique to reduce myopia by flattening the cornea with radial incisions.

Photo-refractive keratectomy (PRK) is a laser technique to sculpt the central corneal surface producing a reduction in myopia, hypermetropia or astigmatism. Following PRK in myopes as with the more recent LASIK technique, the peripheral cornea retains its normal contour but the central, ablated zone is much flatter.

Hard lens fitting with conventional designs for both RK and PRK results in central fluorescein pooling, although an acceptable fit may sometimes be achieved using aspherics (e.g. Quantum, Persecon E). Reverse geometry lenses can often give much better corneal alignment and improved comfort (*see* Section 32.4.1). Lenses are best designed from topographical maps of the cornea (*see* Section 8.5) to avoid the use of numerous trial lenses.

Soft lens designs can work with RK, PRK and LASIK but trial and error is often necessary to find a lens that fits adequately, achieves good centration and avoids bubble formation.

Silicone hydrogel materials can also be considered.

32.8 Combination lenses

32.8.1 'Piggy-back' lenses

The combination of a hard lens on top of a soft lens is used with keratoconus and graft cases to achieve good vision with improved comfort where all else has failed.[15]

The foundation soft lens has a large diameter for stability and a typical front surface radius of about 7.60 mm. This is achieved by altering the power of the best fitting, so that a minus lens is necessary for 'K' readings between 6.00 mm and 7.00 mm. A low plus lens is required if the cornea is flatter than 8.00 mm.

The hard lens has a TD of 9.50 mm or larger to give good centration. The BOZR is based on the front surface curvature of the soft lens, measured with the keratometer.

The problems with combination lenses are:

- A large, steep soft lens is required to find a satisfactory fitting.
- Stabilizing the hard lens on the soft lens takes practice.
- Different solutions are needed for each part of the combination except with a miniority of multipurpose solutions such as Quattro.
- Lenses are removed separately. In some cases, the soft part is used for extended wear and the hard lens put in place to help vision during the day. Occasionally, daily disposable may prove useful.

Success may well be improved by using a silicone hydrogel lens with improved rigidity and enhanced oxygen transmissibility.[16]

The reverse combination of a corneal hard lens covered by a thin soft lens is used for sporting purposes. A low-powered daily disposable is ideal for this purpose.

32.8.2 Hard centre with soft periphery

This combination (e.g. Softperm) is designed to give the acuity of hard lenses with the comfort of soft.

The hard central portion has a diameter of 8.00 mm and is made from synergicon A material. The soft peripheral flange has a diameter of 14.30 mm. The basic fittings consist of radii from 7.10 mm to 8.10 mm in 0.10 mm steps and the first choice of lens is near to flattest 'K'. Fitting characteristics of movement and centration are based on soft lens criteria.[17] High molecular weight fluorescein can be used.

Problems with Softperm:

- The soft skirt detaching from the hard centre.
- Bubbles often forming at the hard–soft transition not eliminated by a change in fitting.
- Lenses fitting tightly to the eye, making removal difficult.
- The solutions must be compatible with both hard and soft lenses. Peroxide is now recommended.
- Low *Dk*.

Softperm 2 has been improved and has a mid-water HEMA skirt and a high *Dk* fluorosilicon acrylate centre.

32.8.3 Flexible lenses (e.g. Epicon)

The Epicon (Ultravision International) is a flexible lens, in carbosilfocon A material, mainly designed to be used for keratoconus and after keratoplasty, PRK and RK. The lens has a TD of 13.50 mm to vault over the limbal area. The base curves range from 6.20 mm to 7.60 mm in 0.20 mm steps and the mid-peripheral alignment zone comes in a choice of flat, median or steep edge lifts. The optic zones are 7.00 mm or 8.00 mm and the range of BVPs extends from plano to −18.00 D. The fit is checked with fluorescein in the normal way.[18] Epicon K is fitted with light apical touch. The sagittal depth and degree of touch are adjusted by choosing flatter or steeper base curves while maintaining peripheral alignment. Lens movement and tears exchange are essential to avoid adhesion to the cornea.

32.9 Silicone rubber lenses

Silicone rubber lenses (*see* Section 6.6) have the following therapeutic uses:[19]

- Aphakia.
- Dry eyes, especially following therapy.
- Exposure problems following lid reconstruction.
- Corneal perforations.
- Corneal ulceration.

Lenses are a monocurve design and the parameters available are radii from 7.00 mm to 9.20 mm in 0.10 mm steps, with TDs from 11.20 mm to 13.70 mm in 0.50 mm steps and a power range of ±30.00 D (Silflex). The initial lens is selected between 0.20 mm and 0.40 mm flatter than flattest 'K' and 1.00 mm larger than HVID. Some movement and tear exchange is essential.

Advantages

- Very high *Dk* permits continuous wear.
- Good vision.
- They do not dehydrate and are ideal for dry eyes or tear film problems.
- Low risk of loss or damage.
- Good for corneal reconstruction. The radius can be refitted as the cornea reforms under the lens.
- Resistant to bacterial colonization and therefore ideal for eyes open to infection.
- They do not absorb foreign substances, so medication can be used without fear of contamination.
- Fluorescein can be used to ensure the optimum fitting.

Disadvantages

- Difficult to fit.
- Surfaces deposits. Six-monthly replacements are advisable.
- Lenses can be difficult to remove.
- Adhesion can occur with lenses that are fitted either too steep or too flat.
- Expensive.

32.10 Bandage lenses

32.10.1 Soft lenses

Soft bandage lenses are normally used on an extended wear basis to relieve pain and allow denuded epithelium to regain its normal structure. They are available as high water content soft lens materials or silicone hydrogels and are usually of plano power, since they are not primarily intended for visual improvement.[20] Lenses are not generally handled by the patient and may require replacing every 4–8 weeks because of deposits. They are ideally fitted from stock and are used in cases of:

- Chronic keratitis.
- Post keratoplasty.
- Bullous keratopathy.
- Exposure keratitis.
- Recurrent erosions.
- Corneal perforation.

General considerations

- Biomimetic materials may be the first choice where there is a tear film problem because they dehydrate less (e.g. Proclear 8.60: 14.20 plano for exposure keratitis).
- High water content is better where a painful eye needs several weeks of continuous wear (e.g. Duragel 75 8.50:14.50 plano for bullous keratopathy).
- Silicone hydrogels are ideal where the primary objective is wound healing (e.g. PureVision 8.60:14.00 plano for a persistent epithelial defect).
- 'K' readings are not usually possible. A good starting point with a high water content lens is 8.50:14.50.
- Radii range from 7.80 mm to 9.50 mm, the flatter lenses often being made in the higher water content materials.
- Diameters vary between 13.50 mm and 16.50 mm, the larger lenses being made in the higher water content materials.
- Centre thickness varies between 0.10 mm and 0.25 mm.

32.10.2 Limbal diameter hard gas-permeable lenses

Designs are either bicurve or a spherical optic with aspheric periphery.[21] The BOZR range is from 7.00 mm to 7.90 mm with a TD of

12.50 mm. The AEL varies throughout the range. The aim is to achieve alignment to slight touch with broad edge clearance. The lens:

- Should cover the whole cornea to give complete corneal protection.
- Does not flex.
- Allows a tear reservoir.
- Can be made in a high *Dk* material.
- Can be used for severe dry eye, corneal exposure and trichiasis.
- Assists with wound healing and may offer pain relief.

32.11 Additional therapeutic uses

Drug-release lenses

Soft lenses or shields of a collagen material are used as a drug release mechanism.[22]

Low-vision aid

A Galilean telescope can be of benefit to the low-vision patient, but its cosmetic appearance is improved by using a high minus contact lens as the eyepiece. The powers required to achieve a minimum ×1.5 magnification are at least −25.00 D for the contact lens and +20.00 D for the spectacle lens. The problems are that the field of view reduces as the powers increase, and movement of the contact lens causes apparent movement of the visual field. However, the technique has been used with occasional success.[23,24]

Veterinary lenses

Veterinary lenses (e.g. Cantor+Nissel) represent a good alternative to tarsorrhaphy to promote corneal healing. They can be used on the eyes of cats, dogs, horses and lions for a wide variety of conditions including symblepharon, bullous keratopathy, adnexal problems, indolent ulcers and following superficial keratectomy. Lenses usually have a 74% water content and TDs of up to 25 mm. They are marked with a coloured dot for ease of viewing on the eye.

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Glossary of contact lens-related terms

*Denotes separate entry.

ABERRATION CONTROLLED LENS: Contact lens to improve visual performance by the control of spherical aberration, usually by means of an *aspheric front surface. Sometimes beneficial for early presbyopes.

AESTHESIOMETER: Instrument for measuring the sensitivity of the cornea or lid margins. The most common device is the Cochet-Bonnet aesthesiometer, which uses a nylon filament of constant diameter but variable length.

ANOXIA: The complete absence of oxygen.

ALIGNMENT FITTING: Fitting technique where the *BOZR is selected to be parallel to the corneal surface.

ALTERNATING VISION: Achieved with a bifocal contact lens that has distinct zones for distance and near. The lens must *translate for the different portions to line up with the pupil area for the appropriate visual task. The reading segment may be either fused or solid, and only hard lenses have proved successful.

APICAL CLEARANCE (apical pooling): A contact lens fitting, usually steep, in which there is a pool of tears between the back surface of a hard lens and the anterior surface of the corneal apex. Generally observed with *fluorescein.

APICAL TOUCH: A contact lens fitting, usually flat, in which the back surface of the lens rests on the apex of the cornea. Generally observed with *fluorescein.

ASEPTICIZATION: *See* pasteurization.

ASPHERIC (aspherical) LENS: Lens design where one or both surfaces are of non-spherical construction. Aspherics usually take the form of a parabola, ellipse or hyperbola, and are defined by *eccentricity.

AUTOCLAVE: Instrument for heat sterilization of contact lenses under pressure, usually at a temperature of 121°C for a minimum of 15 minutes.

AXIAL EDGE LIFT (AEL): Distance between a point on the back surface of a lens at a specified diameter and the continuation of the back central optic zone, measured parallel to the lens axis.

BACK OPTIC ZONE DIAMETER (BOZD): Diameter of the central optic zone of a contact lens. Previously known as the optic diameter.

BACK OPTIC ZONE RADIUS (BOZR): Radius of curvature of the central optic zone of a hard contact lens; previously known as back central optic radius (BCOR).

BACK PERIPHERAL RADIUS (BPR): Radius of curvature of a peripheral curve of a contact lens.

BACK SURFACE TORIC: Lens design where part or all of the back surface is of toric construction. The front surface may be either spherical, or toroidal in which case it is a *bitoric.

BANDAGE LENS: Soft contact lens used to protect the cornea, reduce pain and assist healing in conditions such as bullous keratopathy, ulcers and burns.

BASE CURVE: Term used to specify the back optic radius of a soft contact lens. For hard lenses, *see* back optic zone radius.

BI-ASPHERIC: Lens design having a back surface consisting of two different aspheric curves.

BICURVE: Lens design consisting of the central radius and one peripheral curve.

BIOCOMPATIBILITY: The ability of a material to interface with a natural substance without provoking a biological response.

BIOMIMESIS: Where the principles of the complex structure and chemistry of nature are emulated by much simpler scientific means which nevertheless achieve the same results.

BITORIC: Lens design with both front and back surfaces of toric construction.

BLENDING: The smoothing of a lens *transition with a curve intermediate between the two radii. Blending may be light, medium or heavy.

BREAK-UP TIME (BUT): The time in seconds for the break-up of the pre-corneal tear film in a non-blinking eye. Generally observed with fluorescein and the slit lamp. A normal eye has a BUT of 15 seconds or greater. An important diagnostic test in assessing dry eyes (*see* non-invasive break-up time).

BULLOUS KERATOPATHY: A degeneration of the cornea, often following trauma, resulting in vesicles or bullae which cause severe pain on bursting. Frequently assisted by the use of a *bandage lens.

BURTON LAMP: A source of ultraviolet (blue) light of approximate wavelength 400 nm used to excite *fluorescein and for observation.

CARRIER (BS): That part of a lenticulated lens surrounding the front optic zone.

CAST MOULDING: Method of soft lens manufacture employing heat and closed moulds.

COMBINATION LENS: Sometimes called a 'piggy-back' lens. Used for keratoconus or corneal grafts, where a hard lens is fitted on top of a soft lens for greater comfort. The reverse combination of a thin soft lens over a hard lens is used to improve lens stability.

COMPRESSION MOULDING: Method of hard lens manufacture employing granules of polymer, heat and pressure.

CONDITIONING SOLUTION: A storage solution used to enhance the biocompatibility of lens surfaces.

CONOID: Design of fenestrated PMMA lens introduced in the 1960s and fitted 0.3 mm steeper than 'K'. Noted cause of corneal moulding.

CONSTANT AXIAL EDGE LIFT (CAEL): A lens design in which the axial edge lift of the peripheral curves is calculated to remain constant for all BOZRs in a series.

CONTACT ANGLE: Angle formed by a tangent to a sessile drop of fluid at the point where the drop meets a surface. A more wettable material has a smaller angle of contact. The angle is 0° for a completely hydrophilic material.

CONTACT LENS INDUCED PAPILLARY CONJUNCTIVITIS (CLIPC); giant papillary conjunctivitis: Condition of the palpebral conjunctiva characterized by the presence of large papillae. Suggested causes in contact lens wearers are allergic, mechanical and chemical.

CONTINUOUS WEAR: The use of contact lenses without removal for periods in excess of 1 month. *See* *extended wear and *flexible wear.

CONVENTIONAL LENS: Soft lens intended for repeated, non-disposable use.

CORNEAL EXHAUSTION: Loss of tolerance to contact lenses from long-term hypoxia resulting in chronic oedema.

CORNEAL LENS: A hard gas-permeable lens fitted within the area of the cornea. Typical overall sizes are 8.50–10.00 mm.

CORNEAL MOULDING: Change in corneal curvature caused by the presence of a contact lens. Predominantly associated with PMMA-induced oedema but also found with hard gas-permeable lenses, especially aspherics, and occasionally with soft lenses.

DIAGNOSTIC LENS: A special complex diagnostic contact lens used to assess the performance of the design on the eye. Although it may be of any type it is nearly always hard. The reuse of such lenses is permitted only under certain stringent conditions.

DIMPLING: The formation of trapped air bubbles beneath a contact lens. Usually associated with hard lenses but can also occur with soft lenses.

DISINFECTION: The process of reducing the number of viable micro-organisms to a level which is harmful neither to ocular health nor to the quality of contact lenses and accessories.

DISPOSABLE LENS: Soft lens designed for frequent replacement, usually on a daily, weekly or monthly basis.

Dk and *Dk/t*: *See* oxygen permeability and oxygen transmissibility.

ECCENTRICITY: Defines mathematically the departure of an aspheric curve from a circle. Used to describe both a lens form and the curvature of the cornea, which has a typical eccentricity of 0.5.

EDGE LIFT: *See* Axial edge lift and radial edge lift.

EXPIRY DATE: The date, designated by the manufacturer, beyond which a product should not be first used.

EXTENDED WEAR: The regular use of contact lenses without removal, overnight or during sleep, for periods of up to 1 month. *See* flexible wear and continuous wear.

FENESTRATED LENS FOR OPTIC MEASUREMENT (FLOM): A diagnostic hard lens with typical overall size of 13.50–14.50 mm, used to assess the optic fitting and power of a scleral lens.

FENESTRATION: A ventilation hole drilled in a contact lens. Provides additional oxygen to the cornea and may assist the dispersal of air bubbles or dimples.

FLARE: Peripheral blur, usually experienced by hard lens wearers as a reflection or halation around the edge of the contact lens. Caused by decentration or too small a *BOZD and therefore worse with large pupils.

FLEXIBLE WEAR: The intermittent use of contact lenses overnight or during sleep.

FLEXURE: The bending of a soft contact lens fitted flatter or steeper than 'K' to conform to the corneal curvature. Usually applied to soft lenses where negative power is induced, but also applicable to steep-fitting hard lenses where visual distortion may occur.

FLUORESCEIN (sodium fluorescein): A dye that stains live tissue, used in 1% solution or by applicator strips to (1) reveal lesions in the corneal or conjunctival epithelium; (2) assess hard lens fitting characteristics; and (3) evaluate tear film (see break-up time). The dye is orange under white light but fluoresces bright green when excited by ultraviolet light. Molecular weight 330.

FLUOROSILICON ACRYLATES: Hard lens copolymers composed of fluoromonomers and siloxy acrylate monomers. Sometimes loosely called fluorocarbons.

FOOD AND DRUGS ADMINISTRATION (FDA): The regulatory authority in the USA that licenses the manufacture and supply of contact lenses, solutions and ancillary products.

FREQUENT REPLACEMENT: The regular replacement of soft lenses at predetermined intervals, usually at 1, 3 or 6 months. *See* disposable lenses.

FRONT SURFACE TORIC: Lens with a spherical back surface and toroidal front surface, used for the correction of *residual astigmatism. Stabilization is necessary to control axis orientation.

GHOST VESSELS: Vessels in the cornea, caused by vascularization, which have emptied of blood after the removal of the stimulus (e.g. hypoxic or chemical).

GIANT PAPILLARY CONJUNCTIVITIS (GPC): also called *contact lens induced papillary conjunctivitis. Condition of the palpebral

conjunctiva characterized by the presence of large papillae. Suggested contact lens causes are allergic, mechanical and chemical.

HARD GAS-PERMEABLES: Hard lenses made from materials such as *silicon acrylates and *fluorosilicon acrylates which permit the flow through their structure of gases, particularly oxygen and carbon dioxide.

HYDRATION: The uptake of water by a hydrogel material.

HYDROGEL: A material made from a hydrogel polymer which absorbs and binds water into its molecular structure. Describes those lenses that have a percentage water content, although not all hydrogels are necessarily soft.

HYDROPHILIC (water loving): Frequently used as a synonym for soft lenses but more properly applied to define the surface characteristic of a material in relation to its wetting angle.

HYDROPHOBIC (water hating): A surface characteristic of a material which causes the surface to repel water.

HYPERCAPNIA: The accumulation of carbon dioxide within the ocular tissues.

HYPOXIA: Reduced supply of oxygen to the ocular tissues.

IMPRESSION LENS: *Scleral lens fitted by taking a mould of the eye.

INDUCED ASTIGMATISM: Astigmatism created optically when a toric lens is fitted on the cornea because of the difference in the refractive index between tears and contact lens material.

INFILTRATES: Inflammatory cells within the cornea occurring as a response to viral or other infection, toxic or chemical stimulus. Typically seen as greyish disciform patches near the limbus.

ISOTONIC SOLUTION: A solution having the same tonicity as 0.9% sodium chloride.

KERATOMETER: *See* ophthalmometer.

LID ATTACHMENT: Hard lens fitting technique to ensure that the lens periphery is held in a superior 'hitch-up' position by the upper lid and moves with it on blinking. Reduces lid sensation and can avoid 3 and 9 o'clock staining.

MEDICAL DEVICES DIRECTIVE (MDD): The licensing authority in the UK for contact lenses, solutions and associated procedures.

MICROCYSTS: Small vesicles in the corneal epithelium containing fluid and cellular debris. Occur as a typical response to corneal stress, particularly extended wear.

MICRON; micrometre (μm): Unit of length (1/1000th of a mm or 10^{-6} m) used, for example, in defining *tear layer thickness.

MONOVISION: Technique for correcting presbyopia in which reading addition is incorporated into the contact lens for the non-dominant eye.

MUCIN BALLS: Translucent or opalescent dimples containing cellular debris trapped behind a contact lens. Most often associated with *silicone hydrogels and sometimes known as lipid plugs or pre-corneal deposits.

MULTICURVE: Lens design consisting of the central radius and multiple peripheral curves.

MULTIPURPOSE SOLUTION: Solution for lens disinfection that combines more than one function, such as cleaning, soaking and wetting.

NEOVASCULARIZATION: Growth of blood vessels within the corneal stroma towards the pupil area (*see* vascularization).

NEUTRALIZATION: The process by which active ingredients in contact lens care products are rendered inactive and non-toxic to ocular tissues. Usually applied to systems containing hydrogen peroxide.

NON-INVASIVE BREAK-UP TIME (NIBUT): Methods used to measure the stability of the tears film without a staining agent, employing a cold diffuse light source or grid pattern for observation (*see* break-up time).

OPHTHALMOMETER (keratometer): Instrument used for measuring the curvature of the anterior surface of the cornea. Can also be used to measure the radius of curvature of a contact lens.

OPTIC ZONE DIAMETER: Diameter of a specified optic zone, measured to the surrounding junction. If the latter is not circular, the major and minor diameters define the size. N.B. The term may be qualified, for example, 'back central optic zone diameter'.

ORTHOKERATOLOGY: The reduction, modification or elimination of a visual defect by the programmed application of contact lenses. The technique for reducing myopia consists of changing the shape of the cornea by fitting a series of hard lenses progressively flatter than 'K'.

OVER-REFRACTION: Refraction carried out with a contact lens on the eye.

OVERWEAR SYNDROME (acute epithelial necrosis; 3 a.m. syndrome): Extreme, painful response to gross corneal oedema as a result of excessive contact lens wear. Usually found with PMMA and typically occurring in the middle of the night.

OXYGEN PERMEABILITY (*Dk*): The rate of oxygen flow under specified conditions through the unit area of contact lens material of unit thickness when subjected to unit pressure difference.

OXYGEN TRANSMISSIBILITY (*Dk/t*): The value for oxygen permeability divided by the thickness of the measured sample under specified conditions.

PACHOMETER (pachymeter): Instrument for measuring the thickness of the cornea using optical alignment.

PASTEURIZATION: Method of lens disinfection employing heat to reduce micro-organisms to a safe level. Falls short of the absolute efficacy of *sterilization.

PERMEABILITY: *See* oxygen permeability.

PHOTO-REFRACTIVE KERATECTOMY: Surgical technique employing a laser beam to sculpt the central corneal surface. Reduces myopia, hypermetropia or astigmatism.

PLACIDO DISC: Instrument to assess qualitatively the regularity of the cornea or a contact lens surface using concentric circles and a magnifying lens. An illuminated version is known as a Klein keratoscope, and when combined with a camera as a photokeratoscope.

PMMA (polymethyl methacrylate): The plastics material from which almost all rigid lenses were made prior to the introduction of *hard gas-permeables. Also known as perspex or plexiglass.

POLYMEGATHISM: Irregularity in the size of cells of the corneal endothelium. Observed in extended wear and in long-standing PMMA wearers.

PREFORMED LENS: Scleral lens fitted from trial sets without taking a mould of the eye.

PRESERVATIVE: Agent intended to prevent the growth of micro-organisms in a care product.

PRISM BALLAST: The use in a contact lens of base down prism as a weighting or stabilizing device to assist with correct orientation on the eye in toric or bifocal fitting. The amount of prism is usually between 1 and 2^{Δ}. 3^{Δ} is about the maximum available.

PROFILE MATCHING: Technique for assessing the *BOZR of a contact lens by matching its profile shape with a curve of known

radius. This can be by optical projection or physically matching calibrated domes.

RADIAL EDGE LIFT (REL; 'Z' factor): Distance between a point on the back surface of a lens at a specified diameter and the continuation of the back central optic zone, measured along a radius of curvature of the latter.

RADIAL KERATOTOMY (RK): Surgical technique to reduce myopia by flattening the cornea with radial incisions.

RADIUSCOPE: Instrument used to measure the radius of curvature of a contact lens by means of Drysdale's method.

RESIDUAL ASTIGMATISM: Uncorrected astigmatism found by refraction when a spherical contact lens is placed on the cornea. Derives from the crystalline lens and is usually against-the-rule.

REVERSE GEOMETRY LENS: A lens in which the second radius is steeper than the base curve. If more than one intermediate curve is steeper than the *BOZR, the lens may be termed double reverse geometry. Such lenses are used mainly for *orthokeratology but also for other fitting applications such as corneal grafts and post refractive surgery.

ROSE BENGAL: A deep red dye used to stain devitalized (dead) epithelial cells in the cornea and bulbar conjunctiva.

SCHIRMER TEST: Diagnostic test to assess quantitatively the volume of tear flow using a strip of absorptive filter paper placed in the outer temporal part of the lower fornix. Normal tears flow wets at least 15 mm in 5 minutes. A frequently quoted but unreliable procedure.

SCLERAL LENS: A contact lens that fits over both the cornea and bulbar conjunctiva. Typical overall sizes are 22–24 mm.

SEMI-SCLERAL (mini-scleral): A soft lens which extends beyond the limbus onto the bulbar conjunctiva. Typical overall sizes are 14.00–15.00 mm.

SILICON ACRYLATES (siloxanes): Hard lens copolymers with varying proportions of acrylate and silicon.

SILICONE HYDROGELS: Soft lens materials made from a combination of silicone rubber and *hydrogel monomers. They were developed for *extended wear because of their extremely high *oxygen permeability but have several applications for daily wear.

SIMULTANEOUS VISION: Achieved with a bifocal contact lens that positions both distance and reading portions in front of the pupil at the same time. Lenses may be either hard or soft.

SOAKING SOLUTION: A solution designed to keep a contact lens in its functional condition when not in the eye.

SPECTACLE BLUR: Blurred vision with spectacles after wearing contact lenses because of oedema and corneal moulding. Mainly caused by PMMA but also encountered with hard gas-permeable and soft lenses.

SPIN CASTING: Method of soft lens manufacture employing liquid polymer spun to the required shape in rotating open moulds.

STABILIZATION: Used to ensure the correct orientation of a contact lens. Important in the fitting of torics and bifocals (*see* truncation and prism ballast).

STAINING: Usually refers to the uptake of *fluorescein by lesions in the corneal epithelium but applies to any of the commonly used tissue stains (*see* rose bengal).

STERILIZATION: The killing of all micro-organisms (*see* disinfection).

STRIAE: Vertical stress lines observed as folds in the corneal stroma, caused by hypoxia. Vogt striae of different origin are observed in keratoconus.

SURFACTANT: Agent that modifies the surface energy of a contact lens solution.

TEAR LAYER THICKNESS: The thickness of the layer of tears between the back surface of a contact lens and the front surface of the cornea. Usually expressed in microns.

THREE AND NINE O'CLOCK STAINING: Staining of the nasal and temporal areas of the peripheral cornea. Frequently associated with conjunctival injection in the horizontal meridian. Influenced by dry eyes, poor blinking, lens design and lens material.

TORIC LENS: Lens with all or part of at least one surface of toroidal construction (*see* back surface toric, front surface toric, bitoric, toric periphery).

TORIC PERIPHERY: Lens with one or more peripheral curves of toric construction.

TRANSITION: The junction between two adjacent curves on the surface of a contact lens; usually applied to the central radius (BOZR) and first peripheral radius. Transitions may be sharp or blended.

TRANSLATION: The movement of a bifocal contact lens to bring either the distance or reading portion in front of the pupil as the eye changes fixation.

TRANSMISSIBILITY: *See* oxygen transmissibility.

TRIAL LENS: A contact lens used to assess fitting, following which it is either disposed of or dispensed to the patient.

TRICURVE: Lens design consisting of the central radius and two peripheral curves.

TRUNCATION: The shaping of a lens, normally with a straight edge, to assist with correct orientation on the eye in toric or bifocal fitting. Truncation may be single, usually at the base, or double, at top and bottom of the lens.

VASCULARIZATION: Superficial extension of blood vessels from the limbal arcades into the cornea.

WATER CONTENT: Volume of water (0.9% saline) absorbed by a hydrophilic lens, expressed as a percentage of the total weight of the fully hydrated lens.

WATER UPTAKE: Volume of water (0.9% saline) absorbed by a hydrophilic lens, expressed as a percentage of the weight of the lens prior to hydration.

WETTABILITY: A property of the contact lens surface as defined by the contact angle and measured under specified conditions.

WETTING SOLUTION: A solution used with hard lenses to improve the wettability of the lens surface.

XEROGEL: Hydrogel lens prior to hydration.

Appendix

Vertex conversion table

Spectacle lens power	Vertex distance (mm)							
	Plus lenses				Minus lenses			
	8	10	12	14	8	10	12	14
4.00	4.12	4.12	4.25	4.25	3.87	3.87	3.87	3.75
4.50	4.62	4.75	4.75	4.75	4.37	4.25	4.25	4.25
5.00	5.25	5.25	5.25	5.37	4.75	4.75	4.75	4.62
5.50	5.75	5.75	5.87	6.00	5.25	5.25	5.12	5.12
6.00	6.25	6.37	6.50	6.50	5.75	5.62	5.62	5.50
6.50	6.87	7.00	7.00	7.12	6.12	6.12	6.00	6.00
7.00	7.37	7.50	7.62	7.75	6.62	6.50	6.50	6.50
7.50	8.00	8.12	8.25	8.37	7.12	7.00	6.87	6.75
8.00	8.50	8.75	8.87	9.00	7.50	7.37	7.25	7.35
8.50	9.12	9.25	9.50	9.62	8.00	7.87	7.75	7.62
9.00	9.75	9.87	10.12	10.37	8.37	8.25	8.12	8.00
9.50	10.25	10.50	10.75	11.00	8.87	8.62	8.50	8.37
10.00	10.87	11.12	11.37	11.62	9.25	9.12	8.87	8.75
10.50	11.50	11.75	12.00	12.25	9.62	9.50	9.37	9.12
11.00	12.00	12.37	12.75	13.00	10.12	9.87	9.75	9.50
11.50	12.62	13.00	13.37	13.75	10.50	10.37	10.12	9.87
12.00	13.25	13.62	14.00	14.50	11.00	10.75	10.50	10.25
12.50	13.87	14.25	14.75	15.25	11.37	11.12	10.87	10.62
13.00	14.50	15.00	15.50	16.00	11.75	11.50	11.25	11.00
13.50	15.12	15.62	16.12	16.62	12.25	11.87	11.62	11.37

continued

Spectacle lens power	Vertex distance (mm)							
	Plus lenses				Minus lenses			
	8	10	12	14	8	10	12	14
14.00	15.75	16.25	16.75	17.50	12.62	12.25	12.00	11.75
14.50	16.50	17.00	17.50	18.25	13.00	12.62	12.37	12.00
15.00	17.00	17.75	18.25	19.00	13.37	13.00	12.75	12.37
15.50	17.75	18.25	19.00	19.75	13.75	13.50	13.00	12.75
16.00	18.25	19.01	19.75	20.50	14.25	13.75	13.50	13.00
16.50	19.00	19.75	20.50	21.50	14.50	14.12	13.75	13.50
17.00	19.75	20.50	21.50	22.25	15.00	14.50	14.12	13.75
17.50	20.50	21.25	22.25	23.25	15.37	14.87	14.50	14.00
18.00	21.00	22.00	23.00	24.00	15.75	15.25	14.74	14.37
18.50	21.75	22.75	23.75	25.00	16.12	15.62	15.12	14.75
19.00	22.50	23.50	24.75	26.00	16.50	16.00	15.50	15.00

Dioptre to millimetre conversion table $n = 1.336$

36.00	9.37	40.12	−8.41	44.25	−7.63	48.37	6.98	52.50	-6.43
36.12	−9.34	40.25	−8.38	44.37	−7.61	48.50	6.96	52.62	6.41
36.25	−9.31	40.37	−8.36	44.50	−7.58	48.62	6.94	52.75	6.40
36.37	−9.27	40.50	−8.33	44.62	-7.56	48.75	6.92	52.87	6.38
36.50	−9.24	40.62	8.30	44.75	7.54	48.87	6.91	53.00	−6.36
36.62	−9.21	40.75	8.28	44.87	7.52	49.00	6.89	53.12	−6.35
36.75	−9.18	40.87	−8.25	45.00	-7.50	49.12	6.87	53.25	−6.34
36.87	9.15	41.00	8.23	45.12	7.48	49.25	6.85	53.37	−6.32
37.00	9.12	41.12	−8.20	45.25	−7.46	49.37	6.84	53.50	6.31
37.12	9.09	41.25	−8.18	45.37	−7.44	49.50	6.82	53.62	6.29
37.25	−9.06	41.37	−8.16	45.50	7.42	49.62	6.80	53.75	−6.28
37.37	9.03	41.50	-8.13	45.62	−7.40	49.75	6.78	53.87	−6.26
37.50	9.00	41.62	−8.10	45.75	−7.38	49.87	6.77	54.00	6.25
37.62	−8.97	41.75	−8.08	45.87	−7.36	50.00	6.75	54.12	- 6.23
37.75	−8.94	41.87	−8.06	46.00	-7.34	50.12	6.73	54.25	−6.22
37.87	−8.91	42.00	8.03	46.12	7.32	50.25	- 6.72	54.37	−6.21
38.00	−8.88	42.12	8.01	46.25	7.30	50.37	6.70	54.50	−6.19
38.12	-8.85	42.25	7.99	46.37	-7.28	50.50	- 6.68	54.62	−6.18
38.25	-8.82	42.37	7.96	46.50	−7.26	50.62	6.67	54.75	-6.16
38.37	8.79	42.50	−7.94	46.62	−7.24	50.75	6.65	54.87	−6.15
38.50	-8.76	42.62	7.92	46.75	−7.22	50.87	- 6.63	55.00	−6.13
38.62	8.73	42.75	−7.89	46.87	−7.20	51.00	6.62	55.12	6.12

continued

Dioptre to millimetre conversion table $n = 1.376$

38.75–8.70	42.87–7.87	47.00–7.18	51.12–6.60	55.25–6.10
38.87–8.68	43.00–7.85	47.12–7.16	51.25–6.58	55.37–6.09
39.00–8.65	43.12–7.82	47.25–7.14	51.37–6.57	55.50–6.08
39.12–8.62	43.25–7.80	47.37–7.12	51.50–6.55	55.62–6.07
39.25–8.59	43.37–7.78	47.50–7.10	51.62–6.54	55.75–6.05
39.37–8.57	43.50–7.76	47.62–7.08	51.75–6.52	55.87–6.04
39.50–8.54	43.62–7.74	47.75–7.06	51.87–6.50	56.00–6.03
39.62–8.51	43.75–7.71	47.87–7.05	52.00–6.49	
39.75–8.49	43.87–7.69	48.00–7.03	52.12–6.47	
39.87–8.46	44.00–7.67	48.12–7.01	52.25–6.46	
40.00–8.43	44.12–7.65	48.25–6.99	52.37–6.44	

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