The IACLE Contact Lens Course

MODULE 2

Introduction to Contact Lenses

First Edition

Published in Australia by
The International Association of Contact Lens Educators

First Edition 2000

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Acknowledgements

The IACLE Curriculum Project is the result of a desire to raise the standard of eyecare education, to make contact lens wear safer and more successful, and to develop the contact lens business by creating the educational infrastructure that will produce the teachers, students and practitioners of the future.

The concept of the world's best educators making available their most creative educational contributions for the common good without any recompense, other than a sense of satisfaction, was born out of IACLE's idealism.

The Curriculum Project could not be successful without the assistance and generosity of a large number of talented and dedicated people. To all those contributors of lectures, laboratory notes, videos, slides, etc., we say thank you. Your generosity of spirit will benefit many educators, hundreds of thousands of students and millions of patients throughout the world.

The Vice President of IACLE, Professor Desmond Fonn, has made a tremendous contribution since the inception of IACLE, and has provided his considerable expertise in the final editing stage of the Curriculum. This project was commenced under Professor Brien Holden's leadership. The original plan and layout for the Curriculum was prepared by Sylvie Sulaiman, IACLE's Director of Education. Sylvie's dedication and excellent understanding of practitioner and community requirements have given the Project focus and depth.

More recently, the IACLE Curriculum Project has benefited from the work of Dr Lewis Williams as Manager, Educational Development. Dr Williams has done an amazing amount of work to achieve an impressive collation of diverse material, and has created what I believe to be an invaluable collection of contact lens knowledge. Dr Williams has also been assisted by Rob Terry's considerable experience and understanding of the contact lens field.

Kylie Knox has done an excellent job as Project Editor. To complement the efforts of the editors, layout coordinators Barry Brown and Shane Parker have done an admirable job, as have the rest of the graphics team. The Cornea and Contact Lens Research Unit (CCLRU) at the University of New South Wales has contributed substantially to this project through the donation of time, resources and editorial support.

The IACLE global staff including Director of Administration Yvette Waddell, Global Coordinator Pamela O'Brien and Executive Secretary Gail van Heerden, have expertly managed the considerable tasks of production and distribution.

No acknowledgments page in an IACLE document would be complete without a reference to its sponsors. Bausch & Lomb have been a major corporate sponsor since 1990, providing the original stimulus for IACLE's growth by contributing financial support and the involvement of individuals from their International Division. It was Dr Juan Carlos Aragon (when he was at Bausch & Lomb) who first suggested that if IACLE was to be taken seriously by industry, it needed a global plan to address the educational requirements for the safe, effective growth of the contact lens business. Johnson & Johnson Vision Products is our other major corporate sponsor. They have provided excellent assistance through their provision of industry coordinators for Europe, Africa, and the Middle East. CIBA Vision has been a corporate contributor and also provided excellent industry coordination in Latin America. Allergan and Wesley Jessen/PBH have contributed generously as corporate donors, with Alcon Laboratories, contributing as IACLE donor.

IACLE is a cooperative effort, and none of its activities are more collective than the Curriculum Project. The IACLE Contact Lens Course which resulted from this project is provided to assist educators in accredited institutions to impart eyecare and contact lens knowledge. All the contributors deserve recognition for their selflessness and talent.

Debbie Sweeney

President of IACLE

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- **Optics of Contact Lenses**
- **Soft Contact Lens Designs**
- **Rigid Gas Permeable Contact Lens Designs**

Educators Guide to the IACLE Contact Lens Course

Overview

The IACLE Contact Lens Course is a comprehensive package of educational materials and other resources for teaching the subject of contact lenses. This package was designed to encompass *The IACLE Contact Lens Course Syllabus* and covers 360 hours of lectures, practicals and tutorials in ten modules, containing material at basic, intermediate and advanced levels.

The teaching resources have been designed for flexibility, allowing the educator to select the materials appropriate to the students' knowledge and the educational requirements of the class, school, institution or country. The separate document, *The IACLE Contact Lens Course Syllabus,* summarizes the course and includes outlines of Modules 1 to 10.

The English language reference used for the IACLE Contact Lens Course is: Brown L (Ed.). *The New Shorter Oxford English Dictionary.* 1993 ed. Clarendon Press, Oxford (UK). The only spelling exception is *mold* and *mould.* The Oxford dictionary suggests *mould* in all contexts. We chose to use *mold* for manufacturing-related matters and *mould* for fungi, since both meanings and spellings appear regularly in contact lens literature. This differentiation is based on common usage. Where words are 'borrowed' from a language other than English they are reproduced in their native form where possible.

Where standards have been ratified by the International Organization for Standardization (ISO), or where draft ISO standards are at an advanced stage, their relevant terminology and symbology is used. Système International (SI) units of measure are used wherever possible.

Many major contact lens textbooks from around the world, and some important journal articles, are referenced in the Course, and copyright illustrations are reproduced with permission of the original publishers and/or copyright owners. The reference section at the end of each unit details information sources used throughout it.

Teaching Resources - Module 2

Module 2 of the IACLE Contact Lens Course contains the following materials:

1. **Contact lens manual**

   The contact lens manual consists of:

   - Course overviews
   - Lecture outlines and notes
   - Practical outlines, exercises and notes*
   - Tutorial exercises and notes*

   * Not all units have these sections.

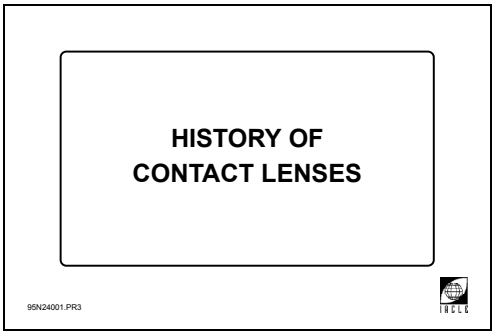
   The suggested allocation of time to the lectures, practicals and tutorials contained in the module is outlined in the Summary of Module 2 on page *x*. In the interests of standardization the manual provides recommended activities, references and textbooks. Ultimately however, the design and methodology of the course is left to the discretion of the contact lens educator.

2. **Slides for lectures, practicals and tutorials**

   The slides have been numbered according to the sequence in which they appear in each lecture, practical and tutorial. Single or dual slide projection can be accommodated. Each slide has an identification code which is based on a cataloguing system in use at the IACLE Secretariat. This code should be used in any communication with IACLE regarding the slides.

For example:

To re-order this slide please quote this identification code



2L195N24-1-1

Symbols, Abbreviations and Acronyms Used in the IACLE Contact Lens Course

SYMBOLS			
↑	increase, high	{	collectively produced by
↓	decrease, low	}	collectively producing
→	produces, towards	Σ	sum of
←	produced by, from	±	plus or minus the value of
↔	no change, not obvious	+	plus, add, include, and
↑↑	significant/great increase	–	minus, reduce
↓↓	significant/great decrease	≈	approximately equal to
%	percentage	=	equal to, the same as
<	less than	&	and, as well as
>	greater than	*x*°	degrees: e.g. 45°
≥	equal to or greater than	@	in the meridian of
≤	equal to or less than	D	dioptres
?	unknown, questionable	X	axis: e.g. –1.00 X 175. – 1.00D cylinder, axis in 175° meridian
n, n_{sub}, n_{sub}'	refractive indices	Δ	prism dioptres or difference
∝	proportional		

ABBREVIATIONS			
µg	micrograms (.001 g)	min	minutes
µL	microlitres (.001 L)	mL	millilitres (.01 L)
µm	microns (.001 mm)	mm	millimetres
µmol	micromoles, micromolar	mmol	millimole, millimolar
cm	centimetres (.01 m)	mOsm	milliosmole
d	day, days	nm	nanometres (10^{-9} m)
Endo.	endothelium	Px	patient
Epi.	epithelium	Rx	prescription
h	hour, hours	s	seconds
Inf.	inferior	Sup.	superior
kg	kilograms	*t*	thickness
L	litre		

ACRONYMS			
ADP	adenosine diphosphate	LPS	levator palpebrae superioris
ATP	adenosine triphosphate	NADPH	nicotinamide adenine dinucleotide phosphate
ATR	against-the-rule	NIBUT	non-invasive break-up time
BS	best sphere	OD	right eye (Latin: *oculus dexter*)
BUT	break-up time	OO	orbicularis oculi muscle
CCC	central corneal clouding	OS	left eye (Latin: *oculus sinister)*
CCD	charge-coupled device	OU	both eyes (Latin: *oculus uterque* - each eye, or *oculi uterque* - both eyes)
cf.	compared to/with	PD	interpupillary distance
CL	contact lens	PMMA	poly(methyl methacrylate)
Dk	oxygen permeability	R	right
DW	daily wear	R&L	right and left
e.g.	for example (Latin: *exempli gratia*)	RE	right eye
EW	extended wear	RGP	rigid gas permeable
GAG	glycosaminoglycan	SCL	soft contact lens
GPC	giant papillary conjunctivitis	SL	spectacle lens
HCL	hard contact lens	TBUT	tear break-up time
HVID	horizontal visible iris diameter	TCA	tricarboxylic acid
i.e.	that is (Latin: *id est*)	UV	ultraviolet
K	keratometry result	VVID	vertical visible iris diameter
L	left	WTR	with-the-rule
LE	left eye		

Summary of Module 2: Introduction to Contact Lenses

Course Program

LECTURE			PRACTICAL SESSIONS (Laboratory)			TUTORIAL (Small Group Teaching)		
Title	***Hrs***	***Level****	***Title***	***Hrs***	***Level****	***Title***	***Hrs***	***Level****
L.2.1 The History of Contact Lenses	1	1						
L 2.2 Contact Lens Materials and Manufacturing	2	1	P 2.2 Identification of Contact Lens Types	2	1	T 2.2 Contact Lens Manufacturing Process	1	1
L 2.3 Optics of Contact Lenses	2	2	P 2.3 Contact Lens Over-Refraction	1	1	T 2.3 Optical Principles of Contact Lenses	2	2
L 2.4 Soft Contact Lens Designs	1	2				T 2.4 Soft Contact Lens Designs	1	2
L 2.5 Rigid Gas Permeable Contact Lens Design	1	2				T 2.5 RGP Spherical and Toric Lens Design	1	2
L 2.6 Contact Lens Verification	1	2	P 2.6.1 RGP Contact Lens Verification	3	1	T 2.6 Modification of RGP Lenses	1	2
			P 2.6.2 Soft Contact Lens Verification	3	1			
			P 2.6.3 Modification of RGP Lenses	8	2			
			P 2.6.4 Inspection of Special Lenses	2	3			

* Level 1 = Basic: essential knowledge
Level 2 = Intermediate: desirable knowledge
Level 3 = Advanced: useful knowledge

Course Time Allocation

LEVEL	LECTURE	PRACTICAL SESSIONS (Laboratory)	TUTORIAL (Small Group Teaching)	TOTAL
Basic	3	9	1	13
Intermediate	5	8	5	18
Advanced	0	2	0	2
TOTAL	**8**	**19**	**6**	**33**

Request for Feedback

This is the first edition of a large work, which we intend to revise and update periodically. To ensure each revision is an improvement on its predecessor, we request your help. We invite you to provide feedback in the form of comments, corrections or suggestions which you think will enhance the accuracy or quality of the Course. Your feedback may then be incorporated in subsequent revisions of the Course. We are particularly interested in receiving corrections to, and suggestions for improvements in, the text and slides of the lectures.

To facilitate this feedback process, a *pro forma* is included on the next page. This can be photocopied. Please complete your contact details, as the editorial team may wish to discuss your suggestions in greater detail or even ask you to participate in any revision resulting from your input.

The IACLE Contact Lens Course
Feedback / Corrections / Suggestions Form

Name: _____ Date: _____
(dd-mm-yy)

Institution: _____

Address: _____

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_____

Module: _____ Unit: _____ Page Number: _____

Slide Code: _____ Section: _____

Comments:

Thank you

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Response #: _____
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Unit 2.1

(1 Hour)

Lecture 2.1: History of Contact Lenses

Course Overview

Lecture 2.1: History of Contact Lenses

I. Historical Account

II. Major Events and Milestones in the Development of Contact Lens Designs and Materials

Lecture 2.1

(1 Hour)

History of Contact Lenses

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I The Early Contributors

1

HISTORY OF

CONTACT LENSES

95N24-1S.PPT

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2

The early 'contributors' were not describing contact lens applications

95N24-2S.PPT

2L195N24-2

The Early Contributors

Many diagrams from work done in the 16th to 19th centuries illustrate refractive systems that have been frequently misrepresented as potential contact lenses. While the work of the developers of these refractive systems did contribute to the overall understanding of the eye and the development of ophthalmic optics, the concept of a correcting lens on the eye did not emerge until Herschel's 'Dissertation on Light' was published in 1845.

3

Ruben, 1975
Contact Lens Practice
Fig 1.1
Baillière Tindall

2L10103-96

Leonardo da Vinci (1508)

Leonardo da Vinci is often claimed to be the first to describe a 'contact' lens. His sketches of a schematic eye (with an iris diaphragm and an artificial crystalline lens) and the head immersed in water have been used to illustrate the concept of a refractive system in 'contact' with the eye. The original translation of his manuscript (called Manuscript D, held at the Bibliotheque Mazarine of the Institute de France) describes the neutralization of the cornea by water and the mechanism of image formation at the optic nerve (Heitz, 1984).

However, Leonardo da Vinci's contribution is controversial. Although purported by some writers as not representative of a contact lens, interpretations of other drawings within the translated manuscript presents da Vinci's concept of contact lenses using water-filled cut glass ampoules on the cornea of each eye (Hofstetter, 1984). da Vinci's idea of glass shells resting on the eye can be interpreted as an embryonic conception of a contact lens refractive correction device.

4

LEONARDO DA VINCI (1508)

- Sketches of a schematic eye
- Describes the mechanism of image formation from the cornea to the optic nerve
- Some drawings may represent the idea of a 'contact' lens

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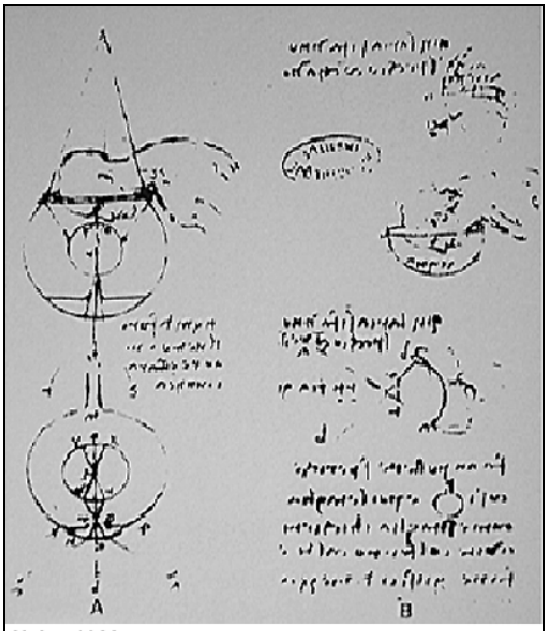
5



Heitz, 1988
The CLAO Guide to Baxic Science & Clinical Practice
Fig. 1.1
WB Saunders Company

2L10111-96

6

Ruben, 1975
Contact lens Practice
Fig 1.2
Baillière Tindall

2L10104-96

René Descartes (1637)

Descartes wrote 'La Dioptrique' in 1637. He understood that better vision could be achieved by enlarging the size of the retinal image, and that this could be achieved by elongating the antero-posterior axis of the eye.

This elongation was achieved with a hydrodiascope, a long tube filled with water and applied to the eye. The same image enlargement could be produced by replacing the refractive elements of the hydrodiascope with lenses.

His theories contributed significantly to the development of the telescope.

7

RENÉ DESCARTES (1637)

- Understood that better vision could be achieved by enlarging the retinal image
- Sketched an elongated tube filled with water placed against an eyeball
- Demonstated the principal of the telescope, not the contact lens

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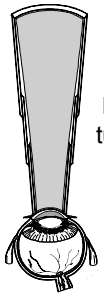
8



René Descarte's water-filled tube used to demonstrate the principle of the telescope by enlarging the retinal image

95N24-5S.PPT

2L195N24-5

9

PHILIP DE LA HIRE (1685)

- Attempted to show how various optical phenomena in myopes were corrected with spectacle glasses applied to the cornea
- Telescopic or image magnifying device
- Not a contact lens

95N24-6S.PPT

2L195N24-6

Philip de la Hire (1685)

Philip de la Hire is often wrongly credited as being the first to design a contact lens. This attribution is based on sketches in his 'Dissertation on Different Accidents of Sight'. He postulated the use of spectacle lenses with various back surface curvatures to correct myopia while neutralizing refraction at the corneal surface and/or increasing the visual field.

10

THOMAS YOUNG (1801)

- Used a water filled tube to study the accommodative process
- Not a contact lens

95N24-7S.PPT

2L195N24-7

Thomas Young (1801)

Thomas Young used a tube 25 mm long and closed at one end by a biconvex lens to study the accommodative process. The tube was filled with water and placed in contact with the eye. His experiments proved that the cornea played no part in the accommodative process.

11

Fatt, 1993
Optician, July
Pg 27
Reed Business Publishing

2L10669-96

Sir John Herschel (1845)

Herschel, an English astronomer, was interested in the correction of corneal astigmatism by a spectacle lens.

He was familiar with the work of Thomas Young and George Airy on the correction of corneal astigmatism. By combining the rationale behind their experiments, he proposed the mechanism by which vision could be corrected with a contact device (see excerpt from Herschel's dissertation, Appendix B). He postulated the fitting of a spherical glass or jelly over the corneal surface, made from an impression of the cornea (Fatt, 1993).

Herschel was probably the first person to describe the concept of cosmetic lenses (Heitz, 1984).

Herschel can be considered the 'father of contact lenses'.

12

JOHN HERSCHEL (1845)

Discussed the correction of irregular cornea by:

"applying in contact with the surface of the eye some transparent animal jelly contained in a spherical capsule of glass; or whether an actual mold of the cornea might not be taken and impressed on some transparent medium"

95N24-8S.PPT

2L195N24-8

13

JOHN HERSCHEL (1845)

Described the following:

- Need to correct irregular cornea
- Contact with the eye
- Eye impressions
- Need for a transparent medium
- Combining a soft material with a rigid overlying material

95N24-9S.PPT

2L195N24-9

14

WILLIAM WHITE COOPER (1859)

- Recommended the insertion of a 'glass mask' filling the fornices, in order to prevent formation of symblepharon following lime burns of the eye
- Possibly the first to suggest use of a therapeutic contact appliance

95N24-10S.PPT

2L195N24-10

15

XAVIER GALEXOWSKI (1886)

- First person to apply a therapeutic contact device
- Used gelatin square soaked in mercury chloride
- First drug delivery system

95N24-11S.PPT

2L195N24-11

Xavier Galezowski (1886)

In 1886, cataract surgeons did not use sutures and the risk of corneal infection was high. Galezowski covered corneal wounds with 0.25 - 0.50 mm thick gelatin squares which had been soaked in a solution of 0.25% mercuric chloride and 0.50 % cocaine hydrochloride. These plaquettes significantly reduced the level of infection.

II The Emergence of Contact Lenses

16

THE EMERGENCE OF CONTACT LENSES

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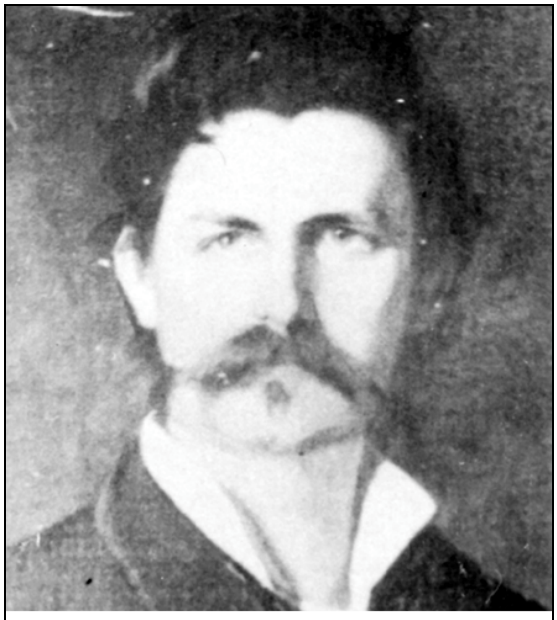
17



Heitz, 1988
The CLAO Guide to Basic Science & Clinical Practice
Fig. 1.5
WB Sauders Company

2L10112-96

18

ADOLF E FICK (1888)

First optical lens covered the entire cornea, later added a scleral flange:

- Diameter = 14.00 mm
- Scleral flange = 3.00 mm
- Corneal curvature = 8.80 mm
- Scleral radius = 14.00 mm
- Tint = black with stenopaic slit

95N24-13S.PPT

2L195N24-13

Adolf E Fick (1888)

Fick was born in Germany in 1852. After studying medicine, he specialized in ophthalmology and worked under the direction of Professor Haab in Zürich. Fick attempted to develop a contact lens corrective device. His initial work was with rabbits. He used blown glass shells which appeared to be well tolerated (Efron and Pearson, 1988).

Fick observed corneal clouding, conjunctival and limbal injection. He discussed the need for lens disinfection and the concept of adaptation to lens wear. He also observed that corneal clouding did not occur as quickly if an air bubble was inserted behind his lens along with a 2% glucose solution.

Fick also requested Professor Ernst Abbe of Jena to produce polished shells of good optical quality and painted irides and pupils on the shells with the following specifications:

- Diameter: 14.00 mm.
- Scleral flange: 3.00 mm.
- Corneal curvature: 8.80 mm.
- Scleral radius: 14.00 mm.
- Tint: black with stenopaic slit.

After animal and cadaver trials by Fick, the shells were trialled on humans. They were fitted on patients with irregular corneal surface with scarring and to avoid enucleation of unsightly eyes.

19

ADOLF E FICK (1888)

- Precorneal space filled with 2% glucose
- First published paper on a practical clinical attempt to correct visual problems
- Glass 'contactbrillen' on irregular corneal surfaces
- Shells were fitted to six patients with highly irregular corneal surface due to scarring

95N24014.PR3

2L195N24-14

20

Pearson, 1989
Optometry & Vision Science
Fig. 1
Lippincott-Raven Publishers

2L10106-96

Eugene Kalt (1888)

Kalt was born in Alsace, France, in 1861. In the 1880s, the treatment of keratoconus consisted of cauterization of the corneal cone with silver nitrate and instillation of miotics accompanied by the application of pressure dressings.

Kalt replaced the pressure dressings with a glass shell which had the same curvature as the cornea. This resulted in a marked improvement in the visual acuity of patients.

21

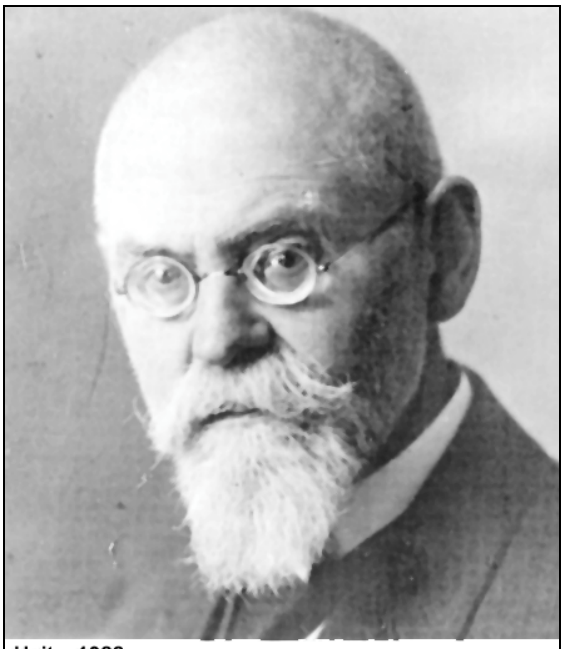
EUGENE KALT (1888)

- Devised the first contact lens for keratoconus
- Wanted to remodel the corneal curvature by using glass contact shells as splints
- Resulted in substantial visual improvement

95N24-15S.PPT

2L195N24-15

22



Heitz, 1988
The CLAO Guide to Basic Science & Clincal Practice
Fig. 1.7
WB Saunders Company

2L10113-96

23

AUGUST MÜLLER (1889)

- Used the term 'Hornhautlinsen' or corneal lens
- Noted that a steeper corneal radius needed a larger dioptric correction which he attributed to the lacrimal meniscus

95N24-16S.PPT

2L195N24-16

24

AUGUST MÜLLER (1889)

- Experienced and described subjective and objective signs of corneal oedema
- Observed that tears had a metabolic function
- Made unsuccessful attempts to take molds of living eyes

95N24-17S.PPT

2L195N24-17

August Müller (1889)

Müller was born in Germany in 1865. His doctoral work at the University of Kiel described in detail the contact lens as a corneal lens or 'Hornhautlinsen'. Due to his own high myopia, he did not continue in ophthalmology, and pursued a career in orthopaedics.

Müller suggested bringing the posterior surface of a lens, similar in shape to the anterior surface of the cornea, close to the eye. He stated that the capillary attraction of the lacrimal film would enable the lens to adhere to the cornea. His first lens had the following specifications:

- Diameter: 20.00 mm.
- Corneal radius: 8.00 mm.
- Scleral radius: 12.00 mm.

Müller compared the results between spectacles and contact lenses which almost totally corrected his 14 D of myopia.

He described effects of corneal oedema including progressive veiling of objects and coloured haloes around lights. He attempted to improve lacrimal circulation by a lens edge lift at the limbus.

Müller also unsuccessfully attempted to replicate the corneal shape by molding the eyes *in vivo*.

25

DE SULZER (1892)

- Observed that a 'fluid lens' acted as an artificial refracting medium
- Shell parameters:
  - Diameter = 14.00 - 15.50 mm
  - Corneal radius = 8.00 mm
  - Scleral radius = 12.00 mm

95N24-18S.PPT

2L195N24-18

D E Sulzer (1892)

Sulzer published a paper in 1892 on the correction of keratoconus, irregular astigmatism and scarring.

He observed that corneal irregularity could be masked by filling the space between a scleral shell and the cornea with liquid having the same refractive index as the cornea and aqueous humor. This 'fluid lens' acted as an artificial refracting medium.

26

HENRY H DOR (1892)

First to replace the glucose solution used by Fick with normal saline

95N24-19S.PPT

2L195N24-19

Henry H Dor (1892)

Dor used Fick's scleral shells which were in popular use at that time. In trying to resolve the problem of corneal clouding experienced with the use of glucose solution, he was the first to investigate the use of normal saline which had the same tonicity as the tears. This greatly reduced the effects of corneal oedema.

27

THOMAS LOHNSTEIN (1896)

- Bilateral keratoconic
- Produced a spectacle with saline-filled lens cups - 'water spectacles'
- Cups could be worn for 1-1.5 hours
- Device was known as the hydrodiascope

95N24-20S.PPT

2L195N24-20

Thomas Lohnstein (1896)

In an attempt to correct his bilateral keratoconic condition, Lohnstein developed 'water spectacles'. His spectacle lens cups were filled with saline and worn successfully for 1 - 1.5 hours at a time. His contact device was also called a hydrodiascope.

28

1896 - 1912

- Very little progress in the contact lens field
- Elschnig's criticism of Fick:
  - CLs only usable in primary position
  - difficult to manufacture
  - difficult to insert
  - cause mechanical irritation

95N24-21S.PPT

2L195N24-21

1896 - 1912

During this period, interest in contact lens fitting waned.

Elschnig, in 1894, in an article about keratoconus wrote (Heitz, 1984):

'Fick's contact lenses were useless in that they are only useable in the primary position, that the difficulty of manufacture and their high price excludes their general use, that their insertion is difficult and that because of the mechanical irritation that they produce, they should only be used with the greatest prudence and reservation'.

III The Pioneering Contact Lens Companies

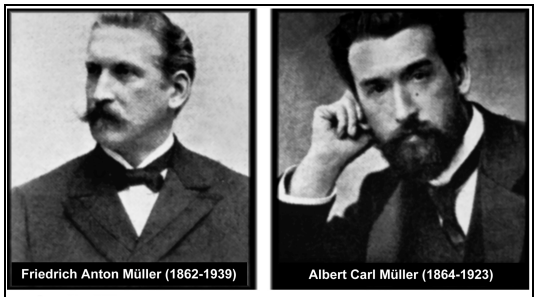
29

THE PIONEERING
CONTACT LENS
COMPANIES

95N24-22S.PPT

2L195N24-22

30



de Carle, May, 1988
Optician, '100 years of the contact lens'
Pg 4
Reed Business Publishing

2L10107-96

31

FA MÜLLER and SONS (1887)

- Artificial eye makers in Wiesbaden, Germany
- In 1887 they fitted a protective glass shell to the eye of a patient who had a partial lid removal

95N24-23S.PPT

2L195N24-23

32

FA MÜLLER and SONS (1887)

- Made lenses from blown glass
- Very regular curvature, no sharp edges at the corneo-scleral junction
- Generally better tolerated than lathe cut lenses
- Designed a lens for ptosis correction

95N24-24S.PPT

2L195N24-24

FA Müller and Sons (1887)

Friedrich Anton Müller and Albert Carl Müller of Weisbaden, Germany were specialists in the manufacture and fitting of glass artificial eyes. They came from the line of Friedrich Adolf Müller who started fitting blown glass ‘contact adhesion spectacles artificial eyes’ in 1868 (Bailey, 1987; Nissel, 1977). In 1910, they published a book titled, ‘The Artificial Eye’ in which they described how in 1887 Dr Theodore Sämisch referred a patient to them who had lost part of the lid tissue due to a cancerous growth. The clinical significance lay in the fact that with the improved design of the Müller lenses no drying and corneal compromise were experienced after 21 hours of wear (Nissel, 1977).

Because these blown glass lenses had very regular curvature and no sharp edges, they were generally better tolerated than those of Zeiss, another company that produced lathe-cut trial lenses. However the Zeiss glasses provided better optics. Special orders for the blown glass lenses continued to be received until 1912, when trial lenses became commercially available.

The Müller brothers also expanded their manufacturing process to produce special lenses such as those with props for ptosis correction.

33

CARL ZEISS of JENA (1911)

- Made lathe cut lenses from molds
- Lathe cutting resulted in a better optical performance
- First commercially available trial lenses
- Complete trial set contained 21 lenses
- Lenses were afocal
- Fitting determined by fluorescein and white light

95N24-25S.PPT

2L195N24-25

Carl Zeiss of Jena (1911)

In 1920, Zeiss produced a fitting set used to correct keratoconus. This appears to be the first trial set of contact lenses ever produced.

The trial lenses were lathe-cut from molds and gave better optical performance. They were available in the following specifications:

- Diameter: 20.00 mm.
- Scleral radius: 12.00 mm.
- Corneal radii: 6.50, 7.10, 8.10 and 9.00 mm.

In the 1930s, an expanded set of trial lenses was developed, consisting of three diameters and seven corneal radii. Fitting assessment was done using fluorescein and observation of bubble formation.

34

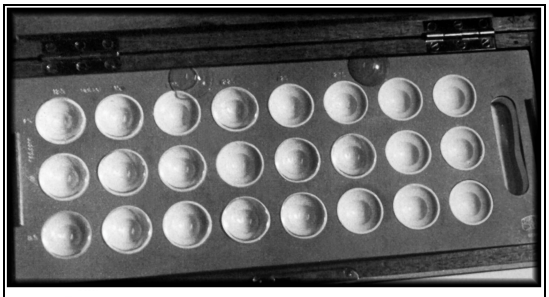
CARL ZEISS of JENA (1911)

- Parameters of first set:
  - Diameter = 20.00 mm
  - Scleral radius = 12.00 mm
  - Corneal radius = 6.50, 7.10, 8.10 and 9.00 mm
- Parameters of complete set:
  - Diameter = 20.00 mm
  - Scleral radius = 11.00, 12.00 and 13.00 mm
  - Corneal radius = 5.00, 6.00, 7.00, 8.00, 9.00, 10.00 and 11.00 mm

95N24-26S.PPT

2L195N24-26

35



Ruben, 1975
Contact Lens Practice
Fig. 1.5
Baillére Tindall

2L10105-96

36

LEOPOLD HEINE (1930s)

- Improved the Zeiss lens by enlarging the series of trial lenses
- Used a supplementary curve between the corneal and scleral component

95N24-27S.PPT

2L195N24-27

Leopold Heine (1930s)

In the 1930s, Leopold Heine expanded the Zeiss trial lens set. It was apparent from the older designs, which consisted of a spherical scleral band, that the corneal surface was not completely spherical. Heine developed a technique of routinely using a supplementary curve between the corneal and scleral components to fit the flatter peripheral cornea.

37

JOSEPH DALLOS (1930s)

- Observed that scleral lenses with more movement were better tolerated
- Suspected that tear flow behind the lens was very important
- Added a supplementary limbal curve and fenestrations

95N24-28S.PPT

2L195N24-28

Joseph Dallos (1930s)

In 1931, Dallos published the results of 120 myopic and aphakic fittings. He emphasized the need for a pre-corneal separation to allow better movement and circulation of lacrimal fluid. The role of the tears in optical performance and the metabolic function of the cornea were discussed by Dallos. Adding a supplementary limbal curve and fenestrations to the Zeiss design was important for maintaining normal metabolism.

38

Arons & Sposato, 1987
Contact lens Spectrum '100years'
Pg 9
Cardinal Business Media, Inc.

2L10108-96

Adolf A Müller-Welt and Müller-Welt Contact Linsen (1947)

The Müller-Welt Contact Linsen firm was established in 1947 by Adolf A Müller-Welt who came from a family of prosthetic eye makers. A system of stock lenses was developed by Müller-Welt. He used this to fit patients in different cities in Germany and Austria by carrying a large supply of scleral contact lenses.

In 1949, Müller-Welt and Joseph L Breger opened a contact lens manufacturing laboratory in Toronto, Canada.

Müller-Welt later entered into a partnership with Donald L Golden in Detroit which pioneered the use of PMMA for corneal contact lenses.

His partnership with Golden dissolved in 1957, and in 1960 Müller-Welt returned to Germany where his family continued his work in the development of corneal contact lenses. He died in 1972.

39

MÜLLER-WELT CONTACT LINSEN

- Founded in 1947, Stuttgart
- Initially devoted to the advancement of glass, fluid lens scleral contact lenses
- Established a Toronto and Detroit laboratory in 1949

95N24-29S.PPT

2L195N24-29

IV Contact Lens Material Developments

IV.A The Development of Poly(Methyl MethAcrylate) (PMMA)

40

CONTACT LENS MATERIAL DEVELOPMENTS

95N24-30S.PPT

2L195N24-30

41

RÖHM & HAAS (1930s)

Produced an acrylic resin (called Plexiglass) for the aviation industry

95N24-31S.PPT

2L195N24-31

The Development of PMMA

Röhm and Haas Company (1930s)

In the early 1930s, Röhm and Haas Company in the US developed a novel plastic from an acrylic resin base. This soft and rubber-like acrylic compound offered many advantages over glass as a contact lens material. This methylacrylate was the forerunner of PMMA.

Röhm and Haas Company introduced PMMA, called Plexiglas™, to the US in 1936 for the aviation industry.

42

J CRAWFORD & R HILL of ICI (1934)

- Developed and patented the material poly(methyl methacrylate) (PMMA)
- Trade name of Perspex (Latin for transparent)

95N24-32S.PPT

2L195N24-32

The Development of PMMA

Crawford and Hill of Imperial Chemical Industries (1934)

Poly(methl methacrylate) (PMMA) was invented in 1934 by John Crawford and Rowland Hill at Imperial Chemical Industries (ICI). ICI produced PMMA under the trade-name Perspex™, which is Latin for 'transparent'.

Another PMMA product, Lucite™, was marketed by EI du Pont de Nemours in the US (Refojo, Dabezies, 1984).

43

PMMA FOR SCLERAL CONTACT LENSES

PMMA rapidly became the material of choice for the construction of corneo-scleral lenses

95N24-33S.PPT

2L195N24-33

PMMA for Scleral Contact Lenses

PMMA rapidly replaced glass as the material of choice for contact lens manufacture. Its advantages were:

Low specific gravity which meant lighter lenses which were therefore less prone to riding low on the eye.

Ease of manufacture, allowing

- thinner designs to be produced
- lens modification by optometrists in their own practices.

IV.A.1 PMMA for Scleral Contact Lenses

44

PMMA FOR SCLERAL CONTACT LENSES

- William Feinbloom (1936)
- Ernest Mullen (1938)
- Theodore Obrig (1938)
- Istvan Gyorrfy (1938)

95N24-34S.PPT

2L195N24-34

PMMA for Scleral Contact Lenses

The literature has attributed recognition to several people for the first use of PMMA as a contact lens material. Rather than offer recognition to one person, the following notes will attempt to recount the contribution of scientists who stimulated and significantly catalysed the development of plastic scleral lenses:

William Feinbloom (1936)
Developed a hybrid contact lens consisting of a glass corneal portion and a translucent plastic scleral skirt. The plastic is said to have been of low specific gravity and to have been compatible with the ocular tissue. In his article in the American Journal of Optometry in 1937, 'A Plastic Contact Lens', he described the use of the impression technique to fit patients with contact lenses (Knoll, 1977).

Ernest Mullen (1938)
Having learned of the work of Feinbloom, Mullen became interested in developing a totally plastic contact lens. In 1938, he used mold casts from patients of Theodore Obrig from which the all-plastic impression scleral lenses were designed and thus, fitted 'perfectly'. During this time he was in constant communication with Obrig until they decided to formalize their association through the Mullen-Obrig Laboratories in Boston. However this partnership was short-lived. Mullen is also reputed to have discovered the effect of the lens tear layer which altered the prescribed power of the lens (Bailey, 1979).

Theodore Obrig (1938)
Obrig had used plastic (scleral flange) in a contact lens, and is attributed as the discoverer of the use of fluorescein and cobalt blue light for examining the post-lens tear fluid. He established that comfort determined success in wearing contact lenses. In 1938, after dissociation of the Mullen-Obrig Laboratories, an 'all-plastic contact lens' was manufactured at the Obrig Laboratories, Inc. (Salvatori, 1979).

Istvan Gyorrfy (1938)
Published a paper, 'The History of the All-Plastic Lens'. He claimed to have identified Plexiglas™ as a suitable contact lens material and used it to successfully manufacture all-plastic scleral lenses for his patients. His other publication in October 1939, detailing his success with his all-plastic lens design, was the first ever on all-plastic contact lenses.

IV.A.2 PMMA for Corneal Contact Lenses

45

DENNIS C ENGLAND (1946)

Patent rejected on the first PMMA corneal contact lens

95N24-35S.PPT

2L195N24-35

Dennis C England (1946)

England established his practice in 1941 and the DMV Contact Lens Company specializing in contact lens accessories. His inventive nature led him to design the first corneal contact lens made from PMMA. He applied for a patent (US Patent No. 642144) on January 19, 1946 but his application was rejected on the following grounds (Bailey, 1986):

- Many eyes present corneal surfaces of irregular curvature; keratometer measurements alone would not avail.
- Corneal clearance is ordinarily a prime requirement for a comfortable fit of a contact lens.
- The objectives of such lenses are obviously met by the E. Kalt (1887) lenses (albeit in glass).

46

Heitz, 1988
The CLAO Guide to Basic Science & Clinical Practice
Fig. 1.21
WB Saunders Company

2L10114-96

Kevin M Tuohy (1946)

Tuohy worked at Mullen-Obrig Laboratories until the mid 1940s when he joined Jay Villagran and Solon Braff at Solex Laboratories.

At Solex Laboratories, Tuohy conceived the idea of making corneal lenses from PMMA. The first lens produced was approximately 11 mm in diameter and 0.4 mm thick. It was fitted flatter than the optic cap of the cornea and had a peripheral curve known as a 'scleral flange' which was designed to keep the upper edge of the lens from impinging on the sclera.

He applied for a patent for his lens design in 1948. It was granted in 1950. It is not clear why Tuohy's patent application was successful whereas England's had not been (Bailey, 1987). This is especially interesting as the Tuohy design was not clinically acceptable or successful, whereas the England lens clearly suggests an on-K fitting - the most common and successful approach to date.

47

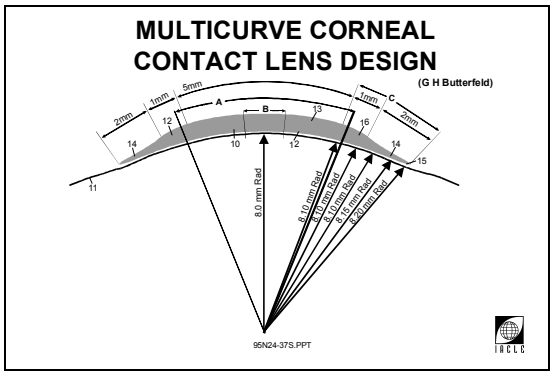
KEVIN TUOHY (1946)

Lens was patented as the first corneal contact lens

95N24-36S.PPT

2L195N24-36

48



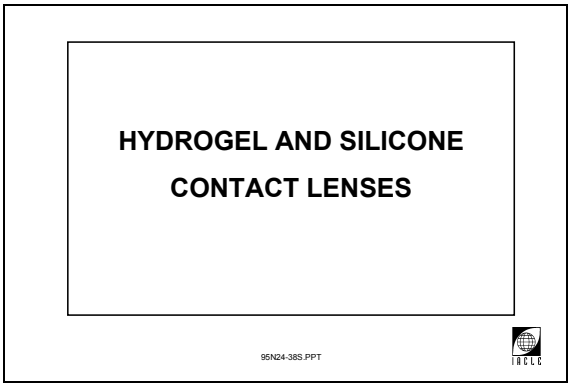
2L195N24-37

George H Butterfield (1950)

Tuohy's corneal contact lens design was a monocurve which had to be fitted 1.50 D flatter than the central corneal curvature. This was improved in the concept of a multicurve design which was first described by Butterfield under US Patent No. 2,544,246 (Mandell, 1988). The flatter posterior peripheral curves approximated the non-spherical corneal shape and thus anticipate the modern concept of fitting rigid corneal contact lenses.

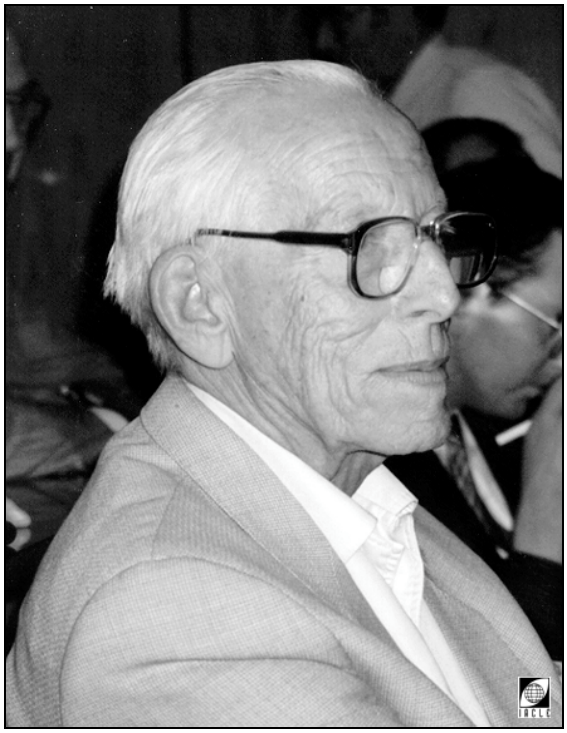
IV.B Hydrogel and Silicone Contact Lenses

49



2L195N24-38

50



2L10115-96

51

Bailey, 1987
Contact lens Spectrum '100 years'
Pg 39
Cardinal Business Media, Inc.

2L10110-96

Otto Wichterle and Drashoslav Lim (1954)

In 1954, Professor Otto Wichterle (slide 50) and Dr Drashoslav Lim (slide 51) of the Institute of Macromolecular Chemistry of the Czechoslovak Academy of Sciences in Prague, suggested to experts in the medical plastics field that a plastic which more closely simulated living tissue would be more suitable for orbital implants than the metallic elements being considered.

They discovered a stable transparent gel, poly-hydroxyethyl-methacrylate (PHEMA), which is a water-absorbing polymer (38.6%), permeable to nutrients and metabolites. They trialled their first lenses in 1956. These were unsuccessful due to the heavy weight and the fragility of the material. The PHEMA material which was mechanically unstable was successfully modified by using a xerogel that could be hydrated without affecting its physical properties. This resulted in the hydroxyethyl methacrylate (HEMA) contact lens processed by centrifugal molding (spin-casting). Manufacture of lenses made from HEMA commenced and ended in 1961 under the auspices of the Czech Ministry of Health.

After the Czech Ministry of Health terminated their support of the project, Wichterle and his wife, Linda, continued their experiments with spin-casting lenses in the kitchen of their home. They used their son's construction set and a series of glass cups that spun around a vertical axis. It was during this period that they were able to produce four very good lenses. They applied for a patent on their new technique in 1961, and were granted approval in the same year. By the end of 1962, they had designed and built a semi-automatic contact lens production line. Automation was achieved in 1963.

52

O WICHTERLE & D LIM (1954)

- Synthesised a hydrogel material that was compatible with the body
- First lenses fitted to human eyes in 1956 but were unsuccessful due to their heavy weight and fragility

95N24-39S.PPT

2L195N24-39

53

O WICHTERLE & D LIM (1961)

- The Czech Ministry of Health ceased support of the project
- Wichterle and his wife continued their research and succeeded in spin casting 'four very good lenses'
- Patented technique in 1961

95N24-39S.PPT

2L195N24-40

54

SOFT CONTACT LENS DEVELOPMENT

- National Patent Development Corporation and Dr Robert Morrison bought spin-casting patent rights - 1964
- Bausch and Lomb acquired license to manufacture spin-cast lenses - 1966

95N24-41S.PPT

2L195N24-41

55

SOFT CONTACT LENS DEVELOPMENT

- US FDA classified soft contact lens as a 'drug' - 1968
- Bausch and Lomb obtained FDA approval to market *Soflens* - 1971

95N24-42S.PPT

2L195N24-42

Soft Contact Lens Development

Wichterle's lens spin-casting production technology, materials and design attracted the interest of the National Patent Development Corporation (NPDC) and Dr Robert Morrison of the United States. In 1964, they bought the patent rights and decided to commercialize the lens (by this stage, NPDC had bought out Dr Morrison's shares).

In 1996, Bausch & Lomb acquired the licensing rights to manufacture the spin-cast lenses until the US Food and Drug Administration (FDA), in 1968, classified them as a 'drug' requiring government approval. The FDA granted approval to Bausch & Lomb to market the soft contact lens, Soflens™ in 1971.

56

SILICONE ELASTOMER

- Walter Becker commenced his silicone elastomer contact lens patent - 1956
- Joe Breger acquired the Becker patent - 1959
- The Dow Corning Company acquired Breger's technology - 1972

95N24-43S.PPT

2L195N24-43

Silicone Elastomer

- By 1956, Walter E Becker had developed his silicone elastomer contact lens. He submitted a patent application in that year.
- His patent was acquired by Breger (Müller-Welt Laboratory, Chicago) in 1959.
- Dow Corning acquired the Breger lens in 1972 but only received FDA approval to market it in 1981.

57

SILICONE ELASTOMER MANUFACTURERS

- Dow Corning received FDA approval for silicone in 1981
- Bausch & Lomb acquired Dow Corning's silicone technology in 1981

95N24-44S.PPT

2L195N24-44

Silicone Elastomer

Manufacturers:

In the 1970s, Ron Seger and Wayne Trombley of Dow Corning in the USA designed a new silicone elastomer lens, called Silsoft™, to be worn as a daily wear cosmetic lens and as an extended wear lens for aphakia. It was submitted to the FDA which granted market approval in 1981.

This technology was bought by Bausch & Lomb in 1985.

Other manufacturers are:

- Danker Laboratories, USA, produced SilaRX™.
- Wohlk Laboratories, Germany, produced Silflex™.
- Titmus Eurocon, Germany, produced Tesicon™.
- Nippon, Japan, produced Nippon™ (no longer marketed)

58

JOHN de CARLE (1970)

- Pioneered the development of continuous wear soft contact lenses
- Developed Permalens™

95N24-45S.PPT

2L195N24-45

John de Carle (1970)

In the UK, de Carle pioneered the concept of continuous wear or permanent wear contact lenses. He theorized that an increase in water content and reduction in lens diameter would offer greater oxygen permeability. This led him to develop Permalens™, a copolymer of HEMA, vinyl pyrrolidone and methacrylic acid (Refojo, 1994) with 71% water. Permalens was manufactured and marketed in the UK by Global Vision Ltd. which was later acquired by CooperVision of the US. It was granted FDA approval in 1981.

59

1970's

Rapid developments in soft contact lens design and manufacturing

95N24-46S.PPT

2L195N24-46

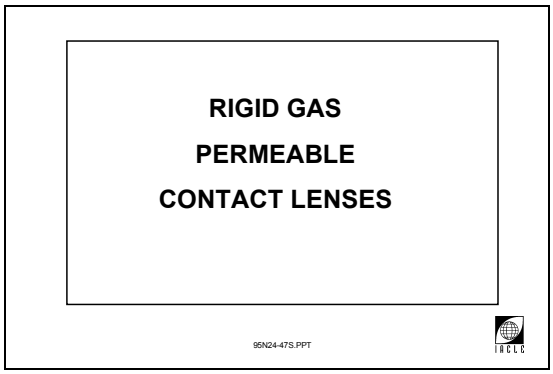
Revolution in Soft Contact Lens Manufacturing: 1970s

The discoveries by Wichterle, Lim and de Carle ushered in the rapid development of various polymers and copolymers by manufacturing companies. These have led to the present-day designs and materials for both extended and daily wear contact lenses.

NOTE: Further information on the historical development of contact lens designs is provided in Units 2.4 and 2.5.

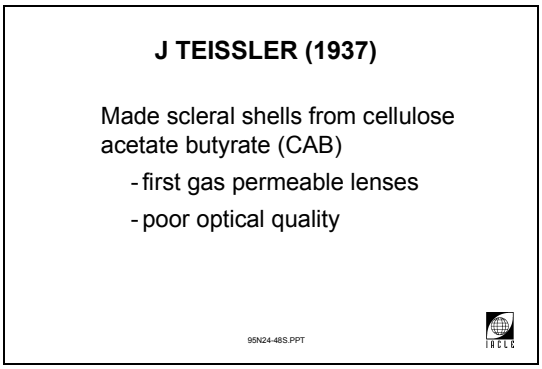
IV.C Rigid Gas Permeable Contact Lenses

60



2L195N24-47

61



2L195N24-48

J Teissler (1937)

Teissler, from the former Czechoslovakia, presented his contact shells at the International Ophthalmological Congress in 1937. The shells were made entirely of a celluloid plastic material (cellulose acetate butylrate) pressed onto a concave mold.

62

Bailey, 1987
Contact Lens Spectrum '100 years'
Pg 30
Cardinal Business Media, Inc.

2L10109-96

Norman Gaylord and Leonard Seidner (1972)

Norman Gaylord (pictured left) was a polymer chemist and President of the Gaylord Research Institute, New Jersey, US.

Leonard Seidner, an optometrist, was president of Guaranteed Laboratories in the US. Later, he became a corporate officer of Polymer Optics, Inc. He has been named the ‘father of the rigid gas permeable contact lens’.

In the latter part of the 1950s, Seidner became interested in developing soft contact materials. In need of a good polymer chemist, he invited Gaylord to develop and manufacture soft contact lens materials. However the cost of acquiring FDA approval for soft contact lens materials was so high that the project was abandoned in 1969.

The search for a rigid lens material which allowed adequate oxygen permeability led to experimentation with silicone and fluorocarbons.

In 1972, Gaylord submitted a patent application to the US FDA for a copolymer of polysiloxanyalkyl acrylic ester and an alkyl acrylic ester. In the same year, another patent was submitted for a fluoroalkyl acrylic ester and a methacrylate material. Approval was awarded for both materials in 1974.

In 1977, Polymer Optics, Inc., corporate owner of the Polycon™ (silicone acrylate) lens and Gaylord’s patent, sold rights to Syntex Ophthalmics which Seidner joined.

63

Bailey, 1987
Contact Lens Spectrum '100 years'
Pg 30
Cardinal Business Media, Inc.

2L10116-96

It is noteworthy that Gaylord's invention led other manufacturers to develop materials with higher oxygen permeabilities, including fluorosilicones, fluorocopolymers, polyethylene, etc.

Pictured at left: Leonard Seidner

64

THE FIRST RIGID GAS PERMEABLE LENS

- Silicone acrylate
- 'Polycon' patented in 1972 by Norman Gaylord

95N24-49S.PPT

2L195N24-49

65

Stahl, Reich, Ivani, 1974
journal of the American Optometric Association
Pg 302
American Optometric Association Inc

2L10666-96

Norman O Stahl, Leon A Reich and Edward Ivani (1974)

In 1974, Stahl, Reich and Ivani published a paper in the Journal of the American Optometric Association describing a new rigid gas permeable lens material. Work on this new polymer (cellulose acetate butyrate - RX-56™), had produced a lens with a high index of refraction, which was strong and resistant to high temperatures (Stahl *et al.*, 1974). Its oxygen permeability which was higher than PMMA, allowing the cornea to better maintain its normal metabolism.

Manufacturing problems arising from its dimensional instability prevented the lens from being commercially viable.

Pictured at left: Norman O Stahl.

66

Stahl, Reich, Ivani, 1974
journal of the American Optometric Association
Pg 302
American Optometric Association Inc

2L10667-96

Pictured at left: Leon A Reich.

67

Stahl, Reich, Ivani, 1974
journal of the American Optometric Association
Pg 302
American Optometric Association Inc

2L10668-96

Pictured at left: Edward Ivani.

V Disposable Contact Lenses

68

DISPOSABLE SOFT CONTACT LENSES

95N24-50S.PPT

2L195N24-50

69

ORLANDO BATTISTA (1978)

- Developed collagen contact lenses
- Conceived the concept of throwaway or disposable lenses

95N24-51S.PPT

2L195N24-51

Orlando A Battista (1978)

Dr. Battista, a scientist-inventor at the Research Services Corporation in Fort Worth, Texas in the US, is credited as having conceived the idea of a 'throw-away lens', now called the disposable soft contact lens, to be distributed in a pack of six pairs (Bailey, 1979). His lens was made from a collagen material which later proved to be unstable and dissolved in some human tear enzymes.

The use of collagen material for contact lenses has still not reached the commercial stage because of the problems alluded to above (Mertz, 1995).

70

MICHAEL BAY (1980s)

- Developed Danalens™ as the first commercially available disposable lens
- In 1984, the Dana disposable lens from Denmark was purchased by Vistakon

95N24-52S.PPT

2L195N24-52

Michael Bay (1980s)

High water content hydrogel materials were introduced as an alternative to collagen for manufacturing disposable contact lenses. However they were not without problems.

Danalens™, the first commercially available disposable contact lens, was an individually packed extended wear hydrogel lens developed by Dr Michael Bay of MIA Contact Lenses. Bay and a group of Danish engineers also invented the stabilised soft molding technique used in making the Danalens™ (Mertz, 1995).

Manufacturing defects (poor optics and edges), costs, and packaging difficulties in the 1970s and 1980s made the marketing of disposable lenses impossible. Frequent replacement programmes provided an alternative approach to the prevention of lens-induced ocular complications.

In the late 1980s, advanced computer technology allowed mass production of lenses without massive increases in manufacturing costs.

71

COMMERCIAL SUCCESS WITH DISPOSABLE LENSES

- 1987
  - Vistakon released the Acuvue lens on a limited basis in the USA
- 1988
  - Vistakon launched Acuvue
  - B & L launched Seequence
  - CIBA Vision launched NewVues

95N24-53S.PPT

2L195N24-53

Commercial Success with Disposable Lenses

Problems with the Danalens™ were resolved by using the FDA approved Etafilcon A material (58% water content) packaged in disposable 'blister' packs. In 1987, the Danalens™ technology which was acquired by Vistakon, Johnson and Johnson evolved into the Acuvue™ Lens and was initially marketed successfully in the US.

In 1988, Bausch & Lomb, marketed its first frequent replacement lens programme. In the same year, CIBA Vision launched New Vues™.

72

DAILY DISPOSABLE LENSES (1994)

- First developed and marketed by Vistakon, Johnson & Johnson
- Uses the automated continuous-flow process technique

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Daily Disposable Lenses (1994)

Frequent replacement programmes were revisited after practitioners discovered that they could prescribe the disposable lenses as daily wear lenses for a period of two weeks. Studies conducted by Vistakon, revealed the physiological advantages of disposable lenses. This prompted the development of a totally automated continuous-flow manufacturing process called 'Maximize' which mass-produces daily disposable contact lenses.

In 1993, 1• Day Acuvue™ by Vistakon, Johnson & Johnson and later that same year, Occasions™ by Bausch & Lomb were marketed as the first daily disposable contact lenses.

Appendix A
Chronology of Major Events and Milestones in the Development of Contact Lens Devices and Materials

1845	John Herschell made a strong theoretical contribution to an application of contact lenses.
1886	Xavier Galezowski employed a therapeutic contact lens for drug delivery to the cornea.
1887	The Müller brothers produced a protective shell of clear blown glass for a patient with lid disease.
1888	Adolf Fick published his work using glass shells on rabbit corneas.
1888	Eugene Kalt used glass shells on patients with keratoconus.
1889	August Müller conducted experiments with glass lenses on his own eyes (-14 D myope) and described the effects of corneal oedema.
1892	DE Sulzer reported on the use of lathe cut glass lenses.
1892	Henry Dor suggested replacing the postlens glucose solution with normal saline.
1896	Thomas Lohnstein produced 'water spectacles' known as the Hydrodiascope.
1896	Adolf Fick lost interest in contact lenses. This followed the publication of A Elschnig's critical commentary in 1894.
1896-1912	Very little contact lens work.
1911	Carl Zeiss of Jena launched first one piece fully ground lens. The lens design was specified numerically and enabled accurate reproduction.
1912	About 2000 lenses were produced for patients, manufactured mainly by Carl Zeiss.
1913	DH Erggelet published a paper on the use of contact lenses for monocular aphakia.
1920s	No more than 5000 pairs of contact lenses made in the USA and Europe combined.
1929	Fischer raised the question of corneal respiration as a factor in contact lens tolerance and advocated the presence of an air bubble between the lens and the eye to act as a reservoir for exhaled CO_2.
1929	Von Csapody attempted to mold the eye by using a low melting point paraffin wax which hardened on the eye.
1930	Poller introduced Negocoll, an alginate material, for taking molds of the eye. The casting material was Hominit.
1930	Dr Andrew Rugg-Gunn felt 'that the psychology of the British people will prove to be on the whole, unfavourable' to the future use of contact lenses.
	Röhm and Haas, of Philadelphia, produced an acrylic resin (Plexiglass, a forerunner of PMMA) for the aircraft industry.
1934	Joseph Dallos made use of fenestrations in the limbal region of the lens.
	John Crawford and Rowland Hill patented the material poly(methyl methacrylate).
1935-1939	About 10,000 pairs of glass lenses were sold in the USA.
1935	Müller-Welt of Germany developed a fitting set of blown glass lenses with toric scleral sections and ground corneal optics.
1937	Dr William Feinbloom attempted to develop a combination glass corneal section/plastic scleral section contact lens.

1937	Dr J Teissler of Prague unsuccessfully attempted to make corneo-scleral shells from a celluloid material.
1938	Theodore Obrig began using 2% sodium fluorescein and ultra-violet light to assess lens fitting.
1938	Further development of poly(methyl methacrylate) (PMMA) material.
1938	First PMMA scleral lenses were made by William Feinbloom, Theodore Obrig, Ernest Mullen and Istvan Gyorrfy.
1939	Clifford Barnes and Harry Hind established the ophthalmic solutions company, Barnes-Hind.
1940s	Increased publicity about contact lenses fitted to services personnel during the war resulted in a post war increase in consumer demand. Improvement in PMMA chemistry.
1946	About 50,000 pairs of lenses were sold in the USA.
1948	Kevin Tuohy developed large diameter (11.5 - 12.5 mm) corneal PMMA lenses fitted much flatter than K. Rapid exodus from scleral PMMA lenses.
1949	About 200,000 pairs of lenses were sold in the USA.
1950s	Increased publication on the relationship of contact lens wear to corneal physiology.
1950	Kevin Tuohy's patent for corneal lenses was granted.
1950	George Butterfield proposed fitting the corneal lens 'on K' and received the patent for the first multicurve design.
1953	Introduction of 'micro lenses' by Sohnges, Neill and Dickinson. Lens diameter was 9.5 mm and was fitted flatter than K by 0.3 - 0.6 mm.
1956	Otto Wichterle and Drahoslav Lim produced an experimental hydrophilic polymer. Suggested the possibility of disposable lenses.
1956	Walter E Becker began work on the use of silicone rubber for contact lens applications.
1961	Wichterle and Lim developed a useable hydrophilic polymer and patented the spin-casting technique of manufacture.
1966	Bausch & Lomb signed a licensing agreement for the hydrogel lens material and production technology.
1970	John de Carle developed a high-water content HEMA lens, Permalens™.
1971	Bausch & Lomb began marketing of the Soflens hydrogel contact lens in the USA.
1972	Dow Corning acquired the technology for silicone elastomer lenses.
1974	The Gaylord gas permeable hard lens patents were approved.
1978	Orlando A Battista developed the collagen contact lens.
1984	The Dana Disposable Lens from Denmark was purchased by Vistakon.
1987	Vistakon began limited release of Acuvue Disposable lenses in the USA.
1988	Disposable SCLs available from Vistakon, Bausch & Lomb and CIBA Vision.

Appendix B
Excerpt from Sir John Herschel's dissertation on light

359. Malconformations of the cornea. Remarkable case, successfully remedied by glasses	But these are not the only cases of defective vision arising from the structure of the organ, which are susceptible of remedy. Malconformations of the cornea are much more common than is generally supposed, and few eyes are, in fact, free from them. They may be detected by closing one eye, and directing the other to a very narrow, well-defined luminous object, not too bright, (the horns of the moon, when a slender crescent, only two or three days old, are very proper for the purpose,) and turning the head about in various directions. The line will be doubled, tripled, or multiplied, or variously distorted; and careful observation of its appearances, under different circumstances, will lead to a knowledge of the peculiar conformation of the refracting surfaces of the eye which causes them, and may suggest their proper remedy. A remarkable and instructive instance of the kind has recently been adduced by Mr G B Airy, (*Transactions of the Cambridge Philosophical Society*,) in the case of one of his own eyes; which, from a certain defect in the figure of its lenses, he ascertained to refract the rays to a nearer focus in the vertical than in a horizontal plane, so as to render the eye utterly useless. This, it is obvious, would take place if the cornea, instead of being a surface of revolution, (in which the curvature of all its sections through the axis must be equal,) were of some other form, in which the curvature in a vertical plane is greater than in a horizontal. It is obvious, that the correction of such a defect could never be accomplished by the use of a spherical lenses. The strict method, applicable in all such cases, would be to adapt a lens to the eye, of nearly the same refractive power, and having its surface next the eye an exact *intaglio* facsimile of the irregular cornea, while the external should be exactly spherical of the same general convexity as the cornea itself; for it is clear, that all the distortions of the rays at the posterior surface of such a lens would be exactly counteracted by the equal and opposite distortions at the cornea itself.‡ But the necessity of limiting the correcting lens to such surfaces as can be truly ground in glass, to render it of any real and everyday use, and which surfaces are only spheres, planes, and cylinders, suggested to Mr Airy the ingenious idea of a double concave lens, in which one surface should be spherical, the other cylindrical. The use of the spherical surface was to correct the general defect of a too convex cornea. That of the cylindrical may be thus explained.
	‡ Should any very bad cases of irregular cornea be found, it is worthy of consideration, whether at least a temporary distinct vision could not be procured, by applying in contact with the surface of the eye some transparent animal jelly contained in a spherical capsule of glass; or whether an actual mould of the cornea might not be taken, and impressed on some transparent medium. The operation would, of course, be delicate, but certainly less so than that of cutting open a living eye, and taking out its contents.

***This excerpt, from Sir John Herschel's dissertation on light in the 1845 edition of Encyclopaedia Metropolitana, Volume 4, presented his theoretical concept of lenses on-eye.**

References

Bailey NJ (1979). *Coming attraction: The throw-away Lens*. CL Forum. 4(2): 21-25.

Bailey NJ (1979). *The Muller story*. CL Forum. 4(2): 77-80.

Bailey NJ (1986). *The contact lens primer: The England lens.* CL Spectrum. 1(2): 56.

Bailey NJ (1987). *The contact lens - past, present and future.* CL Spectrum. 2(7): 6-51.

Bailey NJ (1987). *Neal Bailey's contact lens chronicle.* CL Spectrum. 2:19.

Broff SM (1983). *The Max Shapero lecture: Contact lens horizons*. Am J Optom & Physiol Opt. 60: 851-858.

Efron N, Pearson R (1988). *Centenary celebration of Fick's* Eine Contactbrille. Arch Ophthalmol. 106: 1370 - 1377.

Fatt I (1993). *Sir John Fredrick William Herschel: The man and his time.* Optician. 206(5408): 26-27.

Fieldman GL, Bennett ES (1992). *Aspheric lens designs*. In: Bennett ES, Weissman BA (Eds.) (1992). Clinical Contact Lens Practice. JB Lippincott Company. 1 - 11.

Graham R (1959). *The evolution of corneal contact lenses*. Am J. Optom and Arch Am Acad Optom. 36(2): 55-72.

Heitz R (1983). *Leonardo da Vinci did not invent contact lenses*. CLAO J. 9(4): 313-316.

Heitz RF (1984). *History of contact lenses*. In: Dabezies OH, *Contact Lenses: The CLAO Guide to Basic Science and Clinical Practice, Vol. 1,* Update *3*. Grune & Stratton Inc, Orlando. 1.1 - 2.3.

Hofstetter HW (1984). *Leonardo's contact concept*. CL Forum. 9(12): 15-17.

Knoll HA (1977). *William Feinbloom: Pioneer in plastic contacts.* CL Forum. 1(8): 29-32.

Lowther G, Snyder C (1992). *Contact Lenses: Procedures and Techniques*. 2nd ed. Butterworth-Heinemann, Boston.

Mandell RB (1988). *Contact Lens Practice*. 4th ed. Charles C. Thomas, Springfield. 14-15.

Mertz GW (1995). *Developing Contact Lenses*. in draft.

Nissel G (1977). *The Müllers of Wiesbaden*. Cont Len J. 11(8): 15-19.

Phillips AJ, Stone J (Eds.) (1989). *Contact Lenses*. 3rd ed. Butterworths, London.

Refojoo MF, Dabezies OH (1984). *Classifications of the types of materials used for contact lenses.* In: Dabezies OH, *Contact Lenses: The CLAO Guide to Basic Science and Clinical Practice, Vol. 1,* Update *3*. Grune & Stratton Inc, Orlando. 11.2.

Ruben M, Guillon M (1994). *Contact Lens Practice*. Chapman and Hall, London.

Sabell AG (1989). *The history of contact lenses*. In: Phillips A, Stone J (Eds.) (1989). *Contact Lenses*. 3rd ed. Butterworth & Co. Ltd.

Salvatori PL (1979). *The Obrig story*. CL Forum. 4(1): 36-37.

Sposato P (1986). *Father of the RGP lens*. CL Spectrum. 1(3): 50 - 52.

Stahl NO, Reich LA, Ivani E (1974). *Report on laboratory studies and preliminary clinical application of a gas permeable plastic contact lens.* J Am Optom. 45: 302-307.

Unit 2.2

(4 Hours)

Lecture 2.2: Contact Lens Materials and Manufacturing

Practical 2.2: Identification of Contact Lens Types

Tutorial 2.2: Contact Lens Manufacturing Process

Course Overview

Lecture 2.2: Contact Lens Materials and Manufacturing

I. Properties of the Ideal Contact Lens Material
II. Oxygen Permeability and Transmissibility for Soft and Rigid Lenses
III. Advantages and Disadvantages of Different Classes of Materials
IV. Biocompatibility
V. Manufacturing Techniques for Rigid Gas Permeable (RGP) and Soft Contact Lenses (SCL)
VI. Special Lens Types
VII. Tinting Contact Lenses
VIII. Hybrid Lenses
IX. Regulatory Issues and Good Manufacturing Practice

Practical 2.2: Identification of Contact Lens Types

- Demonstration
- Differentiation of Lens Types

Tutorial 2.2: Contact Lens Manufacturing Process

Lecture 2.2

(2 Hours)

Contact Lens Materials and Manufacturing

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I The Ideal Lens Material

1

IDEAL CONTACT LENS MATERIAL

- Meets cornea's oxygen requirements
- Physiologically inert
- Excellent *in vivo* wetting
- Resists spoilation

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2

IDEAL CONTACT LENS MATERIAL

- Dimensionally stable
- Durable
- Optically transparent
- Requires minimal patient care
- Easily machineable

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Ideal Contact Lens Material

The ideal contact lens would:

- Provide sufficient oxygen for normal corneal metabolism.
- Be physiologically inert.
- Be very wettable on the eye.
- Resist lens spoilage, especially deposit formation.
- Maintain stable dimensions.
- Be durable when handled by wearers.
- Be transparent with minimal light loss.
- Be optically regular so its optics are predictable.
- Have physical properties which allow the creation and retention of high quality surfaces.
- Require minimal maintenance by wearer.
- Be easy to fabricate lenses from.

3

CHARACTERIZING A MATERIAL

Manufacturers rely on *in vitro* data because it's easier *but…*

- Tests often too simple
- Procedures not standardized
- Tests do not reflect clinical reality

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Characterizing a Material

Manufacturers rely on *in vitro* data because it can be obtained readily. However:

- Tests are often over-simplifications of the real situation.
- Testing procedures often vary between manufacturers, and there are few standards.
- Tests frequently do not reflect the actual clinical situations relevant to the specification being determined.

4

IMPORTANT MATERIAL PROPERTIES

- Oxygen permeability
- Wettability
- Scratch resistance
- Rigidity (RGPs)
- Flexibility (SCLs)
- Durability
- Deposit resistance

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Important Material Properties

- Oxygen permeability is a material property and ***not*** a lens property.
- Good wettability is necessary for long-term lens tolerance.
- Scratch resistance is essential to the maintenance of good optical surface properties.
- Rigidity (rigid lenses) is a key determinant of the minimum lens thickness necessary to resist lens warpage on the eye, particularly if the cornea is astigmatic.
- Material must be stable if lens parameters are to remain as manufactured.
- For comfort, good vision and minimal adverse responses, the lens must resist deposits.
- The lens should withstand normal handling and wearing, i.e. not break easily.
- Flexibility (soft lenses) is also a key factor and should allow the lens to conform to the ocular surface.

II Physiological Properties

5

PERMEABILITY
TO
OXYGEN

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Permeability to Oxygen

One of the most important properties of a contact lens material is its permeability to oxygen (Dk). This property is an inherent material property (like specific gravity or refractive index). It is not a function of lens thickness, shape or back vertex power (BVP).

6

OXYGEN TRANSMISSIBILITY

$$\frac{Dk}{t}$$

Material Dk ÷ t

t may be t_c or t_{Local}

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Oxygen Transmissibility

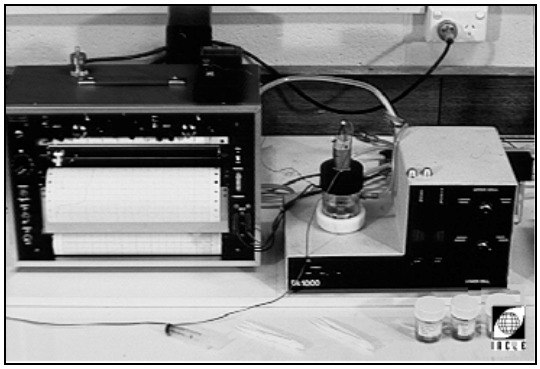
Oxygen transmissibility, Dk/*t,* is the Dk of the material (its permeability) divided by the lens thickness.

The thickness *t* may be t_c (geometric centre thickness) or t_{Local} depending on the transmissibility being calculated.

D = diffusion coefficient of the material.

k = solubility of the gas in the material.

7



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Measuring Oxygen Transmissibility

The JDF - Dk1000™ Coulometric Oxygen Permeation Instrument is illustrated (left). It is one of several types of instruments used to measure the oxygen transmissibility (Dk/*t*) of contact lenses. This device uses the coulometric technique. The lens to be tested is mounted in an environment-controlled cell. Data is fed to either a chart recorder (as in this illustration) or a computer (data logger). Dk is determined indirectly from Dk/*t* and thickness measurements.

For further information on the coulometric and polarographic techniques, see Fat, I (1971) and Winterton *et al.* (1987).

8

Dk_{O_2}

Material	Dk P'graphic	Dk P'graphic (cor)	Dk Coulometric
Toray A	138	103	150
FluoroPerm	74	57	66
Optacryl Z	71	53	56
Equalens	63	49	48
Quantum	55	43	45
Optacryl EXT	53	41	37
Paraperm EW	46	36	39
Paraperm O_2	16	12	11

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A Comparison of Dk Measuring Techniques

The table compares polarographic (with and without correction (cor) factors for edge effects, boundary layers, etc.) and coulometric techniques of Dk determination for several rigid gas permeable (RGP) materials. Note that for most materials, the corrected polarographic and coulometric results are in fair agreement. At higher Dks the differences between the measuring techniques become more apparent, and for high Dk (≥100) materials, coulometric results are more accurate. RGP results are presented here because RGP permeabilities (Dks) cover a much wider range than hydrogels. Theoretically, a volumetric system can also be used. However it is not in current use.

9

OXYGEN TRANSMISSIBILITY

In vitro measurements:

- Dk/*t*

In *vivo (indirect)* measurements:

- Overnight corneal swelling
- EOP
- Corneal oxygen demand following lens removal

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10

EQUIVALENT OXYGEN PERCENTAGE (EOP)

EOP determination is a 2-stage procedure:

- Using gas mixtures & air, calibrate cornea's oxygen demand over 5 minutes, no lens
- Measure cornea's O_2 demand after 5 minutes lens wear & compare with calibration data

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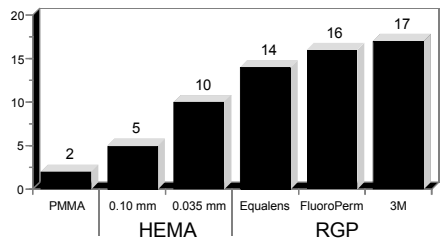
11

EOP UNDER CONTACT LENSES



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Oxygen Transmissibility

In vitro measurements of oxygen transmissibility are used to determine the Dk in a laboratory. The Dk/t is calculated from measured thickness.

In vivo, there are three main *indirect* methods which infer the oxygen transmissibility:

- Corneal swelling after overnight wear.
- EOP or the Equivalent Oxygen Percentage. EOP states the oxygen concentration of a gas mixture (the balance is nitrogen and water vapour) which produces a corneal response equivalent to that resulting from wearing the contact lens.
- Corneal oxygen demand following lens removal.
  The oxygen demand is measured immediately *after* lens removal. The demand is directly related to the oxygen tension that existed under the lens and any oxygen debt lens wear may have produced.

EOP

The EOP may be either *static* (non-blinking) or *dynamic* (normal blinking). Dynamic EOPs for both rigid and soft lenses are approximately 2 to 3% higher than static values (Efron, 1991).

EOP may be determined using either rabbit or human eyes. It is dependent on the lens thickness used and the altitude of the laboratory.

EOP determination is a two-stage procedure.

- Using gas mixtures and air, calibrate the cornea's demand over five minutes, without a lens.
  This procedure establishes a series of curves of corneal oxygen demand *versus* the oxygen concentration of the atmosphere provided (usually via close-fitting goggles). The gases are humidified to prevent corneal dessication.
- Measure the cornea's oxygen demand after five minutes of lens wear and compare it with the calibration data.
  The lens is worn for five minutes in air and the oxygen demand then ascertained. By comparing this data with that determined during calibration, an estimate of the equivalent oxygen level available under the lens, *in vivo*, can be made.

The third slide illustrates the EOPs under various types of lenses and materials. The lenses used represented typical configurations, particularly with regard to t_c and BVP.

12

Low oxygen transmissibility can result in corneal changes:

- Microcysts
- Polymegethism
- Corneal pH
- Oedema
- Blebs

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Low Oxygen Transmissibility Can Result in Corneal Changes

The following corneal conditions are indicative of inadequate oxygen transmissibility of a contact lens:

- Epithelial microcysts.

  Thought to be spherules of disorganized cellular growth, necrotic tissue and cellular debris which accumulate between epithelial cells and which probably contain metabolic by-products. The number of microcysts seen increases during extended wear, particularly if the lenses have a low oxygen transmissibility (Dk/*t*). As the Dk/*t* of lenses increases, the incidence of microcysts decreases in both daily and extended wear (see Brown, 1971, Zantos, 1981, Holden and Sweeney, 1991).

- Polymegethism.

  An increase in the range of endothelial cell sizes believed to be a result of hypoxia.

- Corneal pH.

  An acidic shift results from carbon dioxide retention.

- Oedema.

  Oedema-induced reduction in the efficacy of the endothelial pump results in fluid retention and swelling of the cornea.

- Endothelial blebs.

  Transient changes in the appearance of the endothelial mosaic thought to be due to hypoxia-induced pH changes in the cornea.

13

PREVENTING OEDEMA

How much O_2 is needed?

- 9.9% for DW lenses (Dk/*t* = 24)
- 17.9% for EW lenses (Dk/*t* = 87)

(Holden & Mertz, 1984)

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Preventing Oedema

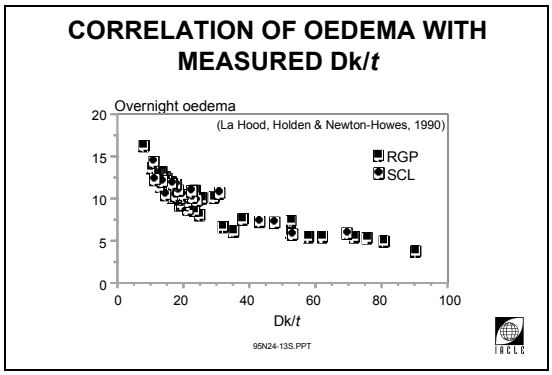
We know that oxygen is required for normal corneal metabolism. However, it has not been established with certainty just how much is actually required. Opinions vary widely.

The following figures from Holden and Mertz, 1984 are widely accepted as being a useful guide:

- **Dk/*t* = 24 for Daily Wear (DW).**
- **Dk/*t* = 87 for Extended Wear (EW).**

These values were determined using contact lenses as the test stimuli.

14



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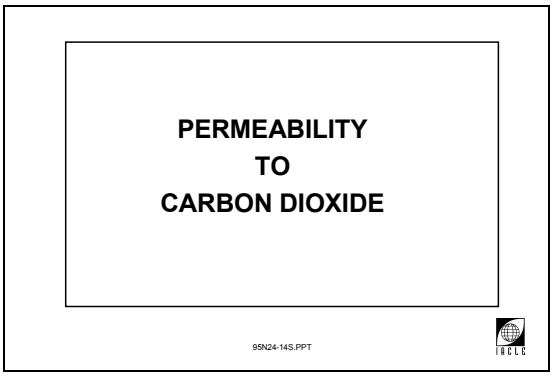
Correlation of Oedema with Measured Dk/*t*

This slide shows data from studies of overnight corneal oedema with RGP and soft lenses of various oxygen transmissibilities (Dk/*t*s). It can be seen that the lens types had little influence on the results. However, the oxygen transmissibilities had significant effects on the oedema levels measured.

15



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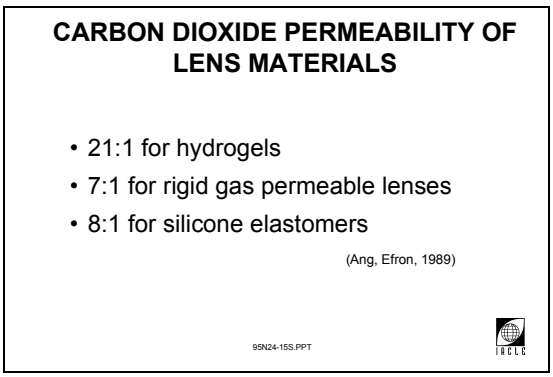

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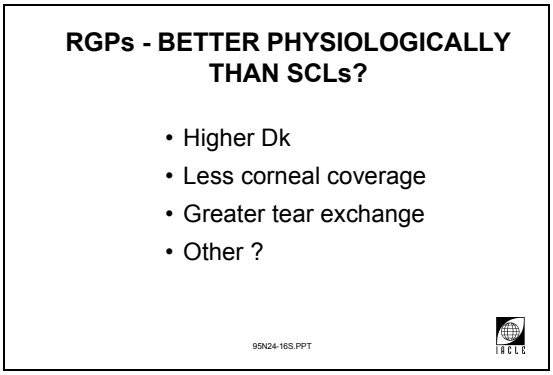
Carbon Dioxide Permeability of Lens Materials

The ratios of carbon dioxide permeability to oxygen permeability for the main material categories are:

- 21:1 for hydrogels.
- 7:1 for rigid gas permeable lens materials.
- 8:1 for silicone elastomers materials.

(Ang, Efron, 1989)

17



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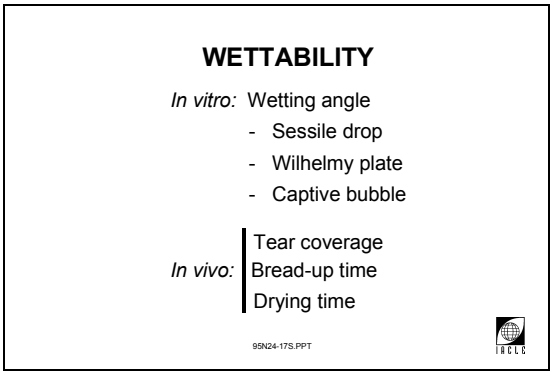
RGPs - Better Physiologically than Soft Contact Lenses (SCLs)?

- RGP materials have a higher Dk than hydrogels, in fact, some have a higher Dk than 100% water - the hypothetical limit of conventional hydrogel technology.
- Significantly less than the total corneal area is covered by an RGP lens, and the uncovered part of the cornea is able to respire approximately normally.
- The tear pump under an RGP lens is a minor contributor to corneal oxygenation. It has been shown that little tear mixing or exchange occurs under an SCL.
- Our knowledge of how contact lenses affect corneal metabolism is incomplete. It has

already been established that the carbon dioxide transmissibility (Dk CO_2) is greater for hydrogels than RGPs, but the clinical significance of this is not yet established fully.

III Physical Properties

18



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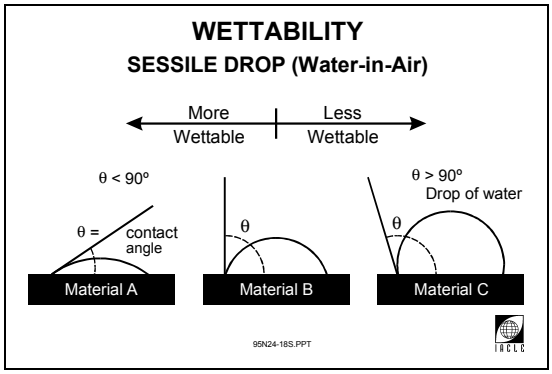

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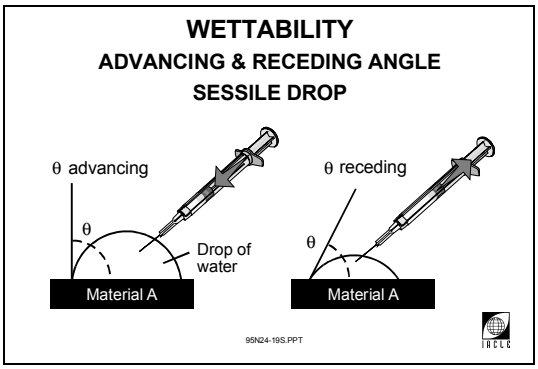

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Wettability

In vitro tests:

- Sessile drop: (Water-in-Air)

  A drop of pure water is placed on the test surface. The angle between the tangent to the drop's surface at the point of contact and the horizontal test surface (θ {theta}) is measured (see slide 22).

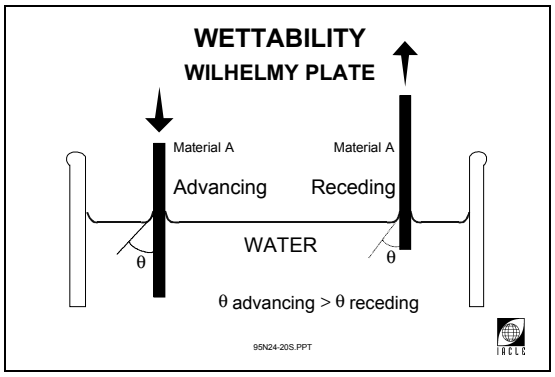
  – a zero angle = completely wettable

  – a low angle = somewhat wettable

  – a large angle (especially > 90°) = poorly wettable.

  When the bubble is expanded by adding more water, the *advancing* angle is determined. By withdrawing some water, the drop decreases in size and the *receding* angle can be measured. Receding angles are usually smaller (indicating better wetting), because the angle involves surfaces previously wetted.

21



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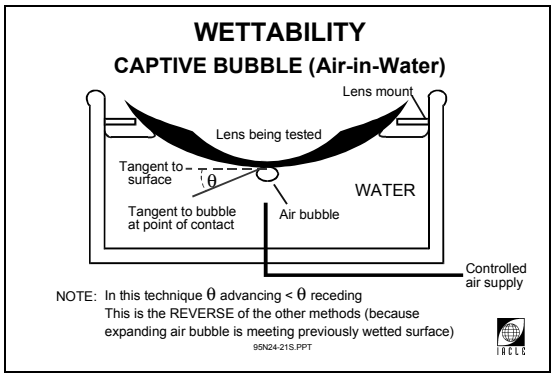
- Wilhelmy plate:

  A flat sample of the test material is lowered into water. This allows assessment of the *advancing* angle to be made, using a method of measurement similar to the sessile drop technique. Similarly, after withdrawing the sample a little, the *receding* angle can be measured. Again the receding angle is smaller.

22

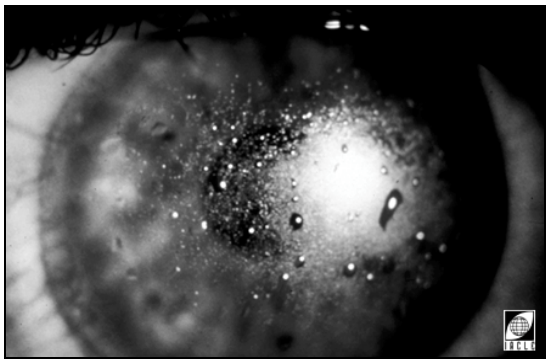


2L296213-21

- Captive bubble:

  An air bubble is introduced under a lens, convex side down in a wet-cell. The bubble floating against the underside of an immersed lens is viewed in profile, and contact angles measured. By increasing or decreasing bubble size the *advancing* or *receding* angles respectively can be measured. Note that in this method the receding angle is greater (i.e. the ***reverse*** of the other methods) because previously unwetted surfaces are involved.

23



2L20015-95

In vivo tests:

- Tear coverage:

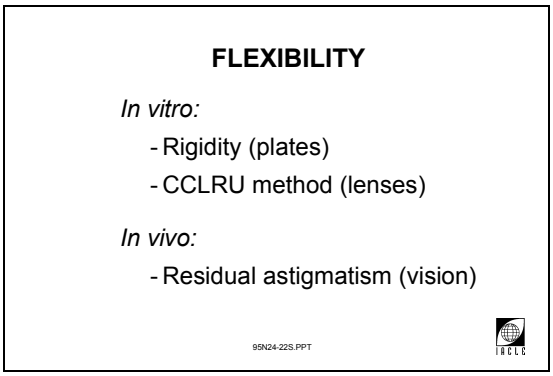
  Assessment of the ability of tears to form a complete film over the lens surface. An incomplete tear film is illustrated in slide 23.

- Break Up Time (BUT):

  An assessment of the ability of a lens to retain a complete tear film.

  Even if a complete tear film forms and is retained, the aqueous component evaporates and the lipid layer diffuses into the aqueous layer. Eventually, lipids contaminate the mucous layer rendering it hydrophobic. This results in a local break in the tear film. The time from the cessation of blinking to the first appearance of a break in the tear film is measured. Very short times indicate poor wettability.

24

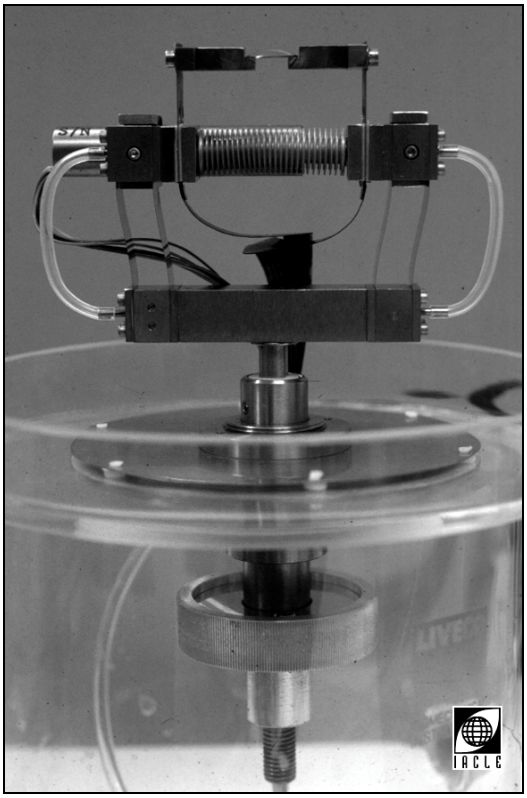


2L294N29-22

25

2L21408-93

26



2L21754-91

Flexibility

In vitro tests:

- Rigidity:

  The force required to produce a pre-determined deformation (bend) of a standard sample mounted in a prescribed manner.

- Cornea and Contact Lens Research Unit (CCLRU) method:

  A lens sample of a standardized design and parameters is loaded across its diameter. The 'force *versus* % change in diameter' curve is determined. This is done using a Vitrodyne™ apparatus (see illustration). Within its glass, controlled-environment chamber, precise loads can be applied pneumatically, and the change in diameter measured accurately by a linear displacement transducer. The detailed image (slide 26) shows the metal bellows which apply the load, the displacement transducer immediately behind them and the jaws with a lens mounted between. The apparatus can be used for both soft and RGP lenses.

In vivo test:

- Residual astigmatism:

  The more rigid a lens material is, the less it will conform to the shape of the cornea. In the case of corneal astigmatism, a more rigid lens will flex less or not at all, and therefore no significant residual astigmatism will be induced.

IV Other Properties

27

What do we require from a contact lens material?

- Optical quality
- Biocompatibility
- Ease of manufacture

95N24-23S.PPT

2L294N29-23

What Other Properties Do We Require From a Contact Lens Material?

Optical quality:

- material must be transparent with little light transmission loss
- material must be optically homogeneous, i.e. its refractive index should not be subject to regional variation unless such variation is intentional and well controlled.

- All lens materials must be biocompatible since they are in intimate contact with a physically and physiologically sensitive organ for extended periods of time. In particular, the material should contain virtually no leachable unreacted chemical components which may affect the cornea and/or conjunctiva.
- From a manufacturer's point of view, ease of manufacture is essential. Use of difficult materials will be adversely reflected in the cost, the reliability of the finished product and the responsiveness of the manufacturer to requests to use it.

28

OPTICAL PROPERTIES

- Refractive index
- Spectral transmission
- Dispersion
- Scatter

95N24-24S.PPT

2L294N29-24

Optical Properties

- Refractive index (*n*): This inherent property of a material ultimately governs the practical thickness of the fabricated lens. Generally, a higher refractive index is better, provided it does not mean other aspects, e.g. specific gravity, offset any gains.
- Spectral transmission should be uniform across the visible spectrum so as not to result in any changes in colour perception due to selective absorption of particular wavelengths or bands of wavelengths. Tints, including light handling tints, may alter the wearer's colour perception.
- Dispersion refers to the differences in refractive index for each wavelength of light. The principle refractive index is that measured for the green mercury line (546.07 nm). The principle dispersion is the refractive index difference demonstrated by a material for *blue* (479.99 nm) and for *red* (643.85 nm) light. Chromatic aberrations are affected by dispersion. The greater the dispersion the greater the chromatic aberrations (longitudinal and transverse).
- Any optical inhomogeneity, translucency or opacity in a lens material will result in the scattering of light. This in turn may result in haze, veiling glare and light loss when a lens made from such a material is worn.

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MATERIAL BIOCOMPATIBILITY REQUIREMENTS

- Be inert
- Contain no leachables
- Not be selectively absorbing
- Not exhibit excessive electophoresis
- Exhibit low friction *in situ*
- Be electrically compatible
- Not induce inflammatory or immunological responses

95N24-25S.PPT

2L294N29-25

Biocompatibility

Contact lenses materials should:

- Be inert, i.e. they should not react with, or cause other materials to react with, the eye tissues, the tears or lens care products with which they come in contact.
- Not take part in any enzymatic, activity or catalyse reactions between themselves and/or other chemical species.
- Contain no leachables, especially hydrogels, since the movement of water through a polymer is potentially a vehicle for the transfer of undesirable materials from inside the lens to the external eye. Common leachables include unreacted monomers, cross-linking agents, unbound or unprecipitated tinting chemicals, hydration accelerators and other chemicals used in lens manufacture.
- Not be selectively absorbing of metabolites, toxins, micro-organisms and other substances present in the environment.
- Not exhibit excessive electrophoresis which may result in the selective absorption, deposition or separation of chemical or biochemical entities from the environment.
- Exhibit low friction *in situ.* The material should be capable of accepting and retaining a good surface finish which, when wetted, will exhibit low friction. This will allow smooth lens movement on the eye and safe digital rubbing as part of the care regimen.
- Be electrically compatible. A lens material should not disturb the cornea's surface electrical properties (surface is negative with respect to the posterior cornea, with the potential difference believed to be in the range 20-40 mV). Generally, RGP lenses have a greater effect on the transcorneal potential than soft lenses.
- Not induce inflammatory or immunological responses in the anterior eye, even after prolonged exposure as in extended wear.

These requirements also apply to other materials used in lens manufacture which could find their way into a wearer's eye.

30

EASE OF MANUFACTURE

A contact lens material should:

- Be homogeneous
- Have consistent mechanical properties
- Be stress-free and dimensionally stable
- Be durable and resist local heating
- Be easy to polish/retain surface finish
- Have predictable hydration characteristics

95N24-26S.PPT

2L294N29-26

Ease of Manufacture

For a contact lens material to be considered easy to work with during the manufacturing process it should:

- Be homogeneous.
  Contact lens materials must be homogenous if the final product, especially its surface quality, is to be predictable and the resultant product reproducible.
- Have consistent mechanical properties.
  A material's mechanical properties are an important determinant of its behaviour during manufacture. For the lenses produced to be consistent, the variation in mechanical properties between individual batches of material must be small.
- Be stress-free and dimensionally stable.
  If lens materials, especially in the button form, are delivered with internal stresses, it is probable that these will be relieved at some stage of the manufacturing process. This can lead to distortions or other shape irregularities in the finished product.
- Should a material exhibit dimensional instability, then alterations in the lens shape or dimensions can occur at any stage of manufacture or after. Such alteration may occur rapidly or slowly, the latter making it very difficult to pinpoint whether the cause lies with a material property, manufacturing procedure or storage system.
- Be durable and resist local heating.
  A material must be able to withstand the rigours of manufacturing, particularly the curve cutting and polishing steps. The latter generates significant localized heating which may affect the surface quality and/or the surface properties of the end product.
- Be easy to polish/retain surface finish.
  Regardless of the material or the manufacturing method, the material must readily accept and retain a quality surface finish. This is especially true when the lens expands significantly during hydration. In this case, a quality surface generally requires a surface that expands uniformly. Materials used for molded lenses must also be capable of accepting and retaining the surface quality imparted to them by molds which have a high quality finish.
- Have predictable hydration characteristics.
  Regardless of whether the lens is rigid or soft, a material's behaviour at the hydration step is of paramount importance. This is especially so for soft lenses formed from xerogel buttons (material is anhydrous or in the 'dry' state). Batch-to-batch consistency, especially in terms of expansion on hydration, is perhaps the

greatest determinant of reproducibility of a lens series using the same material. To achieve the required levels of reproducibility, manufacturers often purchase large quantities of a single batch of lens material, then study and characterize the batch carefully before passing it to manufacturing.

V Rigid Gas Permeable Polymers

31

RIGID GAS PERMEABLE (RGP) POLYMERS

95N24-27S.PPT

2L294N29-27

32

POLY (METHYL METHACRYLATE)

- Patented: 1934, Nov, 16
- Used in contact lenses late '30s (Feinbloom, 1936)
- Readily machined and polished
- Fairly wettable when clean
- Easy to care for
- 0.2% - 0.5% water when hydrated fully
- Almost zero O_2 permeability

95N24-28S.PPT

2L294N29-28

Poly(Methyl MethAcrylate) (PMMA)

- Patented: 1934-Nov-16 by ICI (UK).
- Used in contact lenses late '30s (Feinbloom 1936, Mullen and Obrig, 1938).
- Readily machined and polished.
- Fairly wettable when clean.
- Easy to care for.
- Rigid.
- 0.2 - 0.5% water when hydrated fully.
- Almost zero oxygen permeability.
- Produces 'spectacle blur' and in the long-term, polymegethism and/or 'corneal exhaustion syndrome'.

33

RGP LENS MATERIALS

Early attempts to replace PMMA included:

- Cellulose Acetate Butyrate (CAB)
- Siloxane Acrylates (SAs)
- *t*-Butyl Styrene

95N24-29S.PPT

2L294N29-29

Rigid Gas Permeable Materials

Early attempts to replace PMMA:

Once the shortcomings of PMMA as a contact lens material were understood, attempts were made to find better materials. Early attempts included:

- Cellulose Acetate Butyrate (CAB):

  An engineering plastic which scratched readily, had a low Dk and was difficult to lathe. However it was relatively wettable.

- Siloxane Acrylates (SAs):

  Patented in early 1970s. Eventually led to successful materials from many manufacturers. Variations are still in use.

- *t*-Butyl Styrene:

  A novel material which combined high refractive index and low specific gravity - both desirable properties. However, the surface was prone to scratching and some solutions were reported to reduce lens wettability.

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RIGID GAS PERMEABLE MATERIALS
CAB

- Introduced by Eastman, mid-1930s
- More flexible than PMMA
- Can be molded or lathed
- Hydroxyl groups result in 2% water content
- Material stability lower than PMMA
- Dk range 4 - 8
- Incompatible with Benzalkonium Chloride

95N24-30S.PPT

2L294N29-30

Rigid Gas Permeable Materials

CAB

- Introduced by Eastman, mid 1930s and used in haptic shells by Teissler, 1937. Not used in RGP corneal contact lenses until 1972/73 (RX-56 lenses by Rynco Scientific Corp, see Stahl *et al*, 1974).
- Slightly flexible, water resistant.
- Can be molded or lathed.
- Well tolerated, possibly because hydroxyl groups result in 2% water content and reasonable wettability.
- Material stability lower than PMMA.
- Dk in range 4 - 8 (i.e. from half to approximately the same as polyhydroxyethyl methacrylate (HEMA or PHEMA)).
- Incompatible with the preservative benzalkonium chloride.

35

BUTYL STYRENE

- Dk = 25 (low)
- High refractive index, 1.533
- Low specific gravity, 0.95
- Thinner, lighter lens
- High powered prescriptions

95N24-31S.PPT

2L294N29-31

Rigid Gas Permeable Materials

Butyl Styrene (*t*-Butyl Styrene):

- Dk of 25, while low, was quite competitive at the time of release.
- The refractive index of 1.533 is the highest of any RGP material.
- The specific gravity (SG) of 0.95 is the lowest of any RGP.
- The combination of high *n* and low SG offers the thinnest, lightest lens possible. This made the material ideal for high Rxs.

Material was not particularly successful in the marketplace.

V.A Siloxane Acrylates

36

SILOXANE ACRYLATES
PROPERTIES

- PMMA backbone
- Si-O-Si bond
- Dks 12 - 60 (low - medium)
- Wetting agent added
- Surface is negatively charged

95N24-32S.PPT

2L294N29-32

Siloxane Acrylates

Properties:

- The era of successful RGP materials was heralded by the introduction of Polycon™, the original siloxane acrylate material, in the late 1970s (patented 1974).
- A PMMA backbone gives the material its dominant physical properties, especially rigidity.
- Si-O-Si bond is flexible and extensible. This results in significant increases in oxygen permeability but a reduction in material rigidity.
- Dks in low to medium range are achievable.
- A wetting agent may be incorporated to enhance lens wettability, usually methacrylic acid (MA).
- Material chemistry results in a net negative charge on the lens surface, especially if methacrylic acid is used as the wetting agent.

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SILOXANE ACRYLATES
ADVANTAGES

- Higher Dk than any previous materials
- Reduced rigidity (greater conformity)
- Allowed larger lens diameters (larger optic zones) to be used

95N24-33S.PPT

2L294N29-33

Siloxane Acrylates (SAS)

Advantages:

- SAs have higher oxygen permeabilities than all the lens materials which preceded their development. At the time of their introduction this resulted in improved corneal physiology.
- The lower rigidity of SAs allows lenses to conform more closely to the shapes of the corneas on which they are placed. This reduces the likelihood of the lenses being displaced from the cornea during normal use.
- By offering improved physiology, and to a lesser extent lower rigidity, larger diameter lenses could be fitted. This allowed the optic zone diameter to be increased, thereby overcoming some of the problems of smaller optic zones, especially in low light levels.

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SILOXANE ACRYLATES
DISADVANTAGES

- More deposit prone
- Surface easily scratched
- Higher breakage rate
- Can craze
- Flexure problems
- Parameter instability

95N24-34S.PPT

2L294N29-34

Siloxane Acrylates

Disadvantages:

- Surface charge and surface chemistry make them more deposit prone.
- SA materials have relatively ‘soft’ surfaces, hence they scratch more readily.
- SA materials are relatively brittle and are cracked or broken more easily.
- Some SA materials, when used in conjunction with particular lens care products, have been known to ‘craze’. This phenomenon is possibly the result of induced internal stresses being relieved, leading to surface and matrix failure.
- Low rigidity allows the lens to conform to corneal shape, reducing the completeness of correction of corneal astigmatism by a simple

spherical lens. Flexure problems with SA materials of relatively low rigidity are possibly related to the siloxane content of the material.

- SA lens parameters may be influenced by age, their environment, lens care products and the stresses placed on them by storage cases or astigmatic eyes. Lenses may recover slowly, incompletely or not at all. Unknown factors during lens fabrication may also affect lens parameters.

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SILOXANE ACRYLATES
EXAMPLES

- Boston II, IV
- Alberta II, III
- Menicon O_2
- Optacryl 60, Ext
- Paraperm O_2, EW
- Polycon II, HDK
- Persecon CE

95N24-35S.PPT

2L294N29-35

V.B Fluoro-Siloxane Acrylates

40

FLUORO-SILOXANE ACRYLATES

95N24-36S.PPT

2L294N29-36

41

FLUORO-SILOXANE ACRYLATES

Early attempts to surpass Siloxane Acrylates include:

- Alberta N
- Equalens
- FluoroPerm

95N24-37S.PPT

2L294N29-37

Fluoro-Siloxane Acrylates (FSAs)

The FSA materials were developed as a result of efforts to further increase the Dk of RGP materials and to increase resistance to surface deposition.

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FLUORO-SILOXANE ACRYLATES

- Fluorine monomer added to SA material
- Lower surface charge
- Better wetting (?)
- Reduced deposits (?)

95N24-38S.PPT

2L294N29-38

43

FLUORO-SILOXANE ACRYLATES

- Dks 40 to 100+ (med-high)
- EW potential
- Surface easily scratched
- Greater lens flexure

95N24-39S.PPT

2L294N29-39

Fluoro-Siloxane Acrylates

Properties:

- The element fluorine (F) is added to basic SA chemistry to enhance O_2 permeability.
- A lower surface charge results.
- Some materials may wet a little better.
- Some materials may resist deposits more. However the allusion to Teflon™-like (poly(tetrafluoroethylene) or (PTFE)) properties cannot be justified.
- Dks of 40 - 100 or more are achievable.
- Dks are high enough for extended wear to be a possibility.
- FSAs are generally more flexible than SAs.
- Surfaces are relatively easily scratched.

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FLUORO-SILOXANE ACRYLATES
EXAMPLES

- Equalens
- Fluorex
- FluoroPerm
- Quantum II
- Alberta N-FL

95N24-40S.PPT

2L294N29-40

V.C Perfluoroethers

45

PERFLUOROETHERS

3M fluorofocon A

(Advent ™)

95N24-41S.PPT

2L294N29-41

Perfluoroethers

The 3M perfluoroether lens material is novel and in a distinct material category. It should not be confused with FSAs. Production of the Advent™ lens made from this material has been discontinued.

A perfluoroether consists of:

- Fluorine.
- Oxygen.
- Carbon.
- Hydrogen.

The fluorofocon A material consists of:

- Perfluoroether.
- PVP (poly(vinyl pyrrolidine)).
- MMA (methyl methacrylate).

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PERFLUOROETHERS
ADVANTAGES

- Dk 90+ (high)
- Good EW potential
- Neutral surface charge
- Greater flexibility 'on eye'

95N24-42S.PPT

2L294N29-42

Perfluoroethers

Advantages:

- High Dk, potentially sufficient to support extended wear.
- No surface charge, thus reducing the likelihood of lens spoilage.
- High flexibility results in conformity to the corneal shape *in situ*. This results in stable vision and possibly greater comfort. However, this conformity can also be a disadvantage.

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PERFLUOROETHERS
DISADVANTAGES

- Low refractive index
- High specific gravity
- Low yields/high cost
- Average wettability
- Greater flexibility 'on eye'

95N24-43S.PPT

2L294N29-43

Perfluoroethers

Disadvantages:

- A low refractive index means a thicker lens for a given prescription.
- High specific gravity means a heavier lens for a given prescription.
- These first two points constitute a significant disadvantage. Together they mean a heavier, thicker lens, the reverse of what is desired.
- The success rate during manufacture is lower than for other materials and the cost of each lens is higher. Manufacture of this lens type is therefore more expensive.
- The wettability of the fluorocarbon lens surface is only average.
- The on-eye flexibility and conformity reduces the correction of cornea-induced astigmatism by a spherical contact lens.

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RGP MATERIALS AVAILABLE

Dk	
0	PMMA
Low (<40)	Airlens II, Alberta, Alberta N, Boston IV, Fluorex 100, 200, 400, FluoroPerm 30, Optacryl K, Ext, Paraperm O_2, O_2+, EW Polycon II

95N24-44S.PPT

2L294N29-44

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RGP MATERIALS AVAILABLE

Dk	
Low to Mod (40-60)	Boston 7, Equalens, Fluorex 600, 800, FluoroPerm 60, Polycon HDK
Mod to High (>60)	Equalens II, FluoroPerm 92, Menicon SF-P, Optacryl Z, 92

95N24-45S.PPT

2L294N29-45

RGP Materials Available

Examples presented here are grouped by Dk. Starting with PMMA whose Dk is practically zero, the next group have low Dks (<40). Only a few in this group are still manufactured.

The remaining groups are: Dks of 40 - 60 and >60. These are examples of current RGP material technology.

VI Rigid Gas Permeable Lens Manufacturing

50

RGP LENSES MANUFACTURING ASPECTS

95N24-46S.PPT

2L294N29-46

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RGP MANUFACTURING

Care with:
- Blocking
- Cutting
- Polishing
- Solvents

95N24-47S.PPT

2L294N29-47

RGP Manufacturing

Care is required during RGP contact lens manufacture, particularly in the choice of compounds which come in contact with the lens blank. This is especially true when blocking and solvent cleaning the button or lens.

Care must also be taken with cutting and polishing procedures so as not to produce localized heating of the lens blank, as this may alter the surface properties of the finished lens.

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RGP MANUFACTURING

Poor wettabilitiy associated with:
- Over-polishing (Walker, 1989)
- Incorrect use of solvents (Hogg, 1995)
- Use of incorrect solvents (Hogg, 1995)

95N24-48S.PPT

2L294N29-48

RGP Manufacturing

Poor wettability may be associated with:

- Over-polishing which may result in localised heating of the lens blank surface with a subsequent alteration of its properties (Walker, 1989).
- Either alone or in combination with the first point, the use of the incorrect solvent or the incorrect use of a solvent may also adversely affect the wettability of the finished product (Hogg, 1995).

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FSAs/SAs MANUFACTURING DISADVANTAGES

- Softer materials
- Difficult to get highly polished surface
- Materials susceptible to 'burning'
- Solvents can affect the surface

95N24-49S.PPT

2L294N29-49

Fluoro-Siloxane Acrylates and Siloxane Acrylates

Manufacturing disadvantages:

- Have surfaces which are generally 'softer' than PMMA, i.e. they scratch more easily.
- Are more difficult to finish with a highly polished surface.
- Are more prone to surface 'burning' during manufacture.
- Are more susceptible to solvent damage during manufacture.
- The back optic zone radius (BOZR) of finished lenses has been known to change over time, especially in high minus BVPs.

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FSAs/SAs
MANUFACTURING DISADVANTAGES

- Significant flattening of BOZR
- Higher Dk lenses difficult to modify
- Lower reproducibility

95N24-50S.PPT

2L294N29-50

55

FSAs/SAs
MANUFACTURING DISADVANTAGES

- Manufacturing more difficult
- More sophisticated equipment required
- Increased production costs
- Lower yields than PMMA

95N24-51S.PPT

2L294N29-51

- The more exotic materials of high Dk are often difficult to modify, especially in the contact lens practice.
- The reproducibility of lenses fabricated in these materials is lower than that of less sophisticated materials, especially PMMA and low Dk SAs.
- The manufacturing process is more difficult and requires more care.
- More sophisticated equipment is required to manufacture lenses from these materials.
- The combination of manufacturing difficulties and the need for more sophisticated equipment adds to the cost of production using these materials.
- A lower success rate during manufacture leads to lower production yields. FSAs<SAs<PMMA.

VI.A Manufacturing Methods

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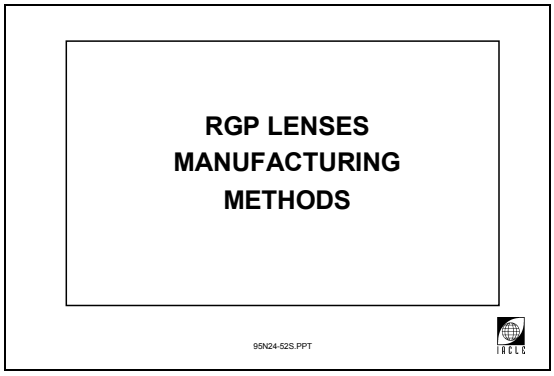

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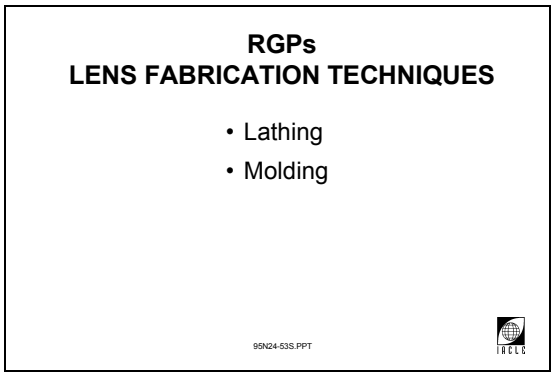

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RGPs

Lens Fabrication Techniques

- Lathing.
  This is the original method. Lathing is a well understood and longstanding method of fabricating anything that can be made symmetrical about an axis of rotation, e.g. a contact lens.
- Molding.
  Molding contact lenses is a more recent adaptation of an old manufacturing technique in which the lens material enters a double-sided mold as a liquid and solidifies *in situ* as a result of polymerization. Once the mold is broken apart, the lens is in its final form and requires little or no secondary manufacturing or finishing.

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2L294N29-54

Lathing

Advantages:

- Lathing is a simple technology which requires little adaptation to contact lens manufacturing. Most of the specialised techniques required have already been pioneered in other industries (e.g. the semiconductor and ultra-precision engineering fields).
- There are few limitations on the parameters that can be lathed (e.g. virtually any radius required can be cut), especially with modern, computer-controlled machines.
- Most, but not all, materials can be lathed, although some may require special care.
- Minimal investment is required to start a lathe-based production facility, since each lathe represents a finite investment, is usually an off-the-shelf item and the ancillary equipment is not overly complex or expensive.

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LATHING
DISADVANTAGES

- Complex designs difficult
- Labour intensive
- High cost per lens
- Variable surface finish
- Relatively slow
- Volume production difficult
- Reproducibility

95N24-55S.PPT

2L294N29-55

Lathing

Disadvantages:

- Complex designs are difficult, labour-intensive, or even impossible given the requirement that a lathed product be symmetrical and on a locus of the arcuate sweep of the toolholder. Some computer-controlled machines do not have this latter limitation.
- The labour-intensive nature of lathing results in a higher unit cost.
- Since the lathe's cutting tool leaves a very fine spiral tool track in the lens surface, polishing is usually required. The lathing and/or polishing process may lead to variability in the surface finish due to local heating or variations in the completeness of polishing. Some success has been achieved with research into lathing processes that do not require subsequent polishing.
- All processes associated with lathing, and the lathing step itself, require significant time. This limits production rates, meaning that volume production is difficult without the installation of many machines working concurrently.
- Because of the large number of steps involved in lathe-based manufacturing, variations in the overall process are easily introduced. This is reflected in the lower reproducibility usually achieved.

60

MOLDING
ADVANTAGES

- Low cost per lens
- Rapid
- Volume production easy
- Good surface quality
- Good reproducibility
- Complex designs possible

95N24-56S.PPT

2L294N29-56

Molding

Advantages:

- The reduction in the total number of steps and the number of repetitive steps reduces both the time involved in manufacturing and the unit cost. A low unit-cost means that it is feasible to keep manufactured items in stock rather than manufacturing them 'on demand' or 'just in time'.
- This simplicity and brevity means that volume production is both easier and less expensive to attain.
- Surface finish is largely dependent on mold surface quality. Once the latter is satisfactory, all subsequent lenses should exhibit similar surface quality. The same applies to lens parameters, which translate to satisfactory levels of reproducibility.
- Once molds for a complex design are completed satisfactorily, the actual manufacturing process costs no more than for a simpler design. All the major investment is 'up front'. Economic production then depends on maximum utilization of the initial investment in the complex master mold.

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MOLDING
DISADVANTAGES

- Expensive to start production
- Expense limits parameter range
- Not all materials suitable
- Essentially for stock lenses only

95N24-57S.PPT

2L294N29-57

Molding

Disadvantages:

- Since expensive and specialised machinery is required, the start-up costs are usually high. Some customization may also be required.
- New molds are required for each new lens series required. This is more expensive than having to change tool settings which is all that a lathe-based system requires.
- In view of the obvious expense of a new or wider lens series it is usual to limit the parameters and/or the number of lens series manufactured to those which satisfy the maximum demand. The less common needs of the market are ignored.
- Not all materials lend themselves to molding, either due to their chemical composition or undesired dimensional changes during the polymerization process.
- Because of the cost of tooling, custom lens making is not usually undertaken. In practical terms, molding is only suited to volume production of common (higher demand) designs and parameters.

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RGP CONTACT LENSES
BIFOCALS

Translating

- Concentric (annular), distance centre
- Progressive addition
- Implanted segment

Non-Translating

- Diffractive
- Concentic, distance centre
- Minimal movement is essential, but physiologically undesirable

95N24-58S.PPT

2L294N29-58

RGP Contact Lenses

Bifocals

Translating lenses move on the eye when the eye is directed downwards to view a near object. The rest position of the lens amounts to an upward decentration.

- Concentric (annular), distance centre.

  The lens mid-periphery has a blended single-power near addition on its front surface. The distance prescription occurs only in the lens centre. The lens edge is conventional (design and thickness) in the interests of comfort and ease of manufacture.

- Progressive addition.

  The lens mid-periphery has a blended, variable-power, near addition on its front surface. The near addition increases with increasing displacement from the lens centre.

- Implanted segment.

  A higher refractive index segment, usually ‘D’ or crescent-shaped, is incorporated into an RGP button of conventional material.

Non-translating

- Diffractive.

  A series of concentric zones of alternating distance and near powers incorporated into the back surface. Alternation of powers is intended to make the design less dependent on pupil size.

- Concentric, distance centre.

  Similar to the translating type, this lens type incorporates just one distance zone (the centre) and one near zone (the zone of the lens immediately surrounding the centre). The lens periphery follows normal RGP design practice.

- While minimal movement with non-translating designs is essential, it is quite undesirable physiologically.

63

MANUFACTURING RGP LENSES

- Concentric and progressive: made using conventional lathing or molding techniques
- Implanted segments: high refractive index segment incorporated in button. Usually 'D' or crescent-shaped
- Diffractive: concentric zones molded onto back surface

95N24-59S.PPT

2L294N29-59

Manufacturing RGP Bifocals

- **Concentric and progressive bifocals** are made using conventional lathing or molding techniques.
- **Implanted Segments** have a high refractive index segment incorporated in a lens button of conventional material. They are usually 'D' shaped or crescent-shaped.
- **Diffractive:** concentric zones are molded onto the lens back surface.

64

TINTED RGP CONTACT LENSES

Either:

- Dye is dissolved in monomer before mixing and polymerization

or:

- Pigment is dispersed in monomer before mixing and polymerization

95N24-60S.PPT

2L294N29-60

VI.B RGP Lens Quality Assurance

65

2L294N29-61

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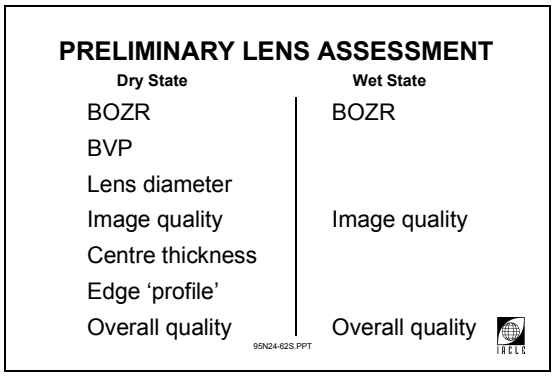

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Preliminary Lens Assessment

Assessment during manufacture

Dry State:

- BOZR and lens diameter are among the most important measurements.
- BVP is measured to determine that the final prescription is as ordered.
- Image quality will give a useful assessment of the quality of the lens optics.
- Centre thickness, whether it be a series standard or a practitioner request, influences the physiological performance of the final lens and some of its physical properties. Its compliance with the order needs to be confirmed.
- Edge profile has been shown to be critical to lens comfort.
- The overall quality of workmanship needs to be assessed to determine the possibility of the finished product delivering less than optimum performance or comfort on the eye. Defects may include edge chips and surface scratches.

Wet State:

- BOZR is critical. It influences the lens fit and the optics of the tear lens. The BOZR will be approximately 0.03 mm flatter after hydration.
- Image quality is again assessed to determine the optical quality of the product. Vision quality depends on the prescription being accurate and the quality of the optics.
- Workmanship again needs to be assessed to confirm that hydration has not revealed any previously undetected defects.

67

CHANGES FROM DRY TO HYDRATED STATE

- Hydration/expansion effects
- Toricity?
- Parameters within tolerance?
- Other?

95N24-63S.PPT

2L294N29-63

Changes From Dry To Hydrated State:

- Expansion resulting from hydration, and its uniformity and predictability, determine the outcome of the hydration step. While hydration is minimal in RGPs, it is still of both manufacturing and clinical significance.
- Any untoward hydration effect has the potential to produce a toric or even an irregular lens shape. Vision quality may suffer as a result.
- Standards, whether they be set by the practitioner or a standards authority, normally stipulate a tolerance. It is expected that finished lenses are within these tolerances.
- Other, less common changes may occur. These may be due to a lack of homogeneity, other variations in the lens material, vagaries of the manufacturing and hydration process or other factors not as yet understood.

68

CENTRE THICKNESS

Affects:

- Lens flexure (vision)
- O_2 transmissibility
- Relevance of trial lens
- Handling

Tolerance $\pm$ 10%

95N24-64S.PPT

2L294N29-64

Centre Thickness

Affects:

- Flexure of the lens *in situ*. Conformity to the shape of the cornea may induce residual astigmatism because of lens flexure.
- Gas transmissibility, which is inversely proportional to the lens thickness, i.e. Dk/*t* decreases as thickness increases.
- If the thickness of the delivered lenses and trial lenses differ markedly, the behaviour of the trial lens may not be truly indicative of the delivered lens.
- Handling. Apart from inherent material properties such as rigidity, the next most important factor affecting lens handling is thickness. The greater its thickness, the easier the lens is to handle.
- Acceptable tolerance. Regardless of the tolerance applied, lenses outside a predetermined range should be rejected. Some countries have national standards which can be applied.

VII Soft Contact Lenses

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SOFT CONTACT LENS MATERIALS AND MANUFACTURING

95N24-65S.PPT

2L294N29-65

70

SCL MATERIALS
PHYSICAL COMPATIBILITY

- Must allow lens movement
- Must be flexible especially in thicker lenses

95N24-66S.PPT

2L294N29-66

Soft Lens Materials

Physical Compatibility

- Mechanical properties of the lens in combination with its fit must allow for lens movement.
- The lens material must be flexible enough, especially in thicker lenses, to allow the lens to conform somewhat to the anterior eye's topography. This ensures comfort and satisfactory physiological performance.

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SCL MATERIALS
OPTICAL QUALITY

- Depends on surface quality after hydration
- Shape regularity after hydration
- BVP within tolerance
- No unwanted toricity
- Accurate cylinder axis if toric

95N24-67S.PPT

2L294N29-67

72

SCL MATERIALS
IMPORTANT PHYSICAL/ CHEMICAL PROPERTIES

- O_2 permeabiltiy (Dk)
- Water content
- Elasticity
- Ionicity
- Deposit resistance
- Refractive index
- Durability
- Enviromental suscepibility

95N24-68S.PPT

2L294N29-68

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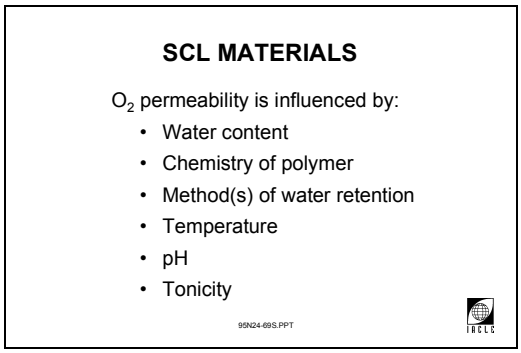

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SCL Materials

Oxygen Permeability of SCLs is Influenced by:

- Water content.
  In general, the higher the water content, the greater the Dk. This is believed to be the result of oxygen dissolving in the water, especially if it is unbound (free).
- Chemistry of the polymer.
  The packing density of a material's molecules influences the ease with which oxygen may pass through the material. If large, open, but rigid-side molecules are present, the packing density is limited and the permeability is enhanced. If molecular chains are flexible or 'loosely' arranged, the packing density is again lower and the Dk higher. Alternatively, densely packed molecules make oxygen passage virtually impossible because of the restricted space between adjacent molecules e.g. PMMA. The presence of crosslinks as well as their length and density also contribute to the 'packing density' of the polymer.
- Method(s) of water retention.
  The water normally exists as a dipole which can be attached electrostatically to a charged material molecule (bound) or simply locate itself within the inter-molecular spaces (free). The greater mobility of 'free' water enhances Dk.
- Temperature.
  Higher temperatures increase agitation of molecules, resulting in an increase in potential inter-molecular space and easier passage of O_2 through the material. Dks are often quoted at eye temperature (around 34°C) because the figures are higher than at room temperature (usually quoted at around 21°C).
- pH.
  As the pH of the lens environment decreases (becomes more acidic), so too does the water content. As it increases (becomes more basic or alkaline), the water content increases (Masnick, Holden, 1972). The magnitude of the change may be dependent on the material's chemistry as well as its water content.
- Tonicity.
  The tonicity of the surrounding medium (tears or lens care products) can affect the water content. Hypertonic solutions decrease the water content, hypotonic solutions increase it.

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SCL MATERIALS

Water content influences:

- O_2 permeability
- Refractive index
- Rigidity (handling)
- Durability
- Minimum thickness to prevent pervaporation
- Environment susceptibility including spoilage
- Lens care choice

95N24-70S.PPT

2L294N29-70

Water Content Influences: (at least for hydrogels)

- Oxygen permeability.
  Generally the higher the water content of the lens, the greater the oxygen permeability.
- Refractive index.
  Higher water content materials have a lower *n*.
- Rigidity (handling).
  Higher water content materials are generally less rigid and are more difficult to handle when thin.
- Durability.
  Higher water content materials are generally less durable.
- Minimum thickness to prevent pervaporation.
  Usually this is a problem of higher water content lenses made too thin. Ultra-thin low water content lenses can exhibit the problem in susceptible wearers.
- Environmental susceptibility including spoilage.
  High water content lenses, especially if ionic, are more easily spoiled and/or influenced by their environment.
- Lens care system choice.
  Not all lens materials are suited to all available lens care regimens.

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SOFT LENS MATERIALS
Dk @ 34° C

Water Content	DK
<40%	5 - 8
40 - 55%	7 - 19
>55%	18 - 28

95N24-71S.PPT

2L294N29-71

Soft Lens Materials: Dk @ 34°C

All figures are measured by the coulometric technique at eye temperature (34°±1°C). These figures are generally lower than those used in promotional literature but are believed to represent a more rigorous and realistic set of figures.

76

LOW WATER CONTENT
ADVANTAGES

- Less susceptible to environment influences
  - more stable parameters
- More rigid, easier to handle
- Higher refractive index
- Any lens care product
- Ease of manufacture
- Greater reproducibility
- More wettable
- Pervaporation staining is less likely

95N24-72S.PPT

2L294N29-72

Low Water Content: Advantages

- Lower susceptibility to environmental influences, especially pH, results in lenses which have more stable parameters.
- Greater rigidity provides easier handling.
- Higher refractive index allows a thinner lens to be made.
- Virtually any lens care product can be used.
- All methods of lens fabrication can be used.
- Generally more predictable behaviour and lower expansion on hydration results in greater reproducibility.
- More wettable.
- Pervaporation staining is less likely because the bulk flow of water through such materials is more difficult.

77

LOW WATER CONTENT
DISADVANTAGES

- Low Dk
- Less flexible
- Thin lenses difficult to handle

95N24-73S.PPT

2L294N29-73

Low Water Content: Disadvantages

- Because of low Dk, only the thinnest lenses provide adequate oxygen for daily wear.
- The greater rigidity of most of these materials results in less conformity to the topography of the anterior eye, which may result in lower comfort levels.
- Thin lenses (for adequate Dk/*t*) are usually more difficult to handle, especially in lower BVPs.

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LOW WATER CONTENT
ADVANTAGES

- Higher Dk
- More flexible
- Faster restoration of shape following deformation

95N24-74S.PPT

2L294N29-74

79

LOW WATER CONTENT
ADVANTAGES

- Fragile
- More deposit prone
- More susceptible to the environment
- Lower refractive index
- Less stable parameters, lower reproducibility
- Thermal disinfection not recommended (trial lenses)
- More difficult to manufacture
- Cannot be made too thin - pervaporation

95N24-75S.PPT

2L294N29-75

High Water Content: Disadvantages

- Greater fragility.
- More deposit prone. Larger ‘pore’ size, often in combination with an ionic chemistry, increases uptake of foreign material including tear proteins.
- More susceptible to the environment, especially pH changes.
- Lower refractive index requires a thicker lens to be made.
- Less stable parameters, lower reproducibility.
- Thermal disinfection is not recommended as protein uptake is higher and the risk of protein denaturation greater. This also has rami-fications for trial lens disinfection i.e. high water trial lenses should not be thermally disinfected.
- Optical quality is more difficult to achieve because the expansion on hydration is very significant. This means a polished xerogel (‘dry’ or anhydrous) lens undergoes major changes on hydration. Surface quality and shape are not necessarily retained. Alternative manufacturing methods, e.g. stabilized soft molding, may overcome these problems.
- More difficult to manufacture by lathing since a small, steep xerogel lens is required for the hydrated product to have ‘normal’ parameters.
- Pervaporation staining, due to bulk flow of water through the lens, limits the thinness of the lens.

80

PHYSICAL PROPERTIES
ELASTICITY

- Elastic limit should be large
- Should be strong (high Young's modulus)
  - combination of above should result in a durable lens
- Shape recovery should be rapid

95N24-76S.PPT

2L294N29-76

Physical Properties: Elasticity

Materials:

- Should have a large elastic limit.
  For a material exhibiting elastic properties, there is a limit to the extension it can undergo before permanent changes may be induced. This is the material's elastic limit. A *lower* limit is the Limit of Proportionality. Within this limit, stress (the load or force per unit area) is proportional to strain (the extension), i.e.
  Stress (the load) $\propto$ (Strain (the extension))
- Should be strong (high Young's modulus).
  Young's modulus is the constant which relates proportional (i.e. within the material's proportionality limit) stresses and strains.

  Stress = Y x Strain

  Young's modulus is one of several moduli of elasticity (Barron, 1959).

  A combination of a large elastic limit and a large Young's modulus should result in a durable lens, i.e. the lens material can withstand significant extension, but extends little even under significant load.
- Should recover their shape rapidly following deformation. The recovery should be complete.

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ELASTICITY:
METHODS OF DETERMINATION

In vitro

- Stress vs Strain curve within the elastic limit
- Destructive testing. Exceed elastic limit to point of failure
- Standard test methods may not be applicable to soft lens materials

95N24-77S.PPT

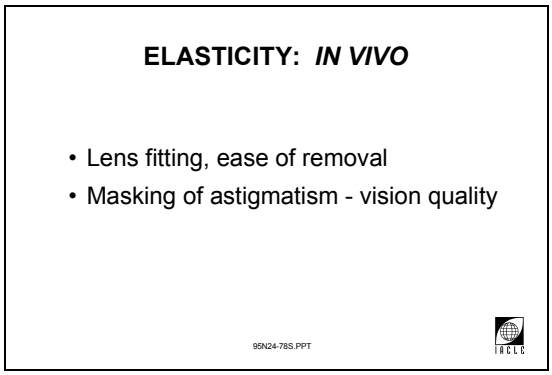
2L294N29-77

Elasticity: Methods of Determination

In vitro

- Stress *versus* strain curve determination within the elastic limit.
- Destructive testing.
  Exceed elastic limit to point of failure.
- Standard test methods may not be applicable to soft lens materials:
  - environment must be normal saline
  - standard test piece shapes or sizes cannot always be obtained, especially with spin-cast products
  - clamping/mounting of test pieces is critical to the determination of how and where the samples fail (failure mode) during testing and the results may be influenced by the method(s) used.

82



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Elasticity

In vivo

- Because of their influence on post-lens tear film thickness, material rigidity and elasticity influence lens fit:
  - a thin tear film results in a slow or unmoving lens which is interpreted clinically as a 'tight' fit
  - similarly, a conforming lens is more difficult to move and remove.
  - an elastic material is desirable as it will survive the repeated deformations of lens removal.
- Masking of astigmatism.
  Rigidity and elasticity of the lens material influences 'on-eye' behaviour, including lens shape and its recovery following a blink. Vision quality and/or the variability of vision may give an indication of this 'on-eye' behaviour. A closely conforming lens will not mask cornea-induced astigmatism significantly. Claims of soft lenses masking 0.75 D or more of astigmatism should be viewed suspiciously.

VIII Soft Contact Lens Materials

VIII.A Soft Contact Lens Polymers

83

SCL POLYMERS

95N24-79S.PPT

2L294N29-79

84

POLY (HYDROXYETHYL METHACRYLATE) (PHEMA)

- Original material (1952-1959, patented 1955) by O Wichterle and D Lim, Czechoslovakia
- A close relative of Poly(methyl methacrylate) (PMMA, patented 1934)
- Differentiating feature - a polar hydroxyl (OH-) group to which the water dipole may bind, approx 38% water content (W/W).

95N24-80S.PPT

2L294N29-80

Poly(HydroxyEthyl MethAcrylate) (PHEMA)

- Original material (1952-1959, patented 1955) by O. Wichterle and D. Lim, Czechoslovakia.
- A close relative of poly(methyl methacrylate) (PMMA, patented 1934).
- Its differentiating feature is a polar hydroxyl (OH^-) group to which the water dipole may bind. Water content is approximately 38% (W/W). PHEMA is still in regular use by many manufacturers.

85

O WICHTERLE

- Molded PHEMA lenses (1956)
- Developed spin-casting (1961)
- Developed lathing of the xerogel (1963)

95N24-81S.PPT

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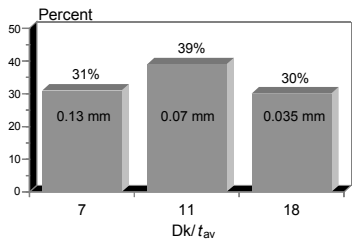
86

INTERNATIONAL USE OF PHEMA



95N24-82S.PPT

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While the majority of PHEMA lenses are in the thin and ultra-thin categories, the percentage of lenses (presumably mostly plus lenses) thicker than 0.10 mm is surprising given the poor Dk/*t* known to result from the combination of low Dk and significant lens thickness.

87

AFTER PHEMA

- Attempts to 'improve' on PHEMA were fueled by patent/legal/marketing issues
- A so-called second generation material was the Griffin 'Bionite' Naturalens (1968)
  - –co-polymer of PHEMA and Poly (Vinyl Pyrollidone) (PVP), 55% water

95N24-83S.PPT

2L294N29-83

After PHEMA

- Attempts to 'improve' on PHEMA were fuelled by patent/legal/ marketing issues.
- A so-called second generation material was the Griffin 'Bionite' Naturalens (1968):
  - a co-polymer of PHEMA and Poly(Vinyl Pyrrolidone) or PVP, 55% water content
  - a direct descendent (vifilcon A), is still in use.

88

AFTER PHEMA

- PVP (poly(vinyl pyrollidone))
- MA (methacrylic acid)
- MMA (methyl methacrylate)
- GMA (glyceryl methacrylate)
- DAA (diacetone acrylamide)
- PVA (poly(vinyl alcohol))
- + a cross-linking agent

95N24-84S.PPT

2L294N29-84

Other Variants Followed

Most were a combination of two (co-polymer) or three (ter-polymer) of the following monomers:

- PHEMA (poly(hydroxyethyl methacrylate)).
- PVP (poly(vinyl pyrrolidone)).
- MA (methacrylic acid).
- MMA (methyl methacrylate).
- GMA (glyceryl methacrylate).
- DAA (diacetone acrylamide).
- PVA (poly(vinyl alcohol)).

In each of these methods, a cross-linking agent is required.

89

Material's chemistry affects:

- Water content
- O_2 permeability (Dk)
- Ionicity
- Physical properties
- Susceptibility to environmental factors

95N24-85S.PPT

2L294N29-85

90

USANC MATERIAL CLASSIFICATION

Combination	USAN	Water Content	Lonicity
PHEMA	polymacon	low	non-ionic
PHEMA, PVP	vifilcon A	high	ionic
GMA, MMA	crofilcon A	low	non-ionic
PVP, MMA	lidofilcon A	high	non-ionic
PHEMA, DAA, MA	bufilcon A	low/high	ionic*
PHEMA, PVP, MA	perfilcon A	high	ionic*
PHEMA, MA	etafilcon A	high	ionic*
PVA, MMA	atlafilcon A	high	non-ionic*

*indicates MA-containing polymer

95N24-86S.PPT

2L294N29-86

Classifying a Lens Material

To define a material generically, each chemical entity has been given a name (including a version, e.g. A, B, etc.) by the US Adopted Names Council (USANC). Regardless of the marketing name used by a manufacturer, the USAN uniquely identifies the actual material. Materials which differ in water content only (usually by altering the proportions of the ingredients) still carry the same name and version e.g. bufilcon A 45% & 55%. The USAN is written in lower case. Note the inclusion of methacrylic acid renders a hydrogel ionic. Similarly, the use of MA as a wetting agent in RGP materials results in a negative surface charge. The UK also has a lens classification system.

VIII.B Ionicity

91

Ionic Materials
- Net negative charge on surface

Non-Ionic Materials
- Still have charged sites within polymer matrix, no net surface charge

95N24-87S.PPT

2L294N29-87

Ionic Materials

- Net negative charge on surface due to one or more of the material components being polar and presenting its negative polar ends to the outside world.

Non-Ionic Materials

- Also have charged sites within polymer matrix. However, the charges are internal to the polymer and no polar ends are presented to the outside world. This results in no net surface charge.

The degree of charge, rather than its presence or absence, may be clinically relevant.

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IONIC MATERIALS

ADVANTAGES
- More wettabe
- Denature tear proteins less (?)

DISADVANTAGES
- Deposit more readily
- Deposits may be bound
- More susceptible to pH changes

95N24-88S.PPT

2L294N29-88

Ionic Materials: Advantages

- More wettable.
  Polar functional groups at the lens surface increase wettability. The more polar groups present, the greater the wettability. Methacrylic acid can be added for this purpose because at physiological pHs it exists as a negatively charged ion.
- It has been reported that ionic materials denature tear proteins less than non-ionic materials, even though they contain more protein. Other data contradict this finding. This issue is still under investigation.

Ionic Materials: Disadvantages

- Accumulate deposits more readily.
  Any charged particles, including positively charged lysozyme, may be attracted to the negatively charged sites in ionic materials.
- Deposits may be bound, and therefore more difficult to remove.
- Ionic materials are more susceptible to pH changes, especially their water content.

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NON-IONIC MATERIALS

ADVANTAGES
- Less deposit prone
- Do not bind charged particles

DIADVANTAGES
- Denature tear proteins more (?)
- Less wettable (?)

95N24-89S.PPT

2L294N29-89

Non-Ionic Materials: Advantages

- Less deposit prone.
- Do not bind charged particles.

Non-Ionic Materials: Disadvantages

- Denature tear proteins more. Studies on the state of tear proteins have produced conflicting results.
- Less wettable. It has been claimed that the absence of polar groups at the lens surface may decrease its attractiveness to the water dipole, rendering the surface less wettable.

IX Soft Contact Lens Manufacturing

IX.A Soft Lens Manufacturing Methods

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SOFT LENS MANUFACTURING METHODS

- Molding - anhydrous (xerogel)
- Spin-casting
- Lathing - xerogel
- Molding/lathing combination
- Spin-casting/lathing combination
- Molding - stabilized soft

95N24-90S.PPT

2L294N29-90

Soft Lens Manufacturing Methods

- Molding - xerogel.
  Monomers are mixed and then poured into a mold (single or double sided) in the absence of water/water vapour (and usually air/oxygen as well) at tightly controlled temperatures.
- Spin-casting.
  An open-backed mold is spun as a small centrifuge. The mold defines the front surface of the lens. Rotational velocity, surface tension and gravity combine to define the back surface.
- Lathing - xerogel.
  An anhydrous button of lens material is lathed conventionally in a controlled atmosphere. Manufacturers are researching methods of eliminating the need for surface polishing by the application of high-precision engineering principles and other advances such as air bearings and anti-vibration mounts.
- Molding/Lathing combination.
  Usually a combination of molding the back surface and body of the lens and lathing the front surface.
- Spin-casting/Lathing combination.
  Usually spin-casting the front surface and body of the lens and lathing the back surface.
- Molding - Stabilized Soft.
  In this recent innovation, a space-taking inert diluent is included in the mix of monomers during molding/polymerization. The diluent is replaced by water at a later stage. The final product is quick to hydrate fully, undergoes minimal expansion on final hydration and provides high quality optics and surface finish.

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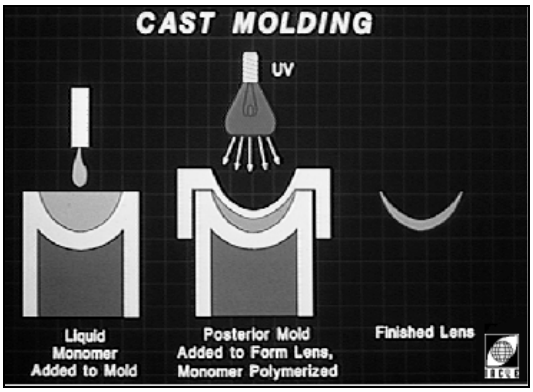

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Cast Molding

- Monomer in liquid form is introduced into a female mold which defines the lens front surface shape.
- As with the to RGP process, the mold may be double-sided or open (single-sided). If double-sided, a UV-transparent male mold is mated to the monomer-containing female mold and the two are clipped or clamped together.
- The process requires strict environmental control, especially of humidity, and in many versions of the process needs to be oxygen-free.
- The combination is UV irradiated until polymerization is complete.
- The mold is disassembled and the lens is then further processed and hydrated.

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SOFT LENS MANUFACTURING MOLDING

- Starts with liquid monomers
- Similar to RGP process
- Requires controlled environment, especially humidity, and often needs to be O2-free
- Polymerization initiator required (usually UV)
- Subsequent steps similar to lathed product

95N24-91S.PPT

2L294N29-91

Subsequent steps are similar to those for lathed products.

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SOFT LENS MANUFACTURING LATHING

- Starts with an anhydrous button
- Method similar to RGPs
- Requires strict control of environment especially of humidity
- Cleaning and hydration required upon completion
- Lens sealed in normal saline
- Packaged product then autoclaved (121°C for 15 minutes)

95N24-92S.PPT

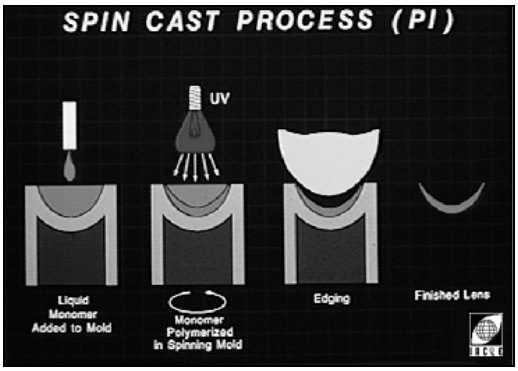
2L294N29-92

Soft Lens Manufacturing

Lathing

- The raw material is an anhydrous (xerogel) button.
- As with the RGP procedure, special contact lens lathes are used, usually numerically controlled by a computer. Numerical control increases both the complexity of design that can be achieved and the level of reproducibility.
- Requires strict control of environment, especially humidity, since a significant relative humidity will result in partial hydration/expansion of the lens material while the lens is being formed. This results in unpredictable outcomes and adversely affects reproducibility.
- Cleaning is required after final surfacing to remove polishing compounds and other surface contaminants including the materials used to block-up the lens button. As for RGPs, the use of incorrect solvents or incorrect use of solvents may affect the surface properties of the completed lens and may lead to differential hydration, reduced optical quality and altered wetting properties.
- Hydration of the lens is required after lens completion. This can be accelerated by initial hydration in a suitable substance other than water, and substitution with water as a final step.
- The lens is then sealed in normal un-preserved saline prior to sterilization.
- The packaged product is autoclaved (121° C for 15 minutes or longer) to sterilize the contents. The product can then be stored safely for a long period of time (often of the order of 3 - 5 years if necessary).

98



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99

SOFT LENS MANUFACTURING
SPIN-CASTING

- Starts with liquid monomers
- Monomers introduced into spinning mold
- Centrifugal force and gravity defines back surface shape and BOZR
- Mold defines front surface

95N24-93S.PPT

2L294N29-93

Soft Lens Manufacturing

Spin Casting

- The raw materials are liquid monomers.
- Monomers are introduced into a spinning mold in a controlled environment of CO_2 at high temperature.
- Centrifugal force and gravity defines the back surface shape and BOZR.
- The mold defines the front surface.
- The process can produce a good surface finish
  - front surface finish depends on mold finish
  - back surface finish depends on surface tension and other surface properties of the resulting polymer.
- Secondary manufacturing steps may be required, e.g. edge finishing.
- Subsequent procedures are similar to those for other manufacturing methods.

100

SOFT LENS MANUFACTURING
SPIN-CASTING/LATHING COMBINATION

- Starts with liquid monomers
- Body and front surface spin-cast
- Back surface lathed to define BOZR and design

95N24-94S.PPT

2L294N29-94

101

SOFT LENS MANUFACTURING
SPIN-CASTING/LATHING COMBINATION

- Starts with liquid monomers
- Body and back surface spin-cast
- Front surface lathed to give BVP and design

95N24-95S.PPT

2L294N29-95

102

SOFT LENS MANUFACTURING
STABILIZED SOFT MOLDING

- Developed for volume production
- An inert water substitute is mixed with lens monomers before polymerization
- Water replaces the substitute at hydration

95N24-96S.PPT

2L294N29-96

Soft Lens Manufacturing

Stabilized Soft Molding

- Developed for volume production requiring quick hydration, good optical quality and good reproducibility.
- An inert diluent is added to monomers in the mold prior to polymerization. The diluent, which is subsequently replaced by water, takes the space the water will eventually occupy.

103

SOFT LENS MANUFACTURING
STABILIZED SOFT MOLDING

- Significantly less expansion on hydration
- Better optical quality
- Better surface finish
- Quicker hydration
- Enhanced reproducibility

95N24-97S.PPT

2L294N29-97

104

SOFT LENS MANUFACTURING
PACKAGING

- Glass vial
  - screw or crimp lid
- Poly(ethylene terephthalate) (PET) vial
  - screw or crimp lid
- Foil pack (disposables)
- Multi-blister pack (daily disposables)

95N24-98S.PPT

2L294N29-98

105

SOFT LENS MANUFACTURING
AUTOCLAVING

- All products are autoclaved after manufacture, regardless of water content
- Foil and blister packs may require a special autoclave

95N24-99S.PPT

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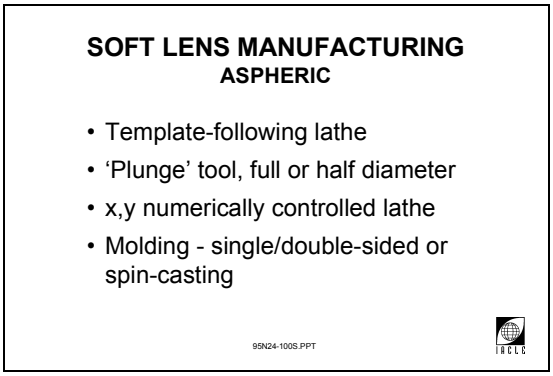
106



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Soft Contact Lens Manufacturing

Aspheric

- Template-following lathe.
  A large scale (e.g. 10X) model is assembled from individual aspects of the lens design (optic, periphery, edge, etc.) and its profile traced by the lathe template follower. The lathe is set to make a lens at a fixed reduction ratio relative to the template (e.g. 1:10).
- A 'plunge' tool is a full or half diameter, full-sized cutter which is shaped to the profile of the lens desired. It remains stationary and is fed slowly into the rotating lens button in a lathe. It machines the inverse of its profile into the button. Large diamonds have been used as the profiled cutter.
- By changing the x, y co-ordinates of a cutting tool under numerical control, quite complex surface shapes can be lathed on to a lens button. This has largely replaced the more expensive and less flexible 'plunge' tool method.
- Molding - single/double-sided or spin-casting methods are no more difficult to execute than simpler designs once the master molds are created. The master molds are produced by one or more of the methods above.

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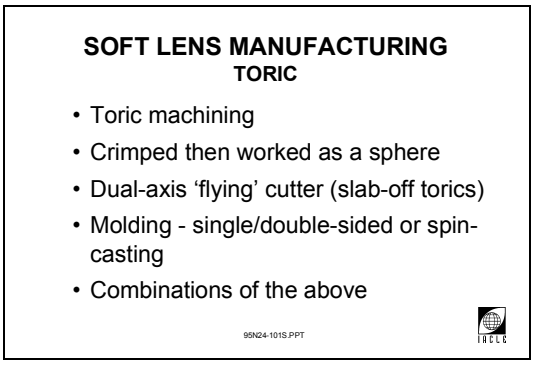

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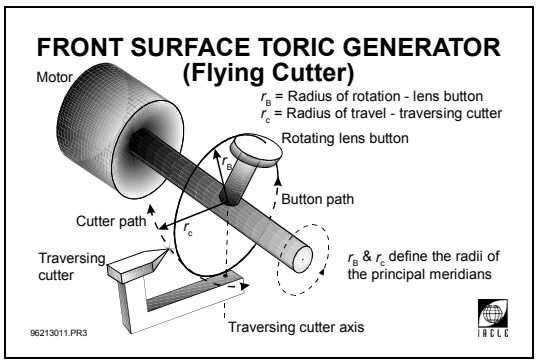

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Soft Contact Lens Manufacturing

Toric

- Toric machining.
  A dual-axis cutting tool can be used on a non-rotating lens button to produce the two radii required.
- By the controlled crimping of a lens blank (not a button) across its diameter, a toric surface can be created. If this toric surface is then worked into a sphere, the release of the crimping pressure will allow the lens to revert to a toric shape.
- If a lens blank or button is mounted to the side of, and parallel to, the axis of a rotating chuck, the displacement from the axis can define one of the principal radii of a toric surface (see r_B in diagram). If the cutting tool moves about an axis tracing out a plane which includes the axis of the rotating chuck, the arc radius can define the second principal radius (see r_c in diagram). Since the tool engages the button for a minority of the time (until the button rotates through the remainder of its circular path), the term 'flying' cutter is often applied. This method is used for producing double slab-off torics.
- Molding - single, double-sided or spin-casting can produce torics just as easily as a simpler lens once the master molds are made. Again one or more of the techniques above is used for this purpose.

Combinations of the above methods may also be used either as the main method or as a secondary step to produce a particular aspect of the lens design.

109

SOFT LENS MANUFACTURING
BIFOCALS

- Concentric (annular)
  - Distance centre
  - Near centre
  - Distance centre, progressive near

95N24-103S.PPT

2L294N29-103

110

SOFT LENS MANUFACTURING
BIFOCALS

- Diffractive bifocal
  - diffractive optics on back surface
- Translating bifocal
  - how much translation possible?

95N24-104S.PPT

2L294N29-104

111

SOFT LENS MANUFACTURING
BIFOCALS

- Lathing
- Molding - single/double-sided or spin-casting
- Spin-casting/lathing combination
- Molding/lathing combination

95N24-105S.PPT

2L294N29-105

Soft Contact Lens Manufacturing

Bifocals

- Concentric (annular) with distance centre
  - similar to RGP designs.
- A concentric (annular) with near centre
  - difficult to manufacture because centre curve is steeper than periphery. This lens type is more suited to molding or spin-casting.
- Concentric (annular) with distance centre, progressive near
  - similar to RGPs.
- Diffractive bifocal
  - similar to RGPs but with fewer zones
  - diffractive optics on back surface.
- Translating bifocal
  - a design with thin zones to allow for easier deformation of lens during translation. One-piece monocentric design used.
  - in practice too little translation is possible and this has limited the success of this design. Further research is required.

IX.B Soft Lens Quality Assurance

112

SOFT LENS MANUFACTURE QUALITY ASSURANCE

95N24-106S.PPT

2L294N29-106

113

SOFT LENS MANUFACTURING

Preliminary lens assessment - dry state (if relevant) and wet state

- BOZR
- BVP
- Optical quality
- Centre thickness
- Edge integrity
- Overall quality

95N24-107S.PPT

2L294N29-107

114

CHANGES FROM DRY TO HYDRATED STATE

- Hydration/expasion effects
- Toricity?
- Parameters within tolerance?
- Other?

95N24-108S.PPT

2L294N29-108

Changes From The Dry To Hydrated State

- Expansion on hydration and its regularity and predictability determine the outcome of the hydration step.
- Any untoward hydration effect has the potential to produce a toric or even irregular lens shape. Vision quality may suffer as a result.
- Standards, set by the practitioner or a standards authority, normally stipulate a tolerance. It is expected that finished lenses will be within these tolerances.
- The possibility always exists that other less common changes may occur. These may be due to our incomplete understanding of the process, inhomogeneities or other variations in the lens material and/or vagaries in the manufacturing and hydration processes.

X Soft Lens Tinting

115

TINTING
SOFT CONTACT LENSES

95N24-109S.PPT

2L294N29-109

116

SOFT LENS MANUFACTURING
TINTED LENSES

- Vat tinting
- Reactive dyeing
- Concentric rod casting
- Front surface printing/stamping
- Lamination
  - hand-painted
  - incorporated photograph
  - opaque ink stamping

95N24-110S.PPT

2L294N29-110

117

TYPES OF SOFT LENSES

- Transparent tint
  - full diameter (handling)
- Transparent tint
  - iris diameter
- Transparent tint
  - iris diameter, clear pupil
- Prosthetic opaque
- Cosmetic opaque

95N24-111S.PPT

2L294N29-111

118

TYPES OF TINTED SOFT LENSES

- UV - absorber (no colour)
  - often full diameter
- UV and a transparent tint
- Clear lens with opaque pupil
- Transparent tint with opaque pupil
- Tints to assist colour defectives

95N24-112S.PPT

2L294N29-112

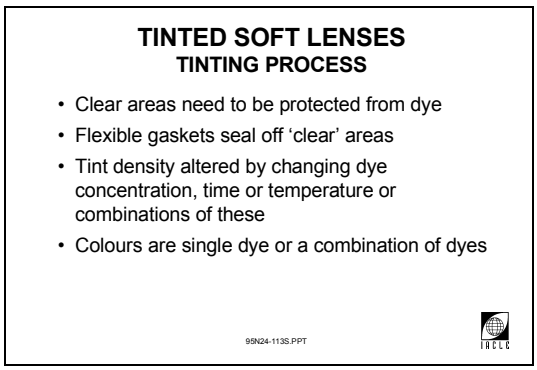
Types of Tinted Soft Lenses

- Transparent tint - full diameter (handling).
  For cosmetic acceptance, the tint density must be low. If too dark, the lens edge would be highlighted by the lighter sclera.
- Transparent tint - iris-diameter tint.
  This is the most common tint for handling or cosmetic purposes. The untinted lens edge remains inconspicuous.
- Transparent tint - iris-diameter tint with clear pupil.
- Prosthetic opaque.
  This tint type is designed for corneal scars, opacities or deformities of the cornea/iris by:
  - blocking light from the anterior eye
  - substituting a realistic image of the iris of the other eye in or on the lens.
- Cosmetic opaque.
  A lens incorporating a partial or complete cover of the natural iris and substitute artwork. This lens type is intended to change the appearance and/or the apparent colour of the eye for non-essential reasons (fashion, performing arts, modelling, etc.).
- UV absorber - often full diameter.
  Most UV tints have little apparent ‘colour’. Consequently the whole lens can be tinted and

still be cosmetically acceptable. Tinting the whole lens is also simpler and less labour intensive.

- UV and a transparent tint.
  A transparent tint can be used in addition to a UV-absorbing tint.
- A clear lens with opaque pupil may be used to conceal a hyper-mature cataract, or pupil deformities in a sighted, partially sighted or blind eye.
- Transparent tint with opaque pupil.
  A variation on the previous theme.
- Tints to assist colour defectives.
  Examples are the X-Chrom and the JLS (by JL Schlanger) lenses. Usually dense tints with quite narrow-band transmission curves. They function by changing the apparent brightness of objects whose colours would otherwise be confused by colour defectives.

119



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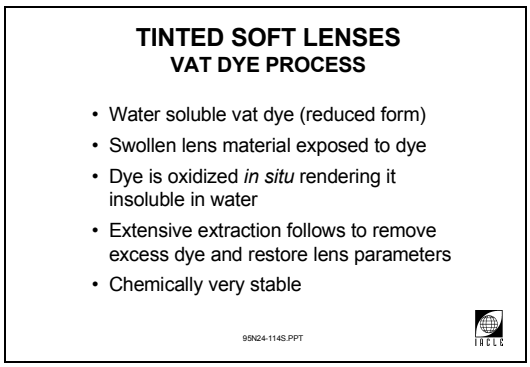
Tinted Soft Contact Lenses

Tinting Process

- Areas not to be tinted need to be protected from dye.
- The lens is mounted in a mold with flexible gaskets which seal off the 'clear' areas.
- Tint density can be altered by changing dye concentration, time, or temperature or combinations of these.
- Some colours are the result of a single dye, others are produced by a combination of dyes. *In situ,* the tint affects both incident and reflected light involving the iris. It is unwise to select tints based on the *in vitro* appearance of a lens.

120



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Tinted Soft Contact Lenses

Vat Dye Process

- Water soluble vat dye (reduced form) is prepared.
- The lens is swollen chemically and then exposed to the dye only in the areas intended.
- The dye is oxidized *in situ*, rendering it insoluble in water and locked into the lens polymer matrix.
- Extensive extraction follows to remove excess dye and restore the lens parameters to normal.
- Chemically, vat dyes are very stable. However it is more difficult to get a uniform tint with them, and the tint can vary with lens thickness (BVP and design).

121

TINTED SOFT LENSES
REACTIVE DYE PROCESS

- Dye molecules bound to hydroxyl group in lens polymer - stable covalent bonds
- Most dyes are colour-fast textile dyes
- Extensive extraction removes excess unreacted/unbound dye
- Chemically stable but susceptible to chlorine compounds and many bleaches

95N24-115S.PPT

2L294N29-115

Tinted Soft Contact Lenses

Reactive Dye Process

- Dye molecules are bound to hydroxyl groups in the lens polymer by forming stable covalent bonds. A tinted polymer is created and the depth of penetration of the tint molecules is small (i.e. surface and just below).
- Most dyes used are colour-fast textile dyes which have been shown to be non-toxic (many such dyes are not).
- Extensive extraction removes excess unreacted/unbound dye.
- While chemically stable, reactive dyes are more susceptible to chlorine compounds and bleaches than vat dyes.
- It is easier to get a uniform tint density and the density is not affected by lens thickness (BVP and design).

122

TINTED SOFT LENSES
OPAQUES

Lamination was the original method

- Artwork recess machined into button face then either - the image is hand painted
  - a stock image is inserted
  - a thin photograph is used
  - an opaque ink is stamped
- Additional polymer cast over artwork
- Lens completed using conventional methods

95N24-116S.PPT

2L294N29-116

123

TINTED SOFT LENSES
OPAQUES

Multi-layered cast rod method

- Starts with a clear rod centre
- Opaque or translucent polymer cast around clear centre
- Clear polymer then cast around the two central layers
- Polymerized rod is then sliced transversely into buttons
- Each button is then lathed into a lens
- Clear layers form clear pupil and edge. Opaque layer forms cosmetic iris

95N24-117S.PPT

2L294N29-117

124

TINTED SOFT LENSES
OPAQUES - DOT MATRIX

- Front surface of clear lens is printed, painted or stamped with coloured opaque 'ink'
- Less than whole surface is covered, natural iris gives depth
- A protective lacquer added to protect artwork and smooth the surface
- Artwork's front surface location usually obvious

95N24-118S.PPT

2L294N29-118

XI Other Types of Contact Lenses

125

HYBRID LENSES

- First hard/soft combination - Saturn
- Followed by Saturn II
- SoftPerm (introduced 1989) is current version

95N24-119S.PPT

2L294N29-119

126

SOFTPERM

- One-piece hybrid material
- Centre, pentasilcon P, a low-Dk siloxane, tertiarybutyl styrene, anhydride-based RGP material with an inherently hydrophilic surface
- Skirt, PHEMA-based hydrogel, 25% water
- Transition zone, narrow region of cross-linking of both materials

95N24-120S.PPT

2L294N29-120

127

NOVEL SOFT LENS MATERIALS

- Siloxane-containing hydrogels
- Fluorine-containing hydrogels

95N24-121S.PPT

2L294N29-121

Research continues into other novel advanced materials, none of which have been released.

XII Regulatory Aspects

128

2L294N29-122

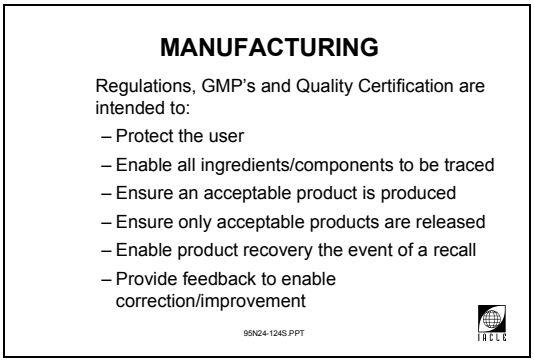
Manufacturing: Regulatory Aspects

Most countries have regulations controlling the manufacturing processes and facilities for therapeutic/medical devices. As well, the ISO 9000 (or similar) quality certification protocol may be applicable.

129

2L294N29-123

130



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GMPs - good manufacturing procedures.

Practical 2.2

(2 Hours)

Introduction to Contact Lens Types

Schedule of Practical Session

Practical Session 1

Students should read about lens types, types of material and design in any of the recommended textbooks before the practical. Record on the form provided the characteristics of the different lens types after inspecting the lenses with a hand magnifier.

Station 1:	Soft contact lenses (low, medium and high water content)
Station 2:	Rigid contact lenses (PMMA and RGP)
Station 3:	Cosmetic soft contact lenses (handling tints, opaque, clear pupil and cosmetic tint)
Station 4:	Specialty contact lenses (toric, bifocal and UV coated, hybrid lenses), scleral lenses, prosthetic eyes.

Practical Session

RECORD FORM

Name:_____ **Date:**_____

Station 1 Soft Contact Lenses

Characteristics	Lens No. 1	Lens No. 2	Lens No. 3	Lens No. 4
Material				
Size				
Tint				
Design				
Lens Type				
Use				

Station 2 Rigid Contact Lens

Characteristics	Lens No. 1	Lens No. 2	Lens No. 3	Lens No. 4
Material				
Size				
Tint				
Design				
Lens Type				
Use				

Station 3 Cosmetic Contact Lenses

Characteristics	Lens No. 1	Lens No. 2	Lens No. 3	Lens No. 4
Material				
Size				
Tint				
Design				
Lens Type				
Use				

Station 4 Specialty Contact Lenses

Characteristics	Lens No. 1	Lens No. 2	Lens No. 3	Lens No. 4
Material				
Size				
Tint				
Design				
Lens Type				
Use				

Tutorial 2.2

(1 Hour)

Contact Lens Manufacturing Processes

Discussion and Open Forum

Questions:

1. **Describe briefly the processes used to generate the back surface of a rigid contact lens.**

2. **What factors differentiate soft lens manufacture from rigid lens manufacture?**

3. **What factors should be controlled during soft lens manufacture to avoid premature hydration of the lens button?**

4. **Which step/s in the manufacturing process of a rigid contact lens can result in alterations to the surface properties of the finished lens?**

5. Describe briefly the various types of tinted soft lenses.

6. What are the purposes of regulations that apply to contact lens manufacturing processes and manufacturing facilities?

7. What are the molding techniques used to manufacture soft contact lenses?

8. Which techniques can be used to determine the surface wettability of a contact lens material?

9. Which manufacturing techniques can be used to produce toric contact lenses?

_____

_____

_____

_____

_____

🕮 References

Ang J, Efron N (1989). *Carbon dioxide permeability of contact lens materials.* ICLC. 16: 48 - 58.

Barron RS (1959). *Mechanics and Properties of Matter.* University Tutorial Press, London.

Bennett ES, Weissman BA (1992). *Clinical Contact Lens Practice.* Revised ed. J B Lippincott, Philadelphia.

Bonanno JA (1996). *Contact lens induced corneal acidosis.* CLAO J. 22: 70 - 74.

Bonanno JA, Polse KA (1987). *Measurement of* in vivo *human corneal stromal pH: Open and closed eyes.* Invest Ophth Vis Sci. 28: 522 - 530.

Brown NA (1971). *Visibility of transparent objects in the eye by retro-illumination.* Br J Ophthalmol. 55: 517.

Dabezies OH (Ed.) (1988). *Contact Lenses: The CLAO Guide to Basic Science and Clinical Practice. Vol. 1.* Grune & Stratton, Inc., Orlando.

Efron N (1991). *Understanding oxygen: Dk/L, EOP, oedema.* J Brit Cont Lens Assoc. 14: 65 - 69.

Fatt I, St Helen R (1971). *Oxygen tension under an oxygen permeable contact lens*. Am J Optom. 48(7): 545 - 555.

Feldman GL (1977). *Chemical and physical properties of cellulose acetate butyrate as related to contact lenses.* Cont Lens J. 11: 25.

Frankland JD (1973). *What lets the water in?* Optician. Dec. 7.

Highgate D (1974). *Relevant properties of hydrophilic polymers for lens performance*. Optician. Jan 4: 10.

Hill RM (1988). *What is EOP?.* CL Spectrum. 3 (5): 34 - 36.

Hogg M (Eycon Laboratories)(1995). Personal Communication.

Holden BA, Sweeney DF (1991). *The significance of the microcyst response: A review.* Optometry Vision Sci. 68: 703 - 707.

Isaacson WB (1989). *Flexible fluoropolymer: A new category of contact lenses.* CL Spectrum. 4 (1): 60 - 62.

Jones L (1990). *Daily wear high water content lenses: Current status and future development. Part 1 & Part 2.* Optician. Feb 2 (Part 1): 17, Mar 2 (Part 2): 15.

La Hood D, Holden BA, Newton-Howes J (1990). *Unpublished Data.* CCLRU.

Mandell R B (1988). *Contact lens practice.* 4th ed. Charles C Thomas, Springfield.

Masnick KB, Holden BA (1972). *A study of water content and parameter variations of hydrophilic contact lenses.* Aust J Optom. 55: 481 - 487.

Phillips AJ, Stone J (1989). *Contact Lenses.* 3rd ed. Butterworths, London.

Refojo M F (1984). *The siloxane bond in contact lens materials: Effect of methyl and phenyl content on oxygen permeability of silicone lenses.* ICLC. 11: 83.

Ruben M (1989). *Color Atlas of Contact Lenses & Prosthetics.* 2nd ed. Wolfe Medical Publications Ltd., London.

Ruben M, Guillon M (1994). *Contact Lens Practice.* Chapman & Hall, London.

Schlanger JL (1985). *The JLS lens: An aid for patients with color vision problems.* Am J Optom Physl Opt. 62: 149 - 151.

Stahl NO, Reich LA, Ivani E (1974). *Report on laboratory studies and preliminary clinical application of a gas-permeable plastic contact lens.* J Amer Optom Assoc. 45: 302 - 307.

Stone RP (1988). *Why contact lens groups?* CL Spectrum. Dec: 38.

Walker J (1989). *Handling high Dk lenses.* Optician. May 5: 35

Winterton LC, White JC, Su KC (1987). *Cuolometric method for measuring oxygen flux and Dk of contact lenses and lens materials.* ICLC. 14(11): 441 - 452.

Zantos S G (1981). *The Ocular Response to Continuous Wear of Contact Lenses.* PhD Thesis, UNSW.

Unit 2.3

(4 Hours)

Lecture 2.3: Optics of Contact Lenses

Practical 2.3: Contact Lens Over-Refraction

Tutorial 2.3: Optical Principles of ContactLenses

Course Overview

Lecture 2.3: Optics of Contact Lenses

I. Review of the Principles of Geometric, Physical and Ophthalmic Optics Relating to Vision and Contact Lenses

II. Magnification

III. Optical Considerations

IV. Accommodation and Convergence

V. Optical Advantages and Disadvantages of Contact Lenses over Spectacles

Practical 2.3: Contact Lens Over-Refraction

- Sphero-Cylindrical Refraction
- Over-Refraction
- Vision and Fitting Assessment

Tutorial 2.3: Optical Principles of Contact Lenses

Lecture 2.3

(2 Hours)

Optics of Contact Lenses

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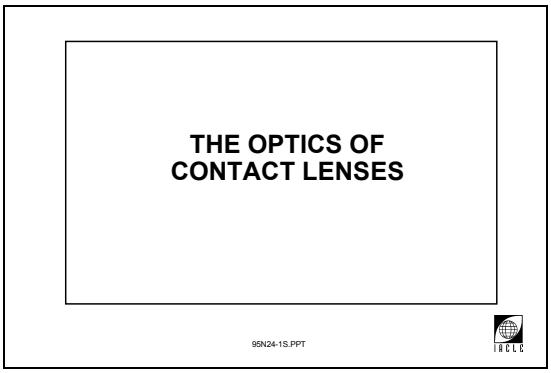
I The Optics of Contact Lenses

1



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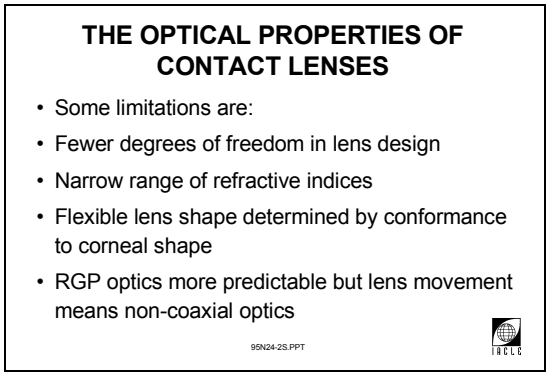
The Optics of Contact Lenses

This lecture presents the optical theory and practice associated with contact lens fitting and usage. Contact lenses and spectacles are also compared as optical devices.

2



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The Optical Properties of Contact Lenses

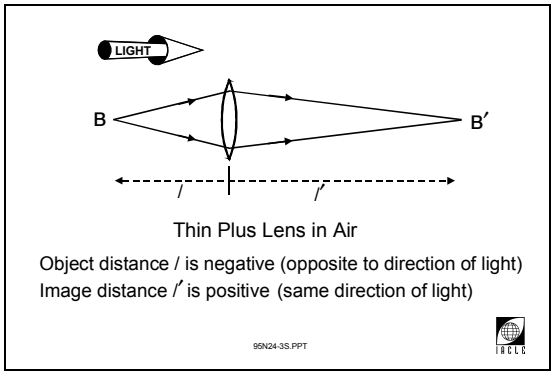
Optically, contact lenses are ***no*** different to other vision correction devices.

Some limitations are:

- Fewer degrees of freedom in lens design. This is because the back surface must relate to corneal topography and/or anterior eye geometry.
- Narrow range of refractive indices. Since *n* is determined by the material selected, which is usually a clinical rather than an optical decision, the lens designer often has no choice of refractive index. The range of indices within a lens type (i.e. rigid or soft) is also relatively narrow.
- The optical surface shape of flexible lenses is determined by conformance to corneal shape, as well as lens profile and material physical properties. The overall lens shape is largely related to anterior eye topography.
- The optics of rigid gas permeable lenses (RGPs), while more predictable, may involve non-coaxial optics due to lens movement and decentration. This may mean the exact effects are difficult to predict or calculate. A decrease in vision is usually experienced in association with these effects.

I.A Basic Concepts

3



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Sign Conventions Used

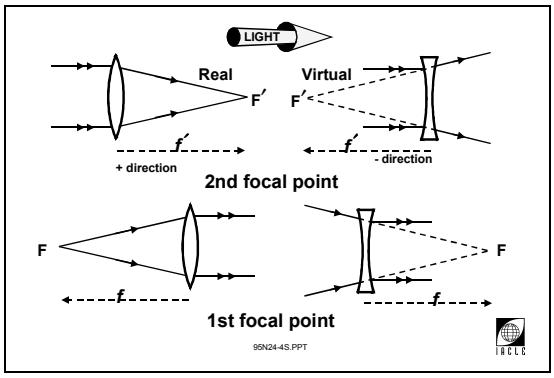
This slide introduces the sign convention used throughout this lecture. It is based on the direction of light which will always travel from left ***to*** right, i.e. **L → R**.

The conventions used are:

All dimensions are measured ***from*** the relevant lens surface ***to*** the point of interest (i.e. focus, image point, object point, centre of curvature, etc.).

If the dimension so measured is ***with*** the direction of light travel then the sign is **+**. If the dimension measured is ***against*** the direction of light travel, the sign is **–**. Examples of the application of this sign convention are presented in the next slide.

4



2L396217-4

Principal Foci

This diagram demonstrates how, using the sign convention detailed in the previous slide, real and virtual foci are treated.

The diagrams include arrows to indicate in which direction the focal lengths (f and f′) are measured for both plus and minus lenses.

The sign convention applies regardless of whether the points of interest are *real* or *virtual.*

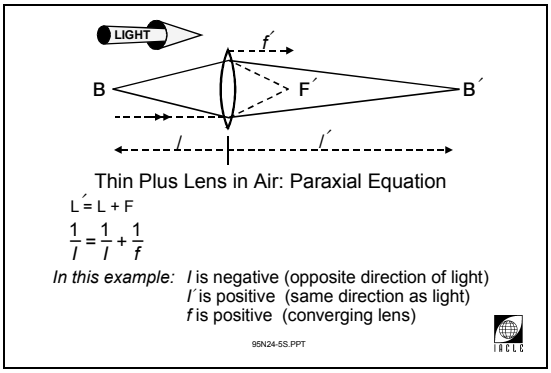
Real:

- Light rays pass through the point of interest when forming an image at it. This description encompasses real images and the foci of plus lenses.
- Light rays emanate from the point of interest. This description encompasses luminous or reflective objects.
- Any point on a lens surface.

Virtual:

- Relevant light rays do not actually pass through the point of interest when forming an image at it. This description encompasses virtual images and the foci of minus lenses.
- Light rays apparently come from, or pass to, virtual points. Such points are found by geometrical/trigonometrical construction and the relevant rays do not actually pass through them.
- Any theoretical point associated with a lens (see principal planes later in this lecture).

5

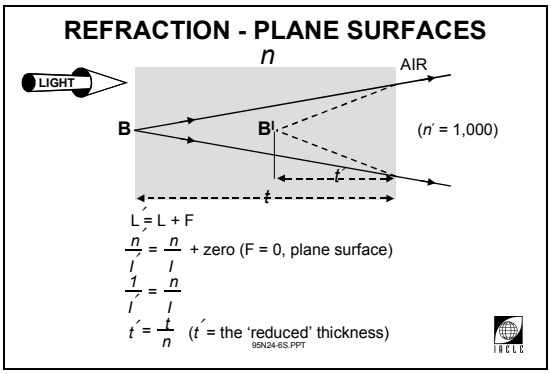


2L396217-5

The Paraxial Equation

The *Thin Lens* paraxial equation is presented diagrammatically and the formula for calculating the power of a lens, when the object and image distances are known, is shown. Essentially, the vergence of light (either 1/distance; or the reduced distance, *n*/distance when the distance is not in air (slide 6) leaving a lens, is the algebraic sum of the vergence of the light entering the lens and the dioptric power of the lens,
i.e. $L' = L+F$. The direction of light is shown and all distances are measured *from* the lens.

6



2L396217-6

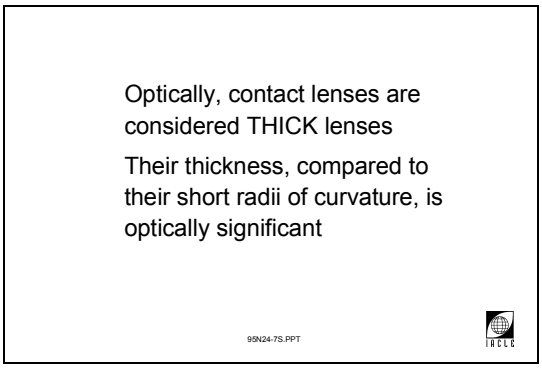
The Concept of Reduced Distance for Plane Surfaces

When light travels to/from an object/image in a medium of refractive index n', its reduced thickness t' must be used when calculating the apparent air distance travelled.

The 'reduced distance' $t' = \dfrac{t}{n'}$

In this lecture *n* is used to indicate the refractive index of the medium in which the *object* is located, i.e. the *object* space, and n' is used for the *image* space. However, in some instances *n* is also used as the general symbol for refractive index without reference to the 'optical' context which might apply (i.e. object or image space).

7



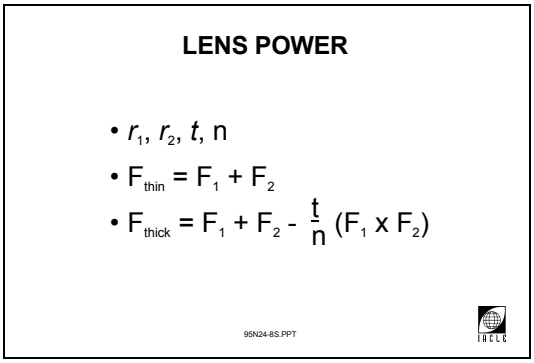
2L396113-7

Optically, contact lenses are considered THICK lenses. Their thickness, compared to their short radii of curvature, is optically significant.

This means that simple thin lens formulae are not used in contact lens work and the more general paraxial thick lens formula must be applied.

I.B Lens Power

8



2L396113-8

Lens Power

Thin Lenses:

$F_{thin} = F_1 + F_2$

This translates to the simple addition of the two lens surface powers. The separation of the surfaces (lens centre thickness) is assumed to be negligible and is ignored.

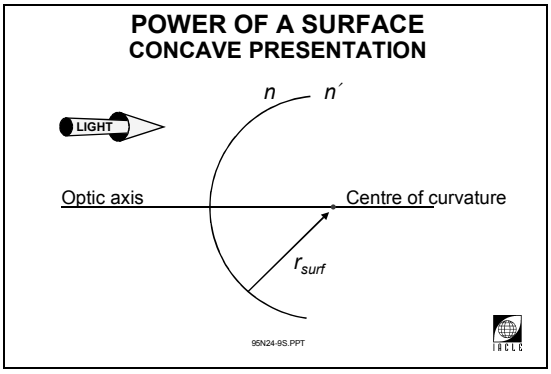
Thick Lenses (Equivalent Lens Power):

$$F_{thick} = F_{=} = F_1 + F_2 - \frac{t}{n}(F_1 F_2)$$

This is the general *thick lens* formula. The power calculated is sometimes referred to as the 'equivalent power' and the focal length the 'equivalent focal length'.

The information required includes:
r_1 and r_2 - the respective lens surface radii in metres,
t - the lens centre thickness (in metres),
n - the refractive index of the medium which makes up the lens (e.g. PMMA n = 1.49). The use of n here is in the general sense and *not* the object space sense.

9

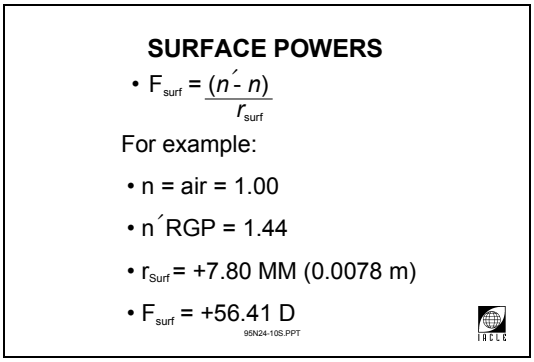


2L396213-9

Power of a Surface Convex Presentation

This diagram shows a spherical surface in isolation whose radius is shown, measured *from* the surface to the centre of curvature which lies on the optic axis. This direction is ***with*** the direction of light travel and is therefore ***positive***. The respective refractive indices are also shown. The calculation of powers is presented in slide 10.

10



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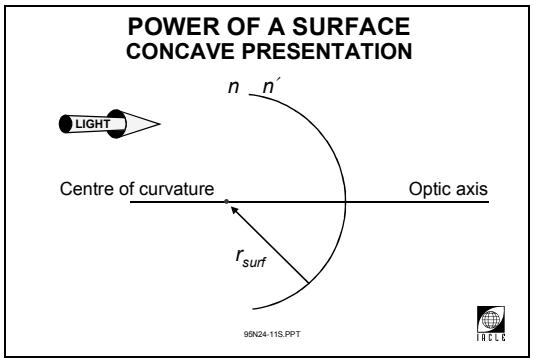
11



2L396213-11

Power of a Surface
Concave Presentation

If the surface of the previous diagram is reversed and the light is incident on its concave surface rather than its convex one, then the radius is negative.

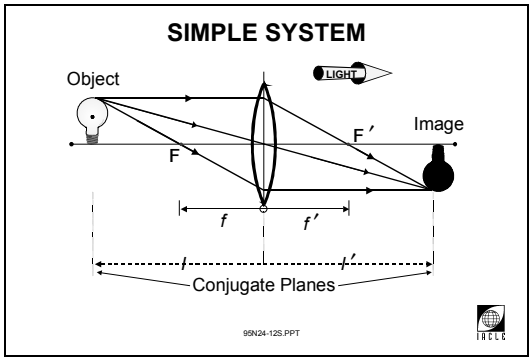
Because the radius measured *from* the surface is in a direction opposite to that of light, it is *negative*. Therefore:

r_{surf} = –7.80 mm (0.0078 m)

F_{surf} = –56.41 D

I.C Conjugate and Principal Planes

12



2L396217-12

Explanation of Conjugate Planes

Simple System

The concept of *conjugate planes* is introduced here for three reasons:

- Firstly, it rounds out the basic theory of image formation and shows how simple trigonometrical construction can be used to locate and size an image formed by a lens.
- Secondly, the concept will be used in the explanation of the ametropias.
- Lastly, the concept will be used in Lecture 2.6: Contact Lens Verification, to explain the optical principles of some measuring instruments.

In the simple system depicted here, conjugate planes are planes perpendicular to the optic axis whose positions are related to each other by the image-forming properties of the lens.

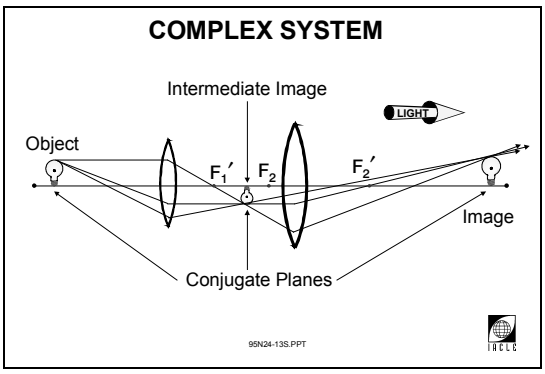
For each object position there is a corresponding image position. This position may be real or virtual, depending on the type of lens and the object's position in relation to the lens. All objects in the object plane and within the field of view of the lens are imaged in a corresponding image plane (for convenience all aberrations are ignored in this discussion). These two planes (the object plane and its corresponding image plane) are said to be *conjugate planes.*

As all light paths are reversible, the object and image plane positions are interchangeable. The defining distances are referred to as *conjugate distances* and when individual points within these planes are described, they are referred to as *conjugate points*.

When an eye (emmetropic or corrected ametropic) accurately focuses on an object, the retina and the object are *conjugate*. If the object cannot be viewed clearly, the retina and the object are not conjugate.

In simple systems the *conjugate planes* are parallel to each other (again ignoring aberrations).

13



2L396217-13

Conjugate Planes

Complex System

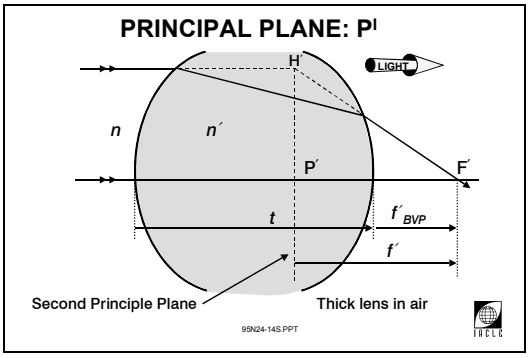
This diagram expands on the concept of *conjugate planes* as it applies to more complex systems.

In systems using more than one lens (as depicted here), the image formed by the first lens behaves as either a real or virtual object for the next lens in the system. In very complex systems this process of relaying light can occur many times. In such systems each object, virtual object, virtual image and image are *conjugate* and they occupy *conjugate planes.*

Should a mirror or prism (of any orientation or any angle) be introduced into the light path thereby making a non-coaxial optical system, the concept of *conjugate planes* still applies. However, these planes are no longer parallel to one another. The angular relationship of the conjugate planes depends on the mirror or prism (and their orientation and properties) inducing the deviation of the light path.

In Lecture 2.6, Drysdale's method of small radius measurement will be detailed. In instruments using this technique, a front-surface semi-silvered mirror in the light path at 45° renders some of the conjugate planes perpendicular to others. This does not alter their properties or significance.

14



2L396217-14

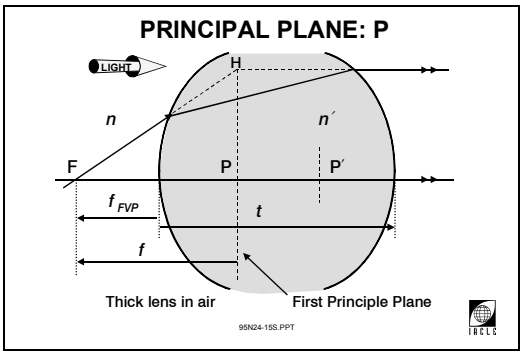
Principal Plane: P′

The concept of *principal planes* is introduced because, while the true power of a system involves distances measured from these planes, the powers used in 'clinical' circumstances are measured from the apices of the lens. The latter are the vertex powers (front and back) and they need to be clearly differentiated from the true powers of a lens system.

Locating P′:

- Instructions for locating P′ and P can be found in slide 16.
- Of note in slide 14 are:
  - the entering (incident) ray travelling parallel to the optic axis and its dotted continuation
  - the exiting ray and its dotted back projection.
- The intersection of these two dotted lines defines just one point in the ***second*** *principal plane*.

15



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Principal Plane: P

Locating P, (P′, determined in the previous slide, is also shown).

This diagram is actually the reverse of the previous slide. The entering (incident) ray is defined as that ray which will exit (be refracted by) the system parallel to the optic axis. The intersection of the incident and refracted rays occurs in the ***first*** *principal plane*.

16

PRINCIPAL PLANES

Found by locating the intersection of:

- Light rays travelling parallel to the optic axis
- The entering or exiting rays travelling through the focal points F′ and F

Extrapolation of the rays may be required

95N24-16S.PPT

2L396113-16

17

PRINCIPAL PLANES

- The planes are perpendicular to the optic axis
- The optics of a thick lens can be represented by its two principal planes and its optic axis only
- Principal planes are conjugate planes of unit positive magnification (PH = P′ H′)
- Sometimes called *unit planes*

95N24-17S.PPT

2L396113-17

18

BACK VERTEX POWER (BVP)

Measured as:

- The position of the second principal focus from the back vertex of the lens

95N24-18S.PPT

2L396113-18

Back Vertex Power

- The true *focal lengths* (*f ´, f*) are measured from the *principal planes*. Since these planes are theoretical constructs, their locations are not obvious. Clinically, it is not practical to measure true *focal lengths* of either contact lenses or spectacles.
- In practice we measure the position of the second *principal focus* from the *back vertex* of the lens since this is accessible. The power so measured is the *Back Vertex Power* (or BVP).

19

PLUS POWER CONTACT LENS
USEFUL PRINCIPAL POINTS

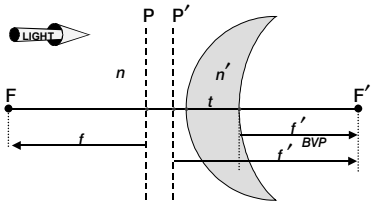

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Diagram of Principal Planes

Positive (+) Power Contact Lenses

For practical reasons, contact lenses are made in the ‘meniscus’ form. Meniscus plus power lenses have their principal planes anterior to the lens as shown. From this diagram it can be seen that the second principal focus is longer than the back vertex focal length ($f' > f_{BVP}'$), hence the BVP overstates the actual power of a positive powered lens. Clinically, we usually only deal with vertex powers (powers measured in terms of the distances foci are from the lens surfaces) since it is vertex powers that focimeters (vertometers, lensometers) actually measure (i.e. BVPs or FVPs, however, contact lenses require special stops).

20

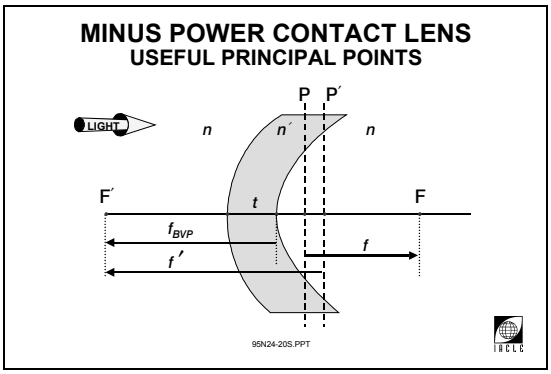

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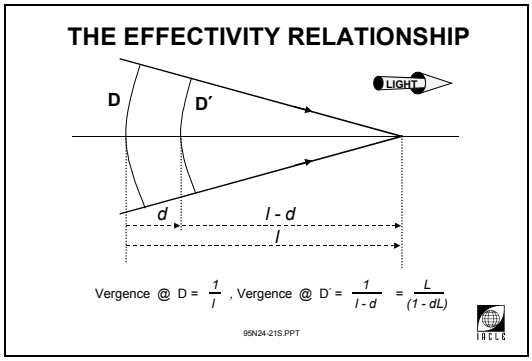
Diagram of Principal Planes

Negative (–) Power Contact Lenses

The *principal planes* of a meniscus minus power lens lie behind the lens. Under these circumstances the BVP again overstates the actual power of the lens.

I.D Back Vertex Power

21



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The Effectivity Relationship

Light rays converging to (as in this diagram), or diverging from, a point are said to have a different vergence at each radial point along the pencil of light. The vergence at any point is the inverse of the distance (*d*) from the point to which it is converging (convergent bundle) or from which it is apparently diverging (divergent bundle). When light is travelling in a medium other than air, the vergence is *n*/*d,* i.e. the *reduced* vergence.

The equation $D' = \dfrac{L}{(1-dL)}$ relates the vergences of light at any two points separated by a distance *d*. Related equations will appear later when calculating a correction for the effect of vertex distance and when calculating BVPs of thick lenses.

22

EFFECTIVITY

Vergence @ D = $1/l$

Vergence @ D′ = $1/(l - d)$

∴ Vergence @ D′ = $L/(1 - dL)$

95N24-22S.PPT

2L396113-22

Effectivity

- When a pencil of light travels a distance *d* towards (converging system), or away from a focus (diverging system), the 'vergence' of the pencil is altered in a calculable manner related to the magnitude of *d*.

$$\text{Vergence @ D} = \frac{1}{l}$$

$$\text{Vergence @ D}' = \frac{1}{(l-d)}$$

$$\therefore \text{Vergence @ D}' = \frac{L}{(1-dL)}$$

- If *d* is not in air, then the reduced distance $\dfrac{d}{n'}$ is used instead for the distance travelled by the light pencil.

23

BVP

$$\text{BVP} = \frac{F_1}{1 - \dfrac{t_c}{n_{Lens}}(F_1)} + F_2$$

Where:

- F_1 = Front surface power
- F_2 = Back surface power
- t_c = Geometric centre thickness
- n_{Lens} = Refractive index of lens material

95N24-23S.PPT

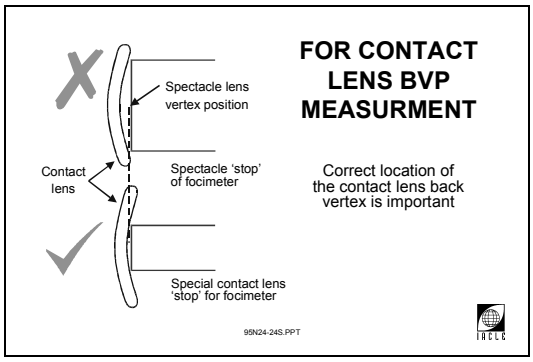
2L396113-23

Back Vertex Power (BVP)

$$\text{BVP} = F'_V = \frac{F_1}{1-\dfrac{t_c}{n_{Lens}}(F_1)} + F_2$$

- The first part of this equation is basically the 'effectivity' of the first surface at the second surface.
- BVP is the only practical 'power' to discuss, since it is the only one that can be easily measured. Clinically BVP is the only power used and when power is referred to 'loosely' it is implicit that it is BVP that is being discussed.
- Measurement of BVP of a contact lens requires a special stage on the focimeter (vertometer, lensometer) to accurately locate the back vertex of a contact lens. See slide 24.

24



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- This is because the sagittal height of spectacle lenses is very much less than that of contact lenses. When the back vertex of either lens type is not correctly located, then the true BVP is not being measured.

To derive an alternative expression for BVP:

$$\text{BVP} = F'_V = \frac{F_1}{1-\frac{t_c}{n_{Lens}}(F_1)} + F_2 \text{ (from above)}$$

Multiplying throughout by: $[1 - \frac{t}{n}(F_1)]$ we get:

$$F'_V \times [1 - \frac{t}{n}(F_1)] = F_1 + F_2 \times [1 - \frac{t}{n}(F_1)]$$

Expanding:

$$F'_V \times [1 - \frac{t}{n}(F_1)] = F_1 + F_2 - \frac{t}{n}(F_1F_2)$$

$$F'_V \times [1 - \frac{t}{n}(F_1)] = F_=$$

$$\therefore F'_V = \frac{F_=}{1-\frac{t_c}{n_{Lens}}(F_1)}$$

(where $F_=$ is the 'equivalent power 'of the lens)

Front Vertex Power

Front vertex power (also called the *neutralizing power*) is sometimes used when specifying the power of haptic lenses. This is because the depth of a scleral shell may prevent the back vertex from touching the focimeter stop. Under these circumstances the FVP can be determined using either a special stop or placing a thin glass flat across the stop to locate the front vertex of the lens.

FVP can be calculated in a similar manner to that used for BVP.

$$\text{FVP} = \frac{F_2}{1-\frac{t_c}{n_{Lens}}(F_2)} + F_1$$

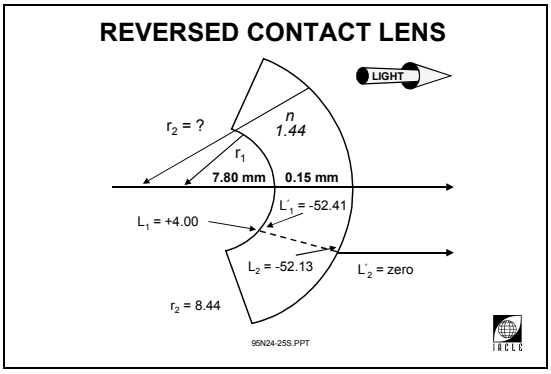
An alternative expression can be derived using a method similar to that used for BVP. It can be shown that:

$$F_V = \frac{F_=}{1-\frac{t_c}{n_{Lens}}(F2)}$$

Standard focimeter (lensometer, vertometer) stops (spectacle and contact lens types) are intended for measuring BVP.

I.E Calculating FOZR

25



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Calculating the Front Optic Zone Radius (r_2) given the following:

- BOZR (r_1)
- $n_{material}$
- t_c (0.15 mm)
- Patient's ocular Rx (i.e. BVP required). If the spectacle Rx is known, the ocular Rx will have to be found by calculation or from a reference table. This step is necessary to allow for the effects of vertex distance (see slide 30).

The lens is reversed to make the calculation easier and the treatment optically is as if the exiting (refracted) light leaves parallel to the optic axis (zero vergence). This is equivalent to the wearer experiencing parallel incident light. Reversal is possible because all optical systems and light paths are reversible without any alteration in behaviour.

Reverse the Lens:

n_{lens}=1.44
t_c=0.15 mm
r_2 = BOZR= –7.8 mm (this is minus because the radius, when measured *from* the lens surface *to* the centre of curvature, is in the opposite direction to light travel).
BVP = –4.00 D

Make L_{CL} = – BVP= +4.00 D
L_{CL}' = Zero (i.e. parallel incident light when lens is oriented *correctly*).

$$F_1 = \frac{(n'-n)}{r_2}$$
$$= \frac{(1.44-1.00)}{-0.0078}$$
= –56.41 D

Vergence immediately after first surface: –52.41 (i.e. –56.41 +4.00)

Effectivity of this at second surface:

$$D = \frac{L_1}{1-\frac{t_c}{n_{Lens}}(L_1)}$$
= –52.13

Now –52.13 + F_2 = Zero (parallel light exiting)

Therefore, $F_2 = +52.13$

$$= \frac{(n - n')}{r_1}$$

$$= \frac{(1 - 1.44)}{r_1}$$

and $r_1 = -8.44$ mm

A negative radius implies a concave surface. In the diagram, the lens is concave towards the direction of light. **However,** *on reversing the lens* so that it is correctly oriented, this surface will be *convex* with a radius +8.44 mm. This will result in a contact lens of the expected meniscus form and of the required BVP.

II Ametropia

26

AMETROPIA
THE FAR POINT

The Far Point is that point which is conjugate with the fovea centralis of the unaccommodated (relaxed) eye.

- It lies at:
- Infinity in emmetropes
- Behind the eye in hyperopes
- In front of the eye in myopes

95N24-26S.PPT

2L396113-26

27

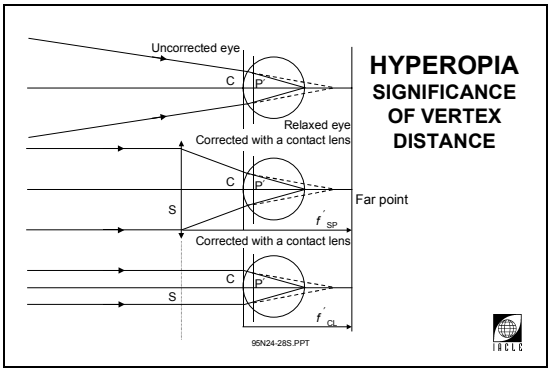
THE CORRECTON OF AMETROPIA

- A correcting lens is that lens which has its *primary focus* at *the Far* Point of the unaccommodated ametropic eye

95N24-27S.PPT

2L396113-27

28



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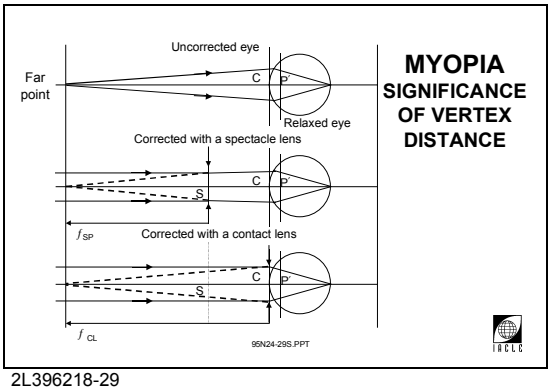
Hyperopia

These diagrams illustrate the unaccommodated, spectacle corrected and contact lens corrected eye of a hyperope. The contact lens form requires a higher BVP than a spectacle lens which performs the same task (i.e. f_{CL}' is less than f_{SP}'). In effect, this is a schematic explanation of a vertex-distance correction table.

29



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Myopia

These diagrams present the myopic case uncorrected and corrected. In myopia, contact lenses of a lower BVP than spectacles are required. The reason for this is provided in the lower diagram which shows that f_{CL}' is larger than f_{SP}'.

30

CORRECTION FOR VERTEX DISTANCE

$$F_{C/L} = \frac{F_{Sp}}{(1 - d\,F_{Sp})}$$

d = Distance form back vertex of spectacle lens to corneal apex

95N24-30S.PPT

2L396113-30

Correction for Vertex Distance

This general formula allows the calculation of the contact lens equivalent of any spectacle Rx, provided the distance between the back vertex of the spectacle lens and the cornea is known.

$$F_{C/L} = \frac{F_{Sp}}{(1 - dF_{Sp})}$$

If the distance (*d*) is not measured, an assumption based on the wearer's anatomy can be made. Too often, the distance is underestimated. In Asian people, figures of 10 - 14 mm generally apply. For Caucasians values of 12 - 15 mm are more likely.

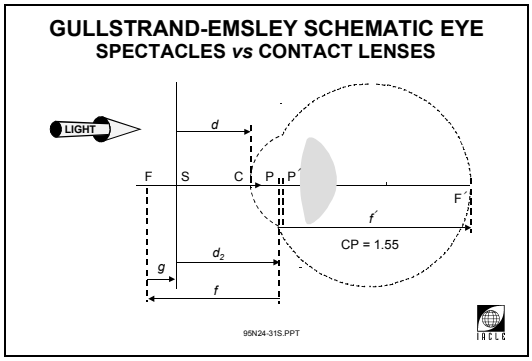
Usually, a vertex distance correction table is used to provide the contact lens BVP required for a full correction.

Most correction tables start at ±4 D since corrections below these values are less than the normal minimum clinical increment of 0.25 D.

A vertex-distance correction table appears in the Appendix to Module 3.

III Magnification

31



2L396218-31

Gullstrand-Emsley's Schematic Eye

This diagram presents the Gullstrand-Emsley Schematic Eye. It represents a modern revision of one of the most widely recognised schematic eyes. Only those important features referred to in subsequent calculations or topics are included.

The key to the diagram follows:

C = Corneal apex

F = 1st principal focus

F´ = 2nd principal focus

S = Spectacle plane (back vertex position)

P & P´ = Principal planes of the eye

III.A Spectacle and Contact Lens Magnification

32

SPECTACLE MAGNIFICATION

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

95N24-32S.PPT

2L396113-32

Spectacle Magnification (SM)

Spectacle Magnification is the ratio of the retinal image sizes in an ametropic eye in the corrected and uncorrected state.

$$SM = \frac{\textit{Corrected ametropic image size}}{\textit{Uncorrected ametropic image size}}$$

This ratio compares a clear image to a blurred image.

33

CONTACT LENS MAGNIFICATION

$$CLM = \frac{\text{Image corrected with contact lenses}}{\text{Image corrected with spectacles}}$$

95N24-33S.PPT

2L396113-33

Contact Lens Magnification (CLM)

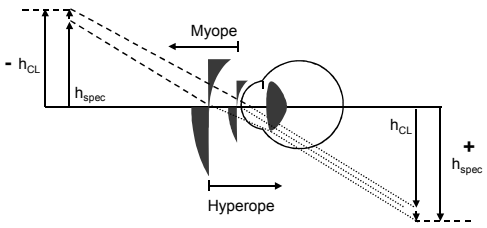
Contact Lens Magnification is the ratio of the image sizes in an ametropic eye corrected by a contact lens (CL) and a spectacle lens (SL).

$$CLM = \frac{\textit{CL corrected image size}}{\textit{SL corrected image size}}$$

CLM is realistic since focused images are used in both the numerator and the denominator of the equation.

34

SPECTACLES vs CONTACT LENSES



- Image size proportional to Focal Length of Correction

95N24-34S.PPT

2L396213-34

Spectacles *versus* Contact Lenses

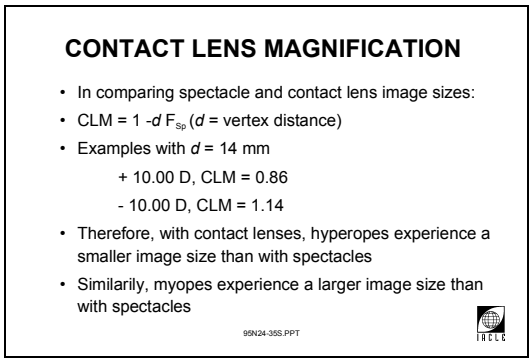
This is a composite diagrammatic representation of CLM for both hyperopia (lower half) and myopia (upper half).

Image size in any optical system is directly proportional to the focal length of the system (or inversely proportional to the lens power).

In hyperopia, the contact lens focal length is shorter than the equivalent spectacle focal length (shorter by the vertex distance in fact). Consequently, the image size is smaller when contact lenses are worn.

The reverse is the case in myopia. The contact lens focal length is longer than the equivalent spectacle focal length, and therefore the contact lens image size is larger.

35



2L396113-35

Contact Lens Magnification

In comparing spectacle and contact lens image sizes:

- CLM = $1 - d F_{Sp}$

Examples with d = 14 mm

+ 10.00 D, CLM = 0.86

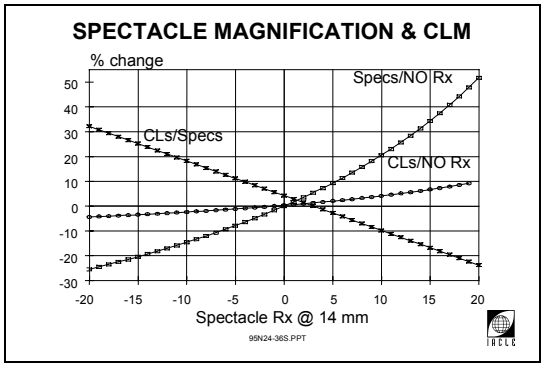
- 10.00 D, CLM = 1.14

With contact lenses, hyperopes experience a smaller image size than they would with spectacles of equivalent power.

Similarly, myopes experience a larger image size than they would with spectacles of equivalent power.

Both of these outcomes are desirable and together constitute perhaps the biggest single advantage of contact lenses over spectacles.

36



2L396213-36

SM and CLM

This is a composite graphical presentation of *Spectacle Magnification* for contact lenses, *Spectacle Magnification* for spectacles and *Contact Lens Magnification*. A vertex distance of 14 mm was used in conjunction with the Gullstrand-Emsley Schematic Eye.

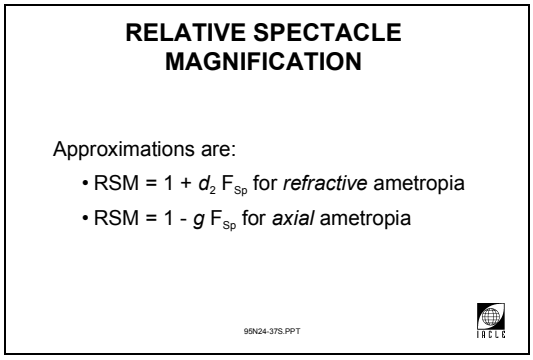
From the graph, it can be seen that when compared with the no-Rx situation, contact lenses produce a nearer to normal image size, albeit a comparison of clear (corrected) and blurred images.

The curve comparing CLs to spectacles depicts graphically the differences ***between*** the image sizes (both clear) resulting from the use of contact lenses and spectacles respectively. It shows, for example, that contact lenses for a –15 D spectacle myope produce a 20% larger image size than spectacles. This is desirable, since –15 D spectacles produce significant image minification (a 20% reduction compared to the uncorrected image size, i.e. the SM = –20%).

Overall, contact lenses produce smaller (much smaller in the case of the higher Rxs) deviations in image size compared to spectacles. It is impossible to compare contact lens-corrected image sizes with emmetropic image sizes without drawing conclusions about the aetiology of the refractive error (i.e. axial or refractive). This is because the same eye cannot be both ametropic and emmetropic with the same optical parameters.

III.B Relative Spectacle Magnification

37



2L396113-37

Relative Spectacle Magnification (RSM)

For a distant object, RSM is the ratio of the image size in the corrected ametropic eye to the image size in the *normal* emmetropic eye. It is also necessary to consider the aetiology of the refractive error, i.e. is it *axial* or *refractive* in origin.

Approximations are:

(Based on Gullstrand-Emsley Schematic Eye (slide 31))

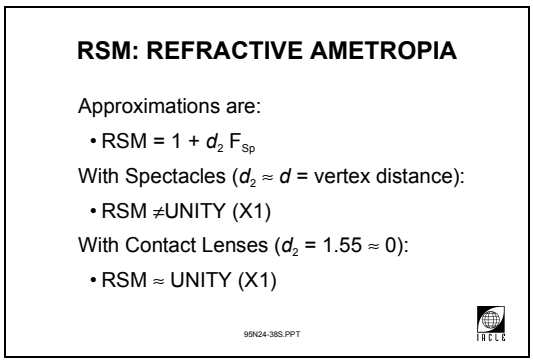
RSM = 1 + d_2 F_{Sp} for *refractive ametropia*.
(d_2 = distance from spectacle point to first principal plane of the eye).

RSM = 1 - g F_{Sp} for *axial ametropia*
(g = distance from first focal point of the eye to the spectacle point.

It is noteworthy that $f = -(g + d_2)$.

Since these equations are approximations and schematic eye data (for the *normal* eye) are normally used, the expression of RSM as a percentage to more than one decimal place cannot be justified.

38



2L396113-38

RSM: Refractive Ametropia

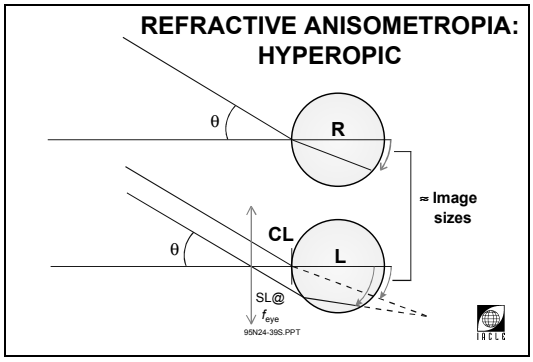
$$RSM = 1 + d_2F_{Sp}$$

With Spectacles ($d_2 \approx d$ = vertex distance):
RSM ≠ *unity* (i.e. ≠X1) (the approximation $d_2 = d$ has little bearing on this statement).

With Contact Lenses, d_2 = 1.55 mm. In this context 1.55 mm is treated as being negligible (≈ 0).

RSM ≈ *unity* (i.e. X1) This is acceptable as a first-order approximation only. An accurate calculation can be made if necessary. However, it is important to remember that RSM involves the theoretical schematic eye.

39



2L396113-39

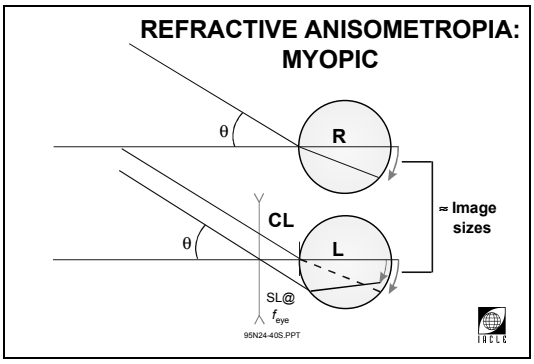
RSM: Refractive Ametropias

For consistency, all RSM ray diagrams have the spectacle lens back vertex located at the anterior focal point of the Gullstrand-Emsley schematic eye (14.98 mm from the corneal apex). This is of little relevance to the refractive ametropias, especially since the focal length varies with the ametropia. However, in the axial ametropias such a spectacle lens location is convenient and simplifies the determination of image size. Regardless, the figure of 14.98 mm is close to a realistic vertex distance.

In all diagrams, the images formed by the contact lens are identified by the use of a *solid* arrow head. In addition, the images of approximately equal size are also indicated.

In the refractive ametropias it can be seen that the images formed by contact lenses approximate the image size of the emmetropic eye. The images

40



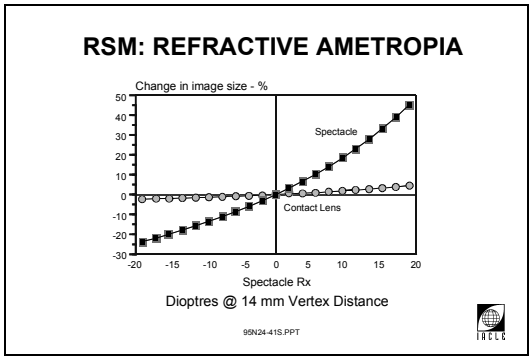
2L396113-40

formed by spectacles are larger and smaller in cases of hyperopia and myopia respectively, as would be predicted by CLM considerations.

Data calculated for a wide range of ametropia (±20.00 D) is presented graphically in slide 41. As with other graphs in this series, a vertex distance of 14 mm was used along with the Gullstrand-Emsley Schematic Eye.

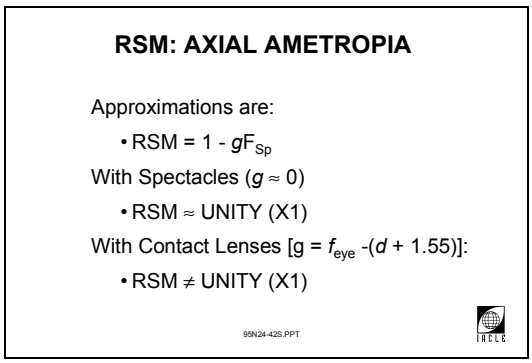
Clearly, if anisometropia results from ametropia (unilateral or bilateral) which is ***refractive*** in origin, ***contact lenses*** would be the ***correction of choice*** because they produce negligible differences between the corrected image size and the *normal* emmetropic image size.

41



2L394N291-41

42



2L396113-42

RSM: Axial Ametropia

Approximations (from slide 31) are:

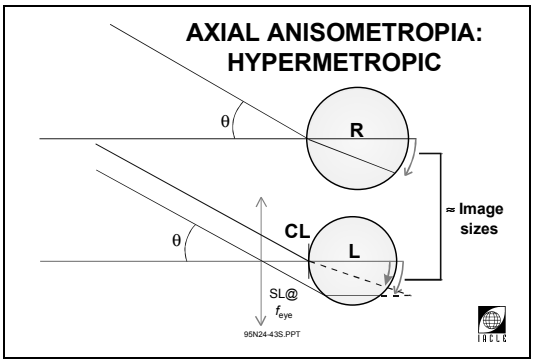
$$RSM = 1 - g\,F_{Sp}$$

With Spectacles ($g \approx 0$ i.e. $d_2 \approx -f$)
RSM ≈ UNITY (X1) (this approximation depends on the accuracy of the assertion $g \approx 0$).

With Contact Lenses $g = f_{eye} - (d + 1.55)$ remembering that f is negative and g and d are positive.

RSM ≠ UNITY (X1)

43



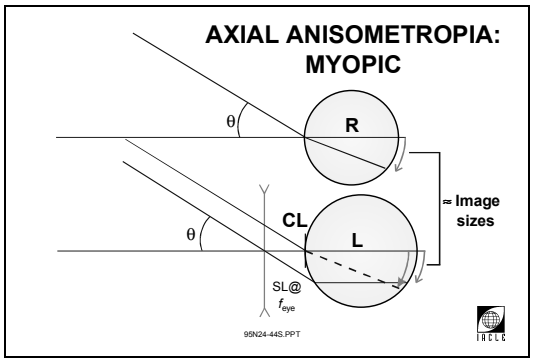
2L396113-43

RSM: Axial Ametropias

The diagrams show that in the axial ametropias spectacles provide the image sizes nearest that of the emmetropic eye. Note that, as with the refractive ametropias, the spectacle image sizes are still larger and smaller in hyperopia and myopia respectively.

Data calculated for the axial ametropias is presented in slide 45. The data used in this graph are patient-based, i.e. the spectacle data are plotted against the *equivalent* contact lens data (image size change calculated using BVP_{CL} corrected for the effect of vertex distance). Some texts show a more curved contact lens-data plot. These would appear to be BVP based, i.e. data for spectacle and contact lenses of the *same* BVP are compared.

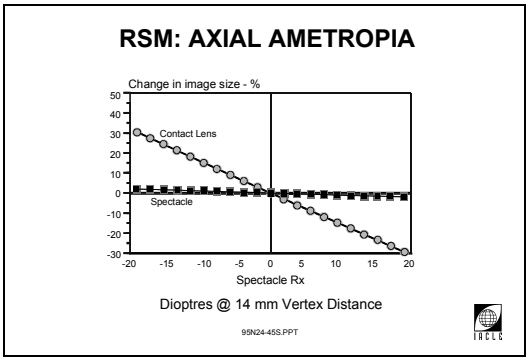
44



2L396113-44

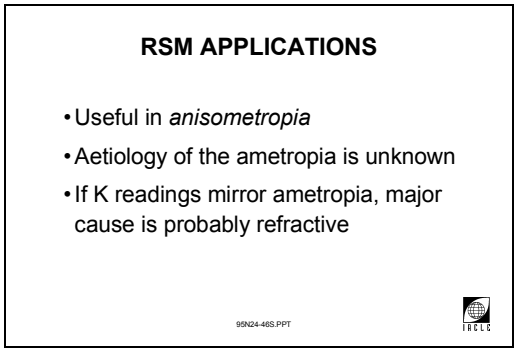
Clearly, if anisometropia results from ametropia (unilateral or bilateral) which is ***axial*** in origin, ***spectacles*** would be the ***correction of choice***.

45



2L394N291-45

46

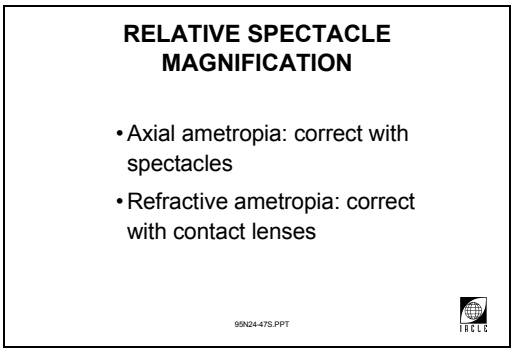


2L396113-46

RSM Applications

- RSM's main application is in clinical decision making in cases of *anisometropia* (i.e. inequality of the refractive states of each eye). RSM is useful in determining the difference in image sizes between two eyes (aniseikonia) for both refractive and axial ametropias.
- Unfortunately, it is difficult to determine the aetiology of the ametropia in most cases. As with many situations in nature, the origin is often a combination of both axial and refractive factors.
- Studies have shown that when K readings mirror the ametropia differences (e.g. steepest corneas in the more myopic eyes), the cause is more likely to be refractive.

47



2L396113-47

Relative Spectacle Magnification

Summary:

- RSM theory suggests that anisometropia which is *axial* in origin is best corrected by *spectacles*.

conversely...

- Anisometropia with a *refractive* aetiology is best corrected by *contact lenses*.

Clinical judgement is required to assess the magnitude of any anisometropia, the likely level of aniseikonia and its probable aetiology. Only then can a decision of spectacles versus contact lenses

be made. In summary, in anisometropia contact lenses are not automatically the correction of choice and clinical judgement is required.

RSM has taken on renewed significance since the advent of refractive surgical procedures (e.g. RK, PRK, LASIK etc.) since all are considered a cornea-based correction. Therefore, all comments concerning the suitability of contact lens correction apply equally to these surgical procedures.

48

AMETROPIA: AXIAL OR REFRACTIVE

- High ametropias usually axial
- Axial anisometropia best corrected with spectacles
- Most ametropes are approximately isometropic
- Choice of correction is then usually based on other considerations

95N24-48S.PPT

2L396113-48

Ametropia: Axial or Refractive

- Studies of the higher ametropias (± 4 to ±8D) suggest an axial aetiology is more likely.
- If the patient is anisometropic as well, spectacles are the correction of choice.
- However, most ametropes are approximately isometropic.
- Choice of the form of correction is then usually based on other considerations such as cosmetic, occupational or safety factors.

49

HOW DO SM, CLM & RSM RELATE TO ONE ANOTHER?

- SM is a comparison of corrected vs uncorrected retinal image sizes
- CLM is a comparison of CL corrected vs spectacle lens corrected, retinal image sizes
- RSM compares image sizes in a corrected ametropic eye and a theoretical emmetropic schematic eye

95N24-49S.PPT

2L396113-49

How do SM, CLM and RSM Relate to One Another ?

- SM is a real-world comparison of corrected (focused) and uncorrected (blurred) retinal image sizes.
- CLM is a more realistic comparison of contact lens corrected *versus* spectacle lens corrected retinal image sizes.
- RSM is a hypothetical magnification comparing image sizes in a corrected ametropic eye and a theoretical emmetropic schematic eye.

50

APHAKIA

- Aphakia is considered refractive
- If IOLs are not implanted, contact lenses are preferable

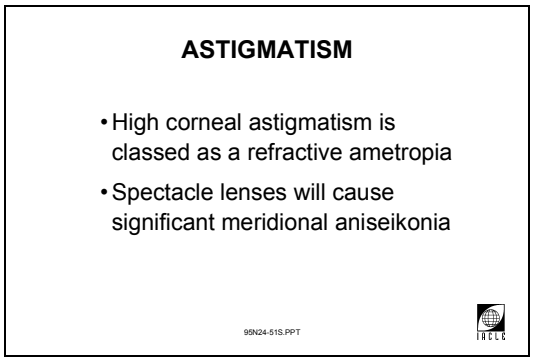
95N24-50S.PPT

2L396113-50

Aphakia

Aphakia is considered predominantly refractive and, if IOLs are not implanted, contact lenses are the preferred alternative. Their relatively low usage since IOLs emerged as a successful procedure is not lamented, since all accept that IOLs provide optical advantages and are the correction of choice.

51



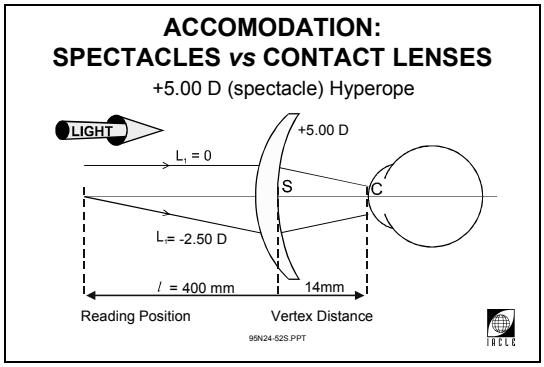
2L396113-51

Astigmatism

- High corneal astigmatism is classed as a refractive ametropia. This is because regardless of the actual aetiology, one meridian can be considered 'normal' and the other can then be considered the cause of the astigmatic refractive error.
- The large amounts of meridional aniseikonia with spectacle lenses make contact lenses the correction of choice, as they minimize the differences.

IV Accommodation with Contact Lenses

52



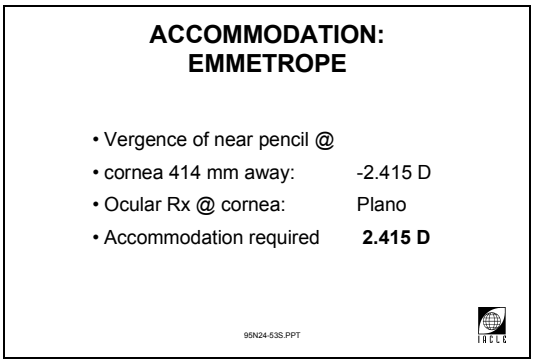
2L396218-52

Accommodation: Spectacles *versus* Contact Lenses +5.00 D Hyperope

The accommodative effort required for a hyperope, an emmetrope and a myope is documented in the following slides.

This diagram shows a 5D hyperope accommodating for a near object at 40 cm. An object at 40 cm reflects light whose vergence is –2.50 D (i.e. the incident light is divergent).

53



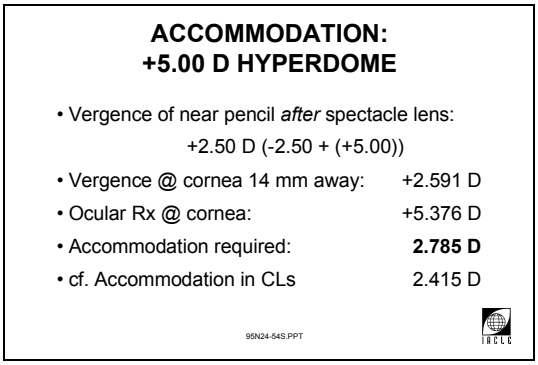
2L396113-53

Accommodation: Emmetrope

The initial calculation will examine the case of an emmetrope under identical circumstances. A vertex distance for the ametropes of 14 mm will be used. For the emmetrope, the object is assumed to be at 414 mm (i.e. 400 + 14) and therefore the accommodative demand is **+2.415 D**.

Under similar circumstances, the eye of a *contact lens wearer is subjected to approximately the same* accommodative demand.

54



2L396113-54

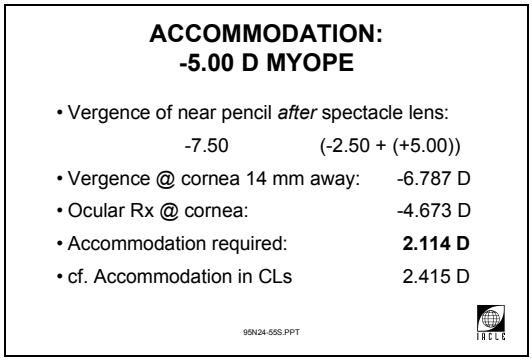
Accommodation: +5.00 D Hyperope

The vergence of light at the corneal plane for a 40 cm working distance after passing through a +5.00 D spectacle lens placed 14 mm in front of the cornea is +2.591 D. The ocular Rx at the corneal plane is +5.376 D and therefore the accommodative demand is:

+5.376 – (+2.591) = **+2.785 D**.

However, since a +5.00 D **hyperope** wearing contact lenses only accommodates 2.415 D, the **accommodative demand in contact lenses is *less*** than when wearing spectacles (2.785 D).

55



2L396113-55

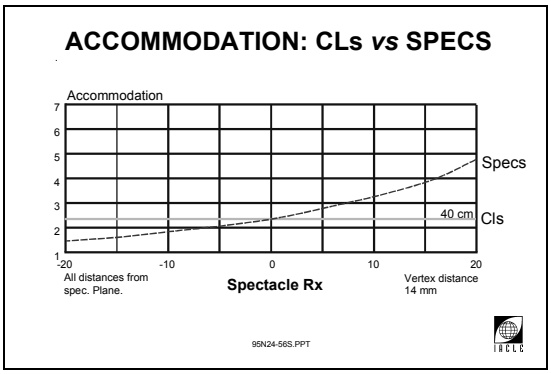
Accommodation: –5.00 D Myope

The vergence of light at the corneal plane for a 40 cm working distance after passing through a –5.00 D spectacle lens place 14 mm in front of the cornea is –6.787 D. The ocular Rx at the corneal plane is –4.673 D and therefore the accommodative demand is:

–4.673 – (–6.787) = **+2.114 D**.

Since a –5.00 D **myope** wearing contact lenses only accommodates 2.415 D, the **accommodative demand in contact lenses is *greater*** than when wearing spectacles (2.114 D).

56



2L396113-56

Accommodation: Contact Lenses *versus* Spectacles

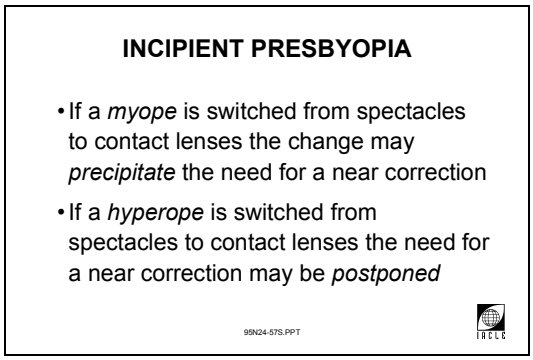
This graph shows the ocular accommodation required for both 25 cm and 40 cm viewing distances (measured from the spectacle plane) for spectacle ametropias between +20D and –20D. The nominal ocular accommodation for a contact lens wearer (or an emmetrope) for the two distances appear as horizontal lines. The data is based on a vertex distance of 14 mm.

While the choice of 25 cm is somewhat unrealistic (it is too close), the figure was chosen to demonstrate clearly the potential accommodative demands a spectacle correction can make on the wearer. This is especially true for high hyperopes. The contact lens alternative is obviously less demanding (less than 4D *versus* more than 7D). Significant differences exist even at the more realistic working distance of 40 cm.

Accommodation: Summary

- Spectacle wearing *myopes* accommodate *less* than spectacle wearing *hyperopes* (2.114 D *versus* 2.786 D).
- With contact lens wear, the accommodation required in ametropia is approximately the *same* as for an emmetrope (≈ 2.415 D).
- The accommodative demand of a *myope* is greater in contact lenses (2.415 D) than with spectacles (2.114 D).
- The accommodative demand of a *hyperope* is greater with spectacles (2.786 D) than with contact lenses (2.415 D).

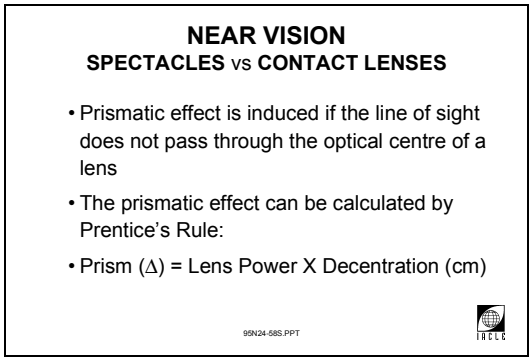
57



2L396113-57

V Convergence with Contact Lenses

58



2L396113-58

Near Vision

Spectacles *versus* Contact Lenses

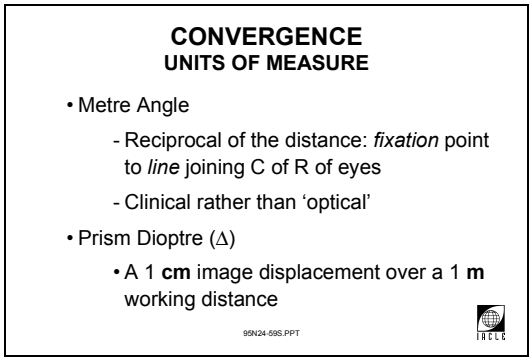
When spectacles are decentred from the visual axis, a prismatic effect is induced. The amount depends on the BVP of the lenses in the horizontal meridian (primarily), or at the position of gaze in the more general case which accounts for head tilt as well as convergence.

The prismatic effect can be calculated by Prentice's Rule:

Prism (Δ) = Lens power x Decentration (in cm)

Prentice's Rule is only an approximation and is based on paraxial theory and *thin* lenses. Since contact lenses are *thick* lenses and peripheral lens zones may be involved, only approximations are possible when applying this rule.

59



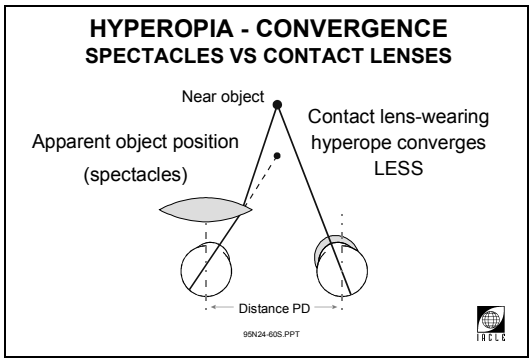
2L396113-59

Convergence: Units of Measure

- Metre Angle
  - The reciprocal of the perpendicular distance from the *point of fixation* to the line joining the *centres of rotation* of the eyes. The Centre of Rotation (C of R) is *not* a fixed point (6 extra ocular muscles, including some obliquely inserted, and a flexible globe position prevents the eye from having a fixed 'pivot point'). C of R is considered to be 13.5 mm behind the corneal apex (Solomons, 1978, Millodot, 1986).
  - metre angle is a clinical rather than an 'optical' measure.
- Prism Dioptre (Δ) is the displacement of an image by **1 cm** over a working distance of **1 m**. Like Prentice's Rule, prism dioptre calculations assume *thin* lenses and paraxial rays.

All fixation points are assumed to be in the *median plane* and *asymmetric* convergence will not be dealt with.

60

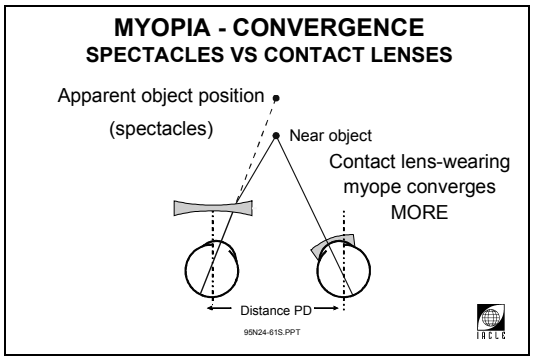


2L396218-60

Convergence in Hyperopia

A hyperope wearing contact lenses converges *less* than when wearing spectacles. This is because of the *base-out* prism effect induced by spectacles acting as an exercising prism which forces more convergence than the viewing distance would suggest. Since a contact lens moves with the eye, no such prismatic consideration applies.

61

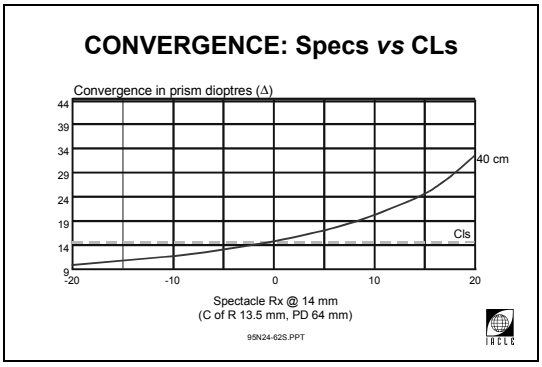


2L396218-61

Convergence in Myopia

A myope wearing contact lenses converges *more* when wearing contact lenses than when wearing spectacles. When wearing spectacles, they behave as a *base-in* relieving prism, and the eye converges less than the viewing distance would suggest. Contact lenses contribute negligible amounts of prismatic effect. Consequently, the effective increase in convergence demand when switching from spectacles to contact lenses may be clinically significant.

62

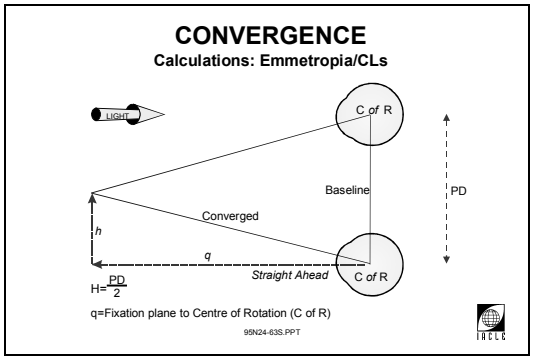


2L396113-62

Convergence: Spectacles *versus* Contact Lenses

This graph demonstrates the differences between a patient wearing contact lenses and wearing spectacles. With respect to convergence, the contact lens wearer is assumed to be in a situation similar to an emmetrope, i.e. the lens moves with the eye and has no effect *per se* on the amount of convergence required. Data for 25 and 45 cm fixation distances are included. Inspection of the graph clearly shows that spectacle-wearing hyperopes have relatively greater demands placed on their adduction reserves than do myopes. Shorter fixation distances exacerbate the difference.

63



2L396113-63

Calculating the Convergence Required

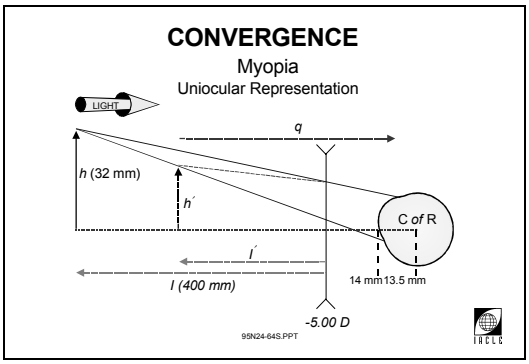
In referring to slide 63 it can be seen that the emmetrope (and contact lens wearer) need to converge each eye to fixate the object of regard, by an amount related to half the interpupilliary distance (PD), labelled as *h* in the diagram.

Monocular vergence:

For a fixation distance of 400 mm from the spectacle plane, a PD of 64 mm, a vertex distance of 14 mm and a C of R 13.5 mm behind the corneal apex, the monocular vergence (in prism dioptres) is:

$\Delta = \dfrac{h\,(in\ cm)}{q\,(in\ m)}$ where q is the distance *from* the plane of fixation *to* the Centre of Rotation (C of R) of the eye. Optically, the plane of fixation may be real (slide 63 & 64) or virtual (slide 65).

64



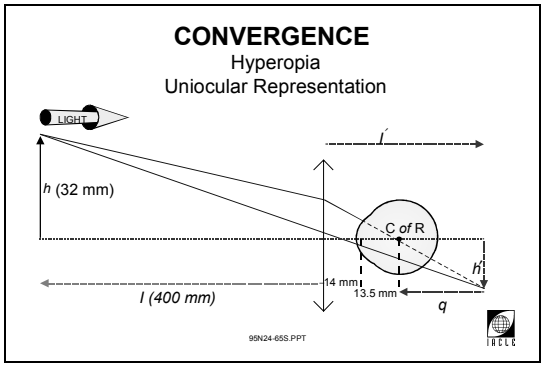
2L396113-64

$$\Delta = \frac{+\,3.2}{+\,(0.4+0.014+0.0135)} = 7.49\Delta$$

∴ Binocularly, **convergence** = 14.97Δ

This is also the **convergence** required by a **contact lens wearer** because their correcting lenses move with their eyes.

65



2L396113-65

Slide 64 shows the monocular situation for a –5.00 D myope in similar circumstances to the previous example.

Monocular $\Delta = \dfrac{h'}{l'}$

From the general magnification formula: $\dfrac{h'}{l'} = \dfrac{h}{l}$

$\therefore\ h' = \dfrac{h\,l'}{l}$

$L' = L + F_s$

$\dfrac{1}{l'} = \dfrac{1}{l} + F_s$

$l = -0.4$ m and $F_s = -5.00$ D

$\therefore\ l' = -0.133$ m

$h' = \dfrac{32(-0.133)}{-0.4} = 10.666$ mm

$\Delta = \dfrac{h'}{q}$, where q is the distance from the plane of fixation (the *image* plane) to the C of R.

$\Delta = \dfrac{+1.0666}{+(0.1333+0.014+0.0135)} = 6.63$

$\therefore$ Binocularly, **convergence** = 13.26 Δ

Note that in the case of ametropes in which the image plane is *behind* the spectacle plane, $q = l'$ – (vertex distance + C *of* R). This is because q is now the distance *from* the *apparent plane of fixation* (measured with respect to the spectacle plane) and the *Centre of Rotation.*

Slide 65 shows the monocular situation for a +5.00 D hyperope in similar circumstances to the previous examples, i.e. PD = 64 mm, reading distance = 40 cm, vertex distance = 14 mm.

Monocular $\Delta = \dfrac{h'}{l'}$

From the general magnification formula: $\dfrac{h'}{l'} = \dfrac{h}{l}$

$\therefore\ h' = \dfrac{h\,l'}{l}$

$L' = L + F_s$

$\dfrac{1}{l'} = \dfrac{1}{l} + F_s$

$l = -0.4$ m and $F_s = +5.00$ D

$\therefore$ l' = +0.4 m (i.e. 40 cm *behind* spectacles)

$$h' = \frac{+32(+0.4)}{-0.4} = -32 \text{ mm}$$

$\Delta = \dfrac{h'}{q}$, where q is the distance from the *image* plane to the centre of rotation.

$$\Delta = \frac{-3.2}{-(+0.4-(0.014+0.0135))} = \frac{-3.2}{-0.372}$$

$\Delta = 8.59\Delta$

$\therefore$ Binocularly, **convergence** = 17.18Δ

Summary: (PD = 64, VD = 14)

CL Rx	CL Convergence	Spectacle Wearer
–5.00D	13.26Δ	14.97Δ
Plano	14.97Δ	14.97Δ
+5.00D	17.18Δ	14.97Δ

VI Corneal Radius of Curvature

66

RADIUS OF CURVATURE OF THE CORNEA

Range of corneal curvature:

Approximately 7.1 - 8.7 mm

95N24-66S.PPT

2L396113-66

67

OPHTHALMOMETRY: PURKINJE- SANSON IMAGE #1

- Ophthalmometers (keratometers) measure RADIUS of Curvature, NOT dioptric power
- indicated dioptric power based on assumption n_{cornea} = 1.3375
- For a 7.8 mm cornea:

  Dioptric power = 48.205 (n=1.376)

  'K reading' = 43.269 (n=1.3375)

  - In effect the assumption only gives 90% (89.76%) of the actual power

95N24-67S.PPT

2L396113-67

Ophthalmometry: Purkinje-Sanson Image #1

All ophthalmometers (keratometers) *measure radius of curvature*, ***not*** dioptric power.

Most instruments indicate dioptric power based on historical and convenient assumption that n_{cornea} = 1.3375 whereas the currently accepted figure is 1.376.

For a 7.80 mm cornea:

Dioptric power = 48.205 (n=1.376)

Dioptric Power = 43.269 (n=1.3375)

The latter is the so-called 'K reading' which appears on an ophthalmometer's scale.

In effect, the assumption (n = 1.3375) only gives 90% (89.76%) of the actual power (ignoring the effects of the thin tear film over the cornea). However, this apparent anomaly is useful since it can be shown (slide 73) that 89.36% of corneal astigmatism can be eliminated by the use of a rigid spherical contact lens on an astigmatic cornea (there are physical limits to the use of rigid spherical lenses on toric corneas but no optical limits). Therefore, the keratometer's estimate of corneal astigmatism is an accurate indication of the amount of astigmatism that can be neutralized by a rigid spherical lens.

VII The Tear Lens

68

CONTACT LENSES ON A CORNEA

- Tear lens under a flexible lens is very thin and has no power
- Tear lens under a rigid lens depends on material rigidity and the fitting relationship
- If a rigid lens decentres, the tear lens will acquire a prismatic component

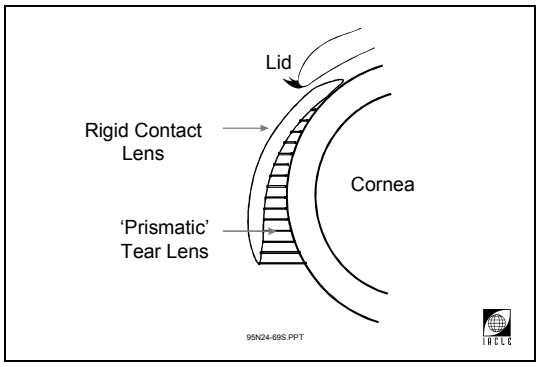
95N24-68S.PPT

2L396113-68

Contact Lenses on a Cornea

- When a flexible lens is placed on the cornea, the 'tear lens' under the contact lens is very thin. It has no dioptric power due to the conformity of the lens to the shape of the cornea.
- If a rigid lens is used, the 'tear lens' depends on the relationship between the curvatures of the lens back surface and the cornea and, to a lesser extent, the material's rigidity.
- If a rigid lens decentres, the tear lens will acquire a prismatic component in addition to the spherical or sphero-cylindrical optics dictated by the fitting relationship.

69

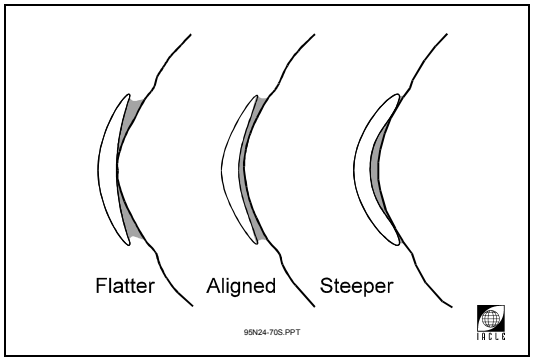


2L396218-69

Decentration-Induced Prism

When a rigid lens decentres, and is possibly tilted by upper or lower lid pressures, a prismatic tear lens may be induced under it. In higher powered lenses, any induced tear prismatic effect may be insignificant when compared with the prism induced by the decentred optics.

70



2L396218-70

Diagram of Flat, Aligned and Steep RGP Fits

This diagram illustrates the three simplest RGP/cornea relationships. No consideration is given to the periphery of either the cornea or the lens and their fitting relationships.

The terminology used to describe these relationships are *flatter* or apical touch, *alignment* or parallel and *steeper* or apical clearance.

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TEAR LENS POWER
RIGID LENSES

Assume tear lens (TL) to be in air, BOZR = 7.80 mm, n_{Tear} = 1.336.

TL/Air front interface power $= \frac{1.336 - 1.000}{0.0078} = +43.077$ D

If flatter by 0.05, interface power $= \frac{1.336 - 1.000}{0.00785} = +42.803$ D

∴ Flatten BOZR by 0.05 mm → Δ-0.274 D in TL power

Similarly, Steeper by 0.05mm → Δ+0.278 D in TL power

Rule of Thumb:

Δ0.05 mm in BOZR ≈ Δ0.25 D in CL BVP

95N24-71S.PPT

2L396113-71

Tear Lens Power with Rigid Lenses

A Rule of Thumb can be derived for tear lenses under rigid lenses. Clinically, it is used frequently.

Assumptions:

- n_{Tears} = 1.336
- n_{Lens} = 1.490
- n_{Air} = 1.000
- r_0 = 7.80 mm
  - *flatter* = 7.85 mm
  - *steeper* = 7.75 mm

For convenience consider that the contact lens and the tear lens (TL) are separated by a thin layer of air.

TL front surface power (FS_{Tears}):

$$= \frac{n'-n}{r}$$

$$= \frac{1.336 - 1.000}{0.0078}$$

FS_{Tears} power = **+43.076923** (BOZR = **7.80 mm**)

If, for example in the interests of lens fit, an alteration to the BOZR was considered clinically desirable, what compensation/s are required before a lens is ordered or re-ordered? Examples of alterations of ±0.05 mm follow.

In *flattening* the BOZR by 0.05, BOZR = 7.85 mm

FS_{Tears} power = **+42.802548** (BOZR = **7.85 mm**)

Δ = +42.802548 – (+43.076923)

= –0.274375 D

$\therefore$ ***Flattening*** produces a **–0.274375 D** effect.

To maintain the same BVP of the 'system' (CL, tear lens, eye) a *compensating +0.274375 D* must be added to the BVP_{CL} (in air) when ordering.

Steepening the BOZR by 0.05, BOZR = 7.75 mm

FS_{Tears} power = **+43.354839** (BOZR = **7.75 mm**)

Δ = +43.354839 – (+43.076923)

= +0.277916 D

$\therefore$ ***Steepening*** produces a +**0.277916 D** effect.

To maintain the same BVP of the 'system' (CL, tear lens) a *compensating –0.277916 D* must be added to the BVP_{CL} (in air) when ordering.

Some further examples, to illustrate the *effects of curvature* on the compensation required, follow:

BOZR:	7.1	**7.8**	8.4
Flatten by 0.05 mm:	–0.33	**–0.27**	0.24
Steepen by 0.05 mm:	+0.34	**+0.28**	0.24

This table shows that within the limits of ±0.12 D, the rule of thumb applies with adequate accuracy.

Rule of Thumb:

Δ0.05 mm in BOZR $\approx$ Δ0.25 D in BVP required to offset Δ in tear lens power.

In the calculations presented here, the tear film is treated as being 'thin' and any optical effects due to thickness are ignored. In some cases, for example haptic lens, the tear film thickness may be significant. In such cases the tear lens should be treated as a 'thick' lens.

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NEUTRALIZATION OF ASTIGMATISM

- Cornea/tears interface is optically insignificant
- Tear lens is sphericalized by the back surface of a spherical lens
- This results in a major reduction of corneal astigmatism with a spherical lens

95N24-72S.PPT

2L396113-72

Neutralization of Astigmatism

- Since the refractive indices of the cornea and the tears are not vastly different, the effectiveness of the optical interface between the two is much reduced.
- Therefore, if an astigmatic cornea is fitted with a rigid spherical lens:
  - the front surface of the tear lens is 'sphericalized' by the back surface of the lens
  - the toric interface between tear lens and cornea has its optical effectiveness significantly reduced.
- This use of a simple spherical lens results in a major reduction of corneal astigmatism.
- While this is true for all cases, the need to limit the physical consequences of the lens rocking on the flatter meridian of the cornea limits the amount of corneal astigmatism which can be 'corrected' by this method.
- It is usually difficult to fit spherical lenses on corneas with 3.00 D of corneal astigmatism. Some claim that 2.00 D is a more realistic upper limit. A further consideration is that the keratometer (ophthalmometer) only measures the central 3 mm (approximately) of the cornea, and no peripheral curvature or shape information is usually available. The wider use of video-based topographical systems may help in this regard.

73

NEUTRALIZATION OF CORNEAL ASTIGMATISM

Ks (mm):	8.7/8.4	7.8/7.5	7.1/6.8
Astig (D):	1.544	1.928	2.336
with CL (D):	0.164	0.205	0.249
residual:	10.64%	10.64%	10.64%

95N24-74S.PPT

2L396113-73

Neutralization of Corneal Astigmatism

Assuming K readings of 8.00 mm and 7.60 mm and the following refractive indices: $n_{cornea} = 1.376$, $n_{tears} = 1.336$

Corneal powers in *air*:

$$D_1 = \frac{n' - n}{r_1} = \frac{1.376 - 1.000}{.008}$$

$D_1 = 47.00$ D

$$D_2 = \frac{n' - n}{r_2} = \frac{1.376 - 1.000}{0.0076}$$

$D_2 = 49.47$ D

Corneal Astigmatism = $D_2 - D_1$

= 2.47D

Corneal powers under *tears*:

$$D_1 = \frac{n' - n}{r_1} = \frac{1.376 - 1.336}{.008}$$

$D_1 = 5.00$ D

$$D_2 = \frac{n' - n}{r_2} = \frac{1.376 - 1.336}{0.0076}$$

$D_2 = 5.26$ D

Corneal Astigmatism = $D_2 - D_1$

= 0.26 D

$$\frac{Astigmatism\,(in\ situ)}{Astigmatism\,(air)} = \frac{0.26}{2.47} = 10.64\%$$

The figure 10.64% is the same for all corneal curvatures and all levels of astigmatism as shown in slide 73.

Rule of Thumb:

Approximately 90% of corneal astigmatism is neutralized by a spherical RGP lens.

Should the corneal astigmatism be neutralized or reduced by astigmata in other ocular components, residual astigmatism may be manifest with an RGP lens. This is because all non-corneal sources remain unaltered.

In the uncommon case of an apparently spherical ametrope who has a significantly astigmatic cornea, the use of spherical RGPs is contraindicated. The residual astigmatism will approximate the corneal astigmatism and will be at 90° to the cornea's astigmatic axis, because the compensating non-corneal astigmata remain unaltered.

VIII Over-Refraction

74

CONTACT LENS OVER-REFRACTION
RIGID LENS

Ocular Rx =

BVP_{Trial} + Tear Lens Power + Over-Rx

95N24-74S.PPT

2L396113-74

Contact Lens Over-Refraction

Rigid Lenses

With a rigid trial lens *in situ,* the over-refraction should be the difference between the ocular refraction (spectacle Rx vertex-distance corrected) and the sum of the BVP of the trial lens and the power of the tear lens.

Oc Rx = BVP_{trial} + $Power_{tear\ lens}$ + Over-Rx

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CONTACT LENS OVER-REFRACTION
SOFT LENS

Ocular Rx = BVP + Over-Rx

Assumptions:

- Lens conformance
- Thin tear film under lens has zero power

95N24-75S.PPT

2L396113-75

Contact Lens Over-Refraction

Soft Lenses

With a trial soft lens *in situ*, over-refraction should only be the difference between the ocular refraction and the BVP of the trial lens.

$$Oc\ Rx = BVP_{trial} + Over\text{-}Rx$$

The underlying assumption is that the lens conforms completely to the anterior eye geometry (especially over the cornea), with the result that the thin layer of tears under the lens has zero power. This assumption may be less valid in the case of low water torics (thicker and less flexible) and those lenses whose materials are relatively rigid, especially when there is significant corneal astigmatism present. The result will usually be variable.

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CONTACT LENS OVER-REFRACTION
REASONS FOR DISCREPANCIES

1. Failure to vertex correct spectacle Rx to derive ocular Rx
2. Failure to vertex correct over-Rx (if>±4.00 D)
3. K readings only represent the central 3 mm
4. K readings incorrect
5. Tear lens power varies slightly with Ks
6. BVP_{TRIAL} may be incorrect - verify it

95N24-77S.PPT

2L396113-76

Contact Lens Over-Refraction

Reasons for Discrepancies

1. Failure to correct for vertex distance of spectacle Rx when deriving the ocular Rx.
2. Failure to correct the over-Rx for vertex distance when it is >±4.00 D. If possible, it is prudent to use a trial lens closer to the ocular Rx since the fitting behaviour is governed by BVP as well as other shape factors and material properties.
3. K readings only represent the central zone (approximately 3 mm) and give no indication of the shape of the periphery. Assuming the entrance pupil is larger than 3 mm, then not just the central zone is involved in image formation.
4. K readings are incorrect. Either the instrument was not in calibration, the data was measured/recorded incorrectly, the Ks changed over time and the readings are not current, or they were changed by the contact lenses.
5. Tear lens power varies slightly with K readings. The text of slide 71 demonstrates how corneal curvature can induce tear lens powers which deviate from the Rule of Thumb: Δ0.05 mm $\approx$ Δ0.25 D, by almost ±0.12 D.

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CONTACT LENS OVER-REFRACTION REASONS FOR DISCREPANCIES

7. Subjective over-Rx is incorrect
8. BOZR of trial lens incorrect - verify it
9. Trial lens is decentred and/or tilted
10. Trial lens flexure *in situ*, rigid and soft
11. Corneal molding by the lens

95N24-78S.PPT

2L396113-77

78

CONTACT LENS OVER-REFRACTION REASONS FOR DISCREPANCIES

12. Corneal shape not spherical or sphero-cylindrical
13. Variable toric tear lens due to trial lens movement/decentration/tilting/rotation
14. Tear lens under a thick, high power, low water soft lens
15. Environment-induced changes in thick, soft trial lens
16. One or more of the above in combination

95N24-79S.PPT

2L396113-78

6. Trial lens BVP may be incorrect. Unless a lens is engraved and its BVP verified, the possibility of the lens not being as labelled needs to be considered. If there is any doubt, its BVP needs to be confirmed.

7. Subjective over-Rx is incorrect. Arguably an over-Rx is subject to greater variability than normal subjective refraction procedures, because a moving additional lens complicates the eye's optics. Rigid lenses are the most complex because of tear lens considerations. The tear film and its properties add further to the potential for variable results.

8. BOZR of the trial lens is incorrect. When applying rules-of-thumb in the case of RGPs, the BOZR is central to tear lens power calculations and must be known accurately.

9. Trial lens is decentred and/or tilted. The variable tear lens power that results may affect the end result.

10. Trial lens flexure *in situ* for both rigid and soft lenses can mislead the practitioner. With RGPs, the problem can be flexure of the lens and/or tear lens considerations. For soft lenses, it is usually only lens flexure.

11. Corneal molding by the lens. The mechanical properties of the cornea are usually unknown. Lenses which are more rigid (RGPs, toric soft and some other soft lenses whose materials are relatively rigid) are more likely to induce such changes.

12. Corneal shape not spherical or sphero-cylindrical. While we measure and treat the eye as if it was a spherical or sphero-cylindrical optical system, it is a biological system and may not be mathematically describable. Often the correcting lenses are the nearest approximations to what the eye needs and which can be made with current technology.

13. Variable toric tear lens due to lens movement, decentration, tilting, rotation. When two toric surfaces (cornea and lens back surface) rotate relative to each other, the tear lens is defined by a pair of obliquely and variably crossed cylinder surfaces. While obliquely crossed cylinders can be resolved into sphero-cylindrical form, nothing can account for the problem of variability. Decentration and tilting are additional possible complications.

14. Tear lens under a thick, high power, low water soft lens. Low water materials are more rigid than high water materials. When combined with the thickness dictated by a high Rx, a tear lens can be induced. This is more likely if corneal astigmatism is also present. Any induced tear lens is likely to be more variable in the case of soft lenses.

15. Environment-induced changes in a thick, soft trial lens. Soft lenses are susceptible to tonicity, temperature and pH changes, especially if a high water content is involved. Changes in thickness, curvature and fitting relationship may therefore contribute to changes in the apparent optical behaviour of the lens. However, it is conceivable that some of these changes have to be accepted and compensated for on the assumption that any prescribed lens will behave similarly.

16. One or more of the above in combination. Many of the possibilities raised in the foregoing produce only subtle changes. However, the combination of two or more of these factors may raise the collective problem above the threshold of clinical significance.

IX Light Loss by Reflection

79

REFRACTIVE INDICES OF CONTACT LENS MATERIALS

PMMA = 1.49
RGPs = 1.48 - 1.41
SCLs = 1.44 - 1.38

95N24-79S.PPT

2L396113-79

Refractive Indices of Contact Lens Materials

These ranges are drawn from manufacturer's data and actual laboratory measurements. All common materials fall within these values. Somewhat surprisingly, the range of indices for RGP materials (0.07) is almost identical to that for soft (0.06).

It should also be noted that the refractive index of any one material is not fixed, and may change as a result of batch variation and the state of hydration.

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FRESNEL'S FORMULA OF REFLECTION

$$R = \left[\frac{(n - n)}{(n + n)} \right]^2$$

R = fraction of light reflected

n = refractive index of medium containing both incident & reflected light

n = refractive index of partially reflecting, partially transmitting, medium

95N24-81S.PPT

2L396113-80

Fresnel's Formula of Reflection

$$R = \left[\frac{(n' - n)}{(n' + n)} \right]^2$$

R = fraction of light reflected by the surface at ***normal incidence***.

n = refractive index of medium containing both incident and reflected light, i.e. the 'outside' medium.

n´ = refractive index of partially reflecting, partially transmitting medium, i.e. the 'inside' material.

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PURKINJE-SANSON IMAGE #1

n = 1.000 (air)
n = 1.336 (tears)
R = 0.0207
∴ Light loss approx. 2.1%

95N24-81S.PPT

2L396113-81

Purkinje-Sanson Image #1

The total loss of light by reflection from the air/tears/anterior cornea interface is about 2.09%.

The tear film reflex (P-S #1), as the brightest reflection from the eye, is of interest for two reasons:

- Its nuisance value during clinical observation and photography.
- Its constructive use in keratometry (ophthalmometry).

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REAL LIGHT LOSSES: C/L SYSTEMS

Sum of (Σ):
Air/Tears, Tears/CL,
CL/Tears, Tears/Cornea

95N24-82S.PPT

2L396113-82

Real Light Losses: Contact Lens Systems

Sum of (Σ): Air/Tears, Tears/CL, CL/Tears, Tears/Cornea interfaces.

Loss = A/T + T/CL + CL/T + T/C

83

SOME FIGURES FOR LIGHT LOSSES

RGP n = 1.48 Σ = 2.6%

RGP n = 1.41 Σ = 2.2%

SCL n = 1.44 Σ = 2.4%

SCL n = 1.38 Σ = 2.1%

- Air/tear film interface is main contributor to loss in *all* cases

95N24-83S.PPT

2L396113-83

Some Figures for Light Losses

Summary:

Little difference in light loss occurs with any lens type (<20% difference according to these calculations).

This is because the main contributor to light loss is the air/tear film interface (2.07%) which exists in both the lens-wearing and no-lens situations. The other surfaces contribute little because their refractive index differences are minimal, hence their reflection losses are low. This means that, provided the lens is untinted, a new lens wearer will not notice any effect attributable to surface reflection light losses.

X Wet-Cell BVP Measurements

84

WET-CELL MEASUREMENTS OF SOFT CONTACT LENSES

- Image quality much improved
- Conversion factor NOT LINEAR
- Conversion factor is large for high water lenses
- Sagittal height affects results
- Lens thickness affects results

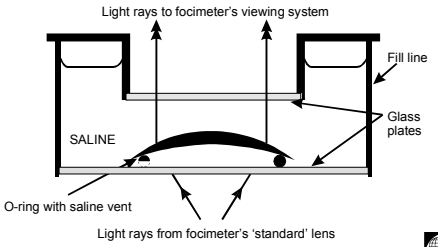
(Williams, 1977)
(Yumori & Mandell, 1981)

95N24-84S.PPT

2L396113-84

85

SOFT LENS WET CELL



95N24-86S.PPT

2L396213-85

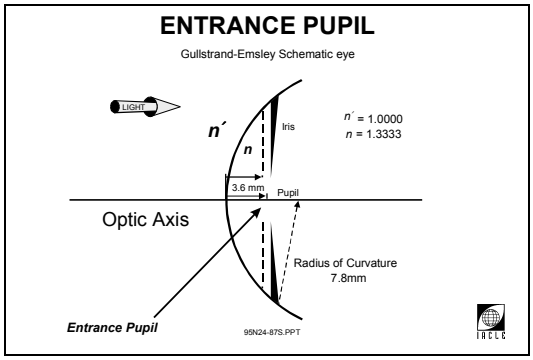
Wet-Cell Measurements of Soft Contact Lenses

Measuring the BVPs of SCLs in a wet cell may result in inaccuracies. While the image quality is much improved, the conversion factor is ***not*** linear and is large for low refractive index (high water) materials. The sagittal height and thickness of the lenses also influences the results.

(Williams, 1977, Yumori and Mandell, 1981)

XI Fields of View

86



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Entrance Pupil: Gullstrand-Emsley Schematic Eye

The entrance pupil is the image of the anatomical pupil formed by the optical system of the anterior eye, i.e. the combination of the cornea and the aqueous humor of the anterior chamber.

For simplicity, a schematic eye is used as the basis of the calculations related to the entrance pupil. As before, the Gullstrand-Emsley Schematic Eye is used.

In keeping with the conventions used elsewhere in this lecture, n is reserved for the refractive index of the *object* medium (which is the aqueous humor in this case, n = 1.3333) and n' for the *image* medium (air, n' = 1.000).

The pupil is 3.6 mm *from* the cornea whose radius of curvature is 7.8 mm. The refractive index of the schematic eye is 1.3333.

$$L = \frac{n}{l}$$ (l is positive: *from* cornea to pupil)

$$L = \frac{1.3333}{+0.0036}$$

L = +370.361

$$F = \frac{(n'-n)}{r}$$

$$F = \frac{(1.000 - 1.3333)}{+0.0078}$$

F = –42.731

$L' = L + F$

L' = +370.361 – 42.731

L' = +327.630

$$l' = \frac{1.000}{+327.630}$$

l' = +3.052 mm

This shows that the entrance pupil is approximately 3 mm *behind* the cornea (see slide) or approximately 0.55 mm in *front* of the anatomical pupil.

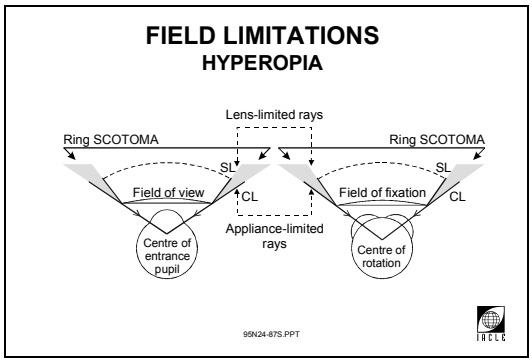
$$\text{Magnification} = \frac{L}{L'}$$

$$m = \frac{+370.361}{+327.630}$$

m = 1.1304

This represents a *magnification* of approximately +13%. Therefore, a 4 mm pupil will have an apparent size of 4.52 mm when measured by an observer.

87



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Fields of View: Spectacles *versus* Contact Lenses

Static Eye:
Field of View is determined by the angular subtense of the spectacle lens edge at the centre of the entrance pupil as well as the lens type (i.e. plus or minus).

Rotating Eye:
Field of View is determined by the angular subtense of the spectacle lens edge at the centre of rotation of the eye as well as the lens type (i.e. plus or minus).

The differences are presented diagrammatically.

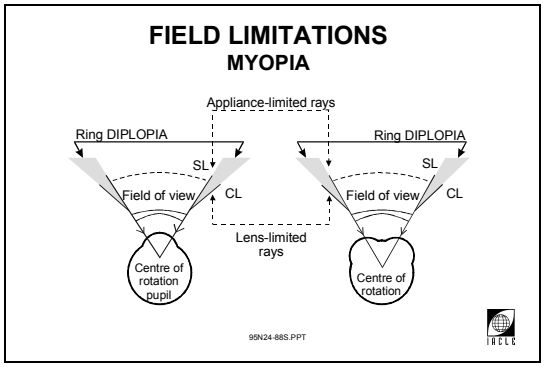
Field Limitations: Hyperopia

The ring 'scotoma' that is produced by the differences between the field limitations imposed by the frame/lens combination and the optics of a plus lens is shown.

Because the field of view is decreased by a plus lens, some parts of the field are not seen at all. This produces a 'ring scotoma' (absence of vision) whose exact shape depends on the shape and power of the lens and the profile/thickness of the spectacle frame.

As a contact lens moves with the eye no such limitations or scotoma results.

88



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Field Limitations: Myopia

The ring 'diplopia' that is produced by the differences between the field limitations imposed by the frame/lens combination and the optics of a minus lens is shown.

Because the field of view is relatively larger with a minus lens than with a plus lens, some parts of the field are seen both clearly through the lens as well as blurred outside the lens. This produces a 'ring of diplopia' (double vision) whose exact shape depends on the shape and power of the lens and the profile/thickness of the spectacle frame.

As a contact lens moves with the eye no such limitations or diplopia result.

XII Advantages and Disadvantages of Contact Lenses

89

OPTICAL ADVANTAGES OF CONTACT LENSES

- No astigmatism of oblique pencils
- No distortion
- No chromatic aberration
- No limitations on the field of view
- No spectacle frame diplopia

95N24-89S.PPT

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Optical Advantages of Contact Lenses

- No astigmatism of oblique pencils. Lens moves with the eye.
- No distortion. Lens moves with the eye.
- No chromatic aberration. More correctly no significant transverse chromatic aberration. Because the lens moves with the eye, the light rays are not oblique and the distance from the optical centre is always small. Axial chromatic aberration which is present theoretically, depends largely on the dispersive properties of the material. Most contact lens materials exhibit low dispersion and their 'lowish' refractive indices may also keep this aberration small.
- No limitations on the field of view.
- No spectacle frame diplopia. (Myopia).
- No spectacle frame scotoma. (Hyperopia).
- No prismatic imbalance in anisometropia. In spectacle anisometropia, vertical prismatic imbalances or asymmetric vergence movements can be induced when the eyes are not looking through the optical centres of the lenses simultaneously. Because contact lenses move with the eyes no imbalances should result in any position of gaze.
- No large spectacle magnification in aphakia.
- Corneal irregularities/astigmatism reduced by 90%.

90

OPTICAL DISADVANTAGES OF CONTACT LENSES

- Lens decentration produces 'ghosting'
- When a toric lens rotates, a toric over refraction and decreased vision results
- Moving lenses may produce disturbances of vision
- In axial ametropia spectacles are better suited

95N24-90S.PPT

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Optical Disadvantages of Contact Lenses:

Lens decentration produces 'ghosting' or flare from the peripheral zone of the lens.

When a toric lens rotates, a toric over-refraction and decreased vision may result.

Moving or generally unstable lenses may produce disturbances of vision.

Practical 2.3

(1 Hour)

Contact Lens Over-Refraction

Purpose of Practical

The purpose of this exercise is to teach students how to measure over-refraction and resulting visual acuity. This result with the contact lens power and the tear lens power should correlate with the habitual refractive error.

Instructions: The students are to work in pairs and perform over-refraction with trial RGP and soft contact lenses. A number of trial lenses of varying BOZR should be used. Students are to follow the steps outlined below, allowing one hour for each student. Findings of the examination procedures are to be recorded on the RECORD FORM provided.

1. Record the uncorrected visual acuity for one eye.
2. Perform a sphero-cylindrical refraction and record the measure and the corrected visual acuity.
3. Measure and record the K-readings.
4. Select BOZR of RGP contact lens to be within ± 0.10 mm of the flattest K-reading or the suggested BOZR based on the philosophy for the RGP lens design being used.
5. Insert this contact lens from a selection of known powers.
6. Wait for the lens to settle and the tearing to subside. Assess and record contact lens fit: centration, lag, fluorescein pattern. The supervisor will check the lens fit.
7. Calculate the tear lens power and the predicted over-refraction.
   - Calculate the effect of the *vertex distance* (distance from the spectacle lens to the cornea) if the spectacle prescription is greater than ± 4.00 D in each primary meridian.
   - Include the effect of the *tear lens power*: If the BOZR is steeper than flattest K, a plus tear power is created; if the BOZR is flatter than the flattest K, a negative tear power is created.
8. Determine the over-refraction by retinoscopy first, and a best sphere subjective over-refraction. Record the visual acuity. A sphero-cylindrical over-refraction should be performed if the visual acuity attained with the spherical over-refraction is worse than the habitual VA.
9. Record the patient's subjective assessment of the quality of vision and possible fluctuations that may occur with blinking.
10. The supervisor will check and confirm the results of the over-refraction.
11. Compare the original sphero-cylindrical refraction with the result of the over-refraction.
12. The procedure above is repeated for soft contact lenses without consideration of the tear lens power.

Practical Session

RECORD FORM

Name:_____ Date:_____

Partner:_____ Group:_____

OCULAR PARAMETERS	FINDINGS	
Eye Tested	Right	Left
Uncorrected VA		
Sphero-cylindrical Refraction	_____Sph _____Cyl _____	_____Sph _____Cyl _____
Corrected VA		
Trial contact lens specification		
Material	_____	_____
BOZR	_____	_____
t_C	_____	_____
BVP	_____	_____
Contact lens fit		
Centration	_____	_____
Movement	_____	_____
Fluorescein pattern	_____	_____
Retinoscopy	_____Sph _____Cyl_____	_____Sph _____Cyl _____
Spherical over-refraction	_____Sph VA _____	_____Sph VA _____
Sph/Cyl over-refraction	_____Sph _____Cyl _____ VA _____	_____Sph _____Cyl _____ VA _____
• Vertex distance: power at the ocular plane = SL power + (1 - distance in m between SL & CL) • Tear lens power (TL): flattest K (D)-BOZR (D) use refractive index of n = 1.3375 CL power = refractive error + TL power + over-refraction		
Assessment of results		

Tutorial 2.3

(2 Hours)

Optical Principles of Contact Lenses

Exercises

Name: _____ **Date:**_____

Instructions: Calculate the answers to the following problems.

1. **The spectacle refraction of a myope at a vertex distance of 14 mm was found to be:**

OD: –3.00 / –1.25 x 180
OS: –2.50 / –0.75 x 175

Compute the ocular refraction:

OD: _____

OS: _____

2. **An RGP is to be empirically ordered with the following specifications:**

BOZR = 7.45 mm

t_C = 0.15 mm

BVP = +1.00 mm

What is the FVP power of the lens?

3. **How does accommodation and convergence change from wearing spectacle lenses to contact lenses?**

4. Graphically compare:

A. Spectacle magnification to contact lens magnification.

B. Relative magnification (with spectacles and contact lenses) for both axial and refractive ametropia.

References

Baron H (1981). *Kontaktlinsen: Ein Lehrbuch und Leitfaden.* Verlag Optische Fachveröffentlichung GmbH, Heidelberg.

Benjamin WJ, Borish IM (1994). *Presbyopia and the influence of aging on prescription of contact lenses.* In: Ruben M, Guillon M, *Contact Lens Practice*. Chapman & Hall Medical, London. 766.

Bennett AG (1974). *Optics of Contact Lenses.* 4th ed. Assoc of Dispensing Opticians, London.

Bennett AG, Rabbetts RB (1984). *Clinical Visual Optics.* Butterworths, London.

Bier N, Lowther G (1977). *Contact Lens Correction.* Butterworths, London.

Fincham WHA, Freeman MH (1974). *Optics.* Butterworths, London.

Goersch H (Ed.) (1983). *Handbook of Ophthalmic Optics.* Carl Zeiss, Oberkochen.

Grosvenor TP (1963). *Contact Lens Theory and Practice.* The Professional Press Inc., Chicago.

Hecht E, Zajac A (1974). *Optics.* Addison-Wesley, Reading.

Longhurst RS (1967). *Geometrical & Physical Optics*. Longman, London.

Lowther G, Snyder C (1992). *Contact Lenses: Procedures and Techniques.* 2nd ed. Butterworth-Heinemann, Boston.

Mandell RB (1988). *Contact Lens Practice.* 4th ed. Charles C Thomas Publisher, Springfield.

Millodot M (1986). *Dictionary of Optometry.* Butterworths, London.

Obstfeld H (1978). *Optics in Vision.* 2nd ed. Butterworth Scientific, London.

Östlund KE (1980). *Kontaktologi.* Almqvist & Wiksell, Uppsala.

Phillips AJ, Stone J (1989). *Contact Lense*s. 3rd ed. Butterworths, London.

Ruben M (1975). *Contact Lens Practice*. Baillière Tindall, London.

Ruben M, Guillon M (1994). *Contact Lens Practice*. Chapman & Hall Medical, London.

Santos CLS (1989). *Lentes De Contacto*. Scriba, Barcelona.

Solomons H (1978). *Binocular Vision: a programmed text.* William Heinemann Medical Books Ltd., London.

Williams L (1977). *Measuring BVP of Contact Lenses in a Wet-Cell*. Paper to the AGM, Contact Lens Society of Australia, Perth.

Yumori RW, Mandell RB (1981). *Optical power calculation for contact lens wet cells*. Am J Optom Physl Opt. 58: 637 - 639.

Unit 2.4

(2 Hours)

Lecture 2.4: Soft Contact Lens Design

Tutorial 2.4: Soft Contact Lens Design

Course Overview

Lecture 2.4: Soft Contact Lens Design

I. Terminology Relating to Soft Contact Lens Parameters
II. Lens Designs
III. Lens Specifications for Soft Contact Lenses
IV. Lens Requirements

Tutorial 2.4: Soft Contact Lens Design

Lecture 2.4

(1 Hour)

Soft Contact Lens Design

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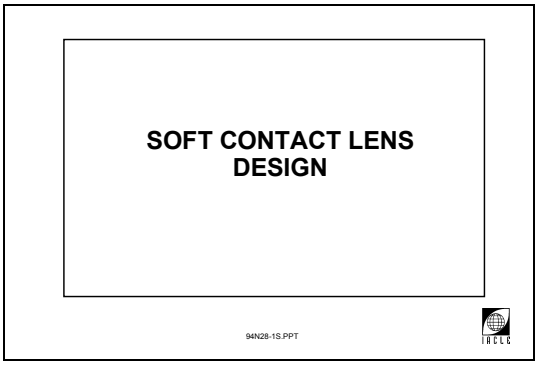
I Soft Contact Lens Design

1



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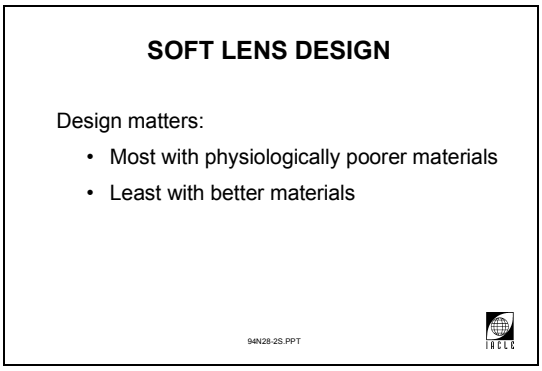

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Design Matters *Most* with Physiologically Less Acceptable Materials, *Least* with Good Materials

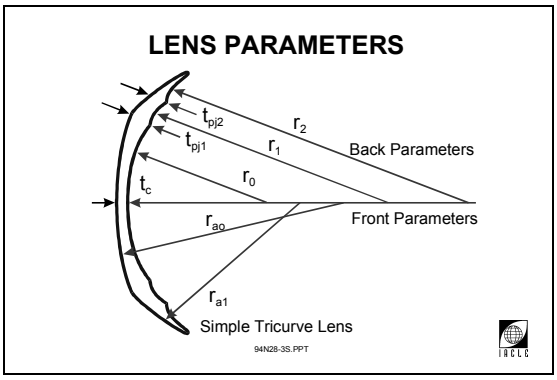
Adverse responses are likely to result from the use of less acceptable materials. To minimize these responses, lens design may need to be considered in some detail.

For example, the use of a low water material (low Dk) in a high plus Rx, produces hypoxia. Steps must be taken to reduce centre thickness and overall thickness to increase oxygen transmissibility.

The use of better materials allows greater design freedom without compromising the eye's minimum physiological requirements. For example, if a higher water material (higher Dk) was used in a low minus daily wear lens, the product may be difficult to handle. In this case, the thickness may be increased slightly to improve handling without resulting in physiological compromise of the cornea.

II ISO Terminology

3



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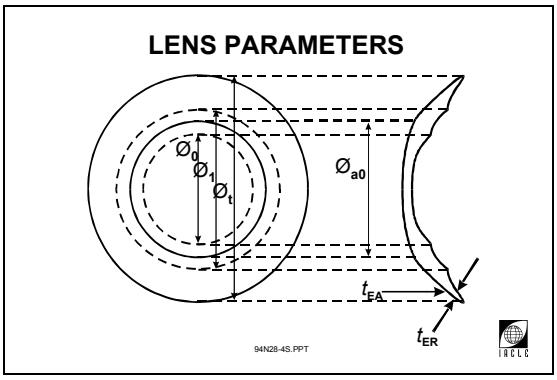

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Lens Parameters: *ISO* Terminology

This lecture uses the symbology and terminology promulgated in the draft *ISO* Standard # 8320.

Most parameter symbols are *italicized* but the subscripts are romanized (e.g. t_c).

In the interests of simplicity, a simple tricurve lens design is used to illustrate both *ISO* terminology and symbology.

Two views are presented. The legend to these follows:

r_0 = Back Optic Zone Radius (BOZR)

r_1 = Back Peripheral Radius, First (BPR_1)

r_2 = Back Peripheral Radius, Second (BPR_2)

r_{a0} = Front Optic Zone Radius (FOZR)

r_{a1} = Front Peripheral Radius, First (FPR_1)

t_c = Geometric Centre Thickness

t_{pj1} = Peripheral Junction Thickness, First

t_{pj2} = Peripheral Junction Thickness, Second

t_{ER} = Radial Edge Thickness

t_{EA} = Axial edge Thickness

$Ø_0$ = Back Optic Zone Diameter (BOZD)

$Ø_{a0}$ = Front Optic Zone Diameter (FOZD)

$Ø_1$ = Back Peripheral Zone Diameter (BPZD)

$Ø_T$ = Total Diameter (TD)

Miscellaneous (not shown):

F_v' = Back Vertex Power (BVP)

F_v = Front Vertex Power (FVP)

III Design Factors

5

SCL DESIGN FACTORS

- Geometric centre thickness (t_c)
- Lens diameter (total diameter, TD,$Ø_T$)
- Back optic zone radius (BOZR, r_0)
- Back surface design
- Front optic zone radius (FOZR, r_{a0})
- Front surface design

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6

SCL DESIGN FACTORS

- Radial edge thickness (t_{ER})
- Edge design
- Material physical/mechanical properties
- Material physiological properties
- Peripheral junctional thicknesses if transitions exist (t_{pj})

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SCL Design Factors, Each Can Affect 'On-Eye' Performance

7

DESIGN

- Diameter: greater than HVID
- Thickness: overall profile, centre, mid-periphery
- Curvature: variation in radius across lens, curvature in centre
- Design: front/back surfaces
- Relationship with the eye:

  Ks cf. lens back surface, total diameter cf. HVID

94N28-7S.PPT

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Design

- Diameter.
  All soft lenses are fitted larger than the Horizontal Visible Iris Diameter (HVID).
- Thickness.
  Apart from obvious thicknesses such as centre, mid-periphery and edge, the overall lens thickness profile is also important. Local thickness is the only relevant thickness when calculating local O_2 availability since there is little tear mixing under a soft lens, and local Dk/*t* is the only measure of O_2 performance relevant to a particular corneal region.
- Curvature.
  While the Back and Front Optic Zone Radii are important to Rx determination (the optical design), other radii define the physical design of the lens which also affects lens behaviour.
- Design.
  After defining centre thickness and front and back radii in the optical zone, the remainder of the lens design is defined by the radii of peripheral curves, their widths, their number and the junctional thicknesses. Front design is often made in the interests of comfort, thickness,

  durability and manufacturing ease or combinations of these factors.

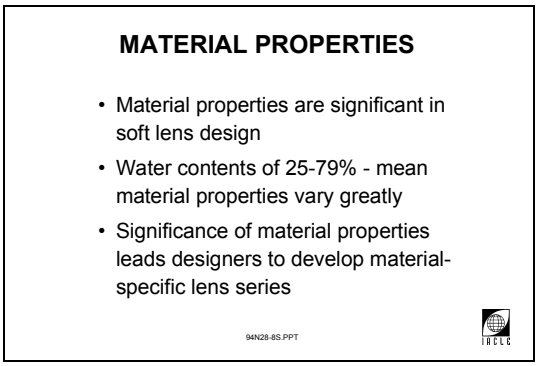
- Relationship with the eyes.

  The parameters of a contact lens should closely match the dimensions of the ocular surface, e.g.:

  - corneal topography compared with back surface radii and lens design
  - HVID, or other corneal size measure, compared with total lens diameter.

III.A Material Properties

8



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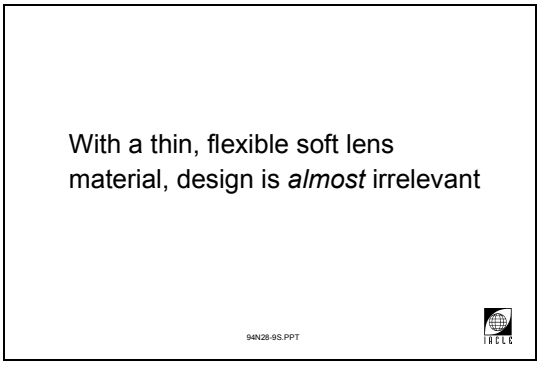
Material Properties

- Material properties are very significant in soft lens design which is not necessarily the case with RGPs.

  While some RGP physical properties such as rigidity influence the minimum thickness of a lens for an astigmatic cornea, they are not significant in the wider context, especially with regard to lens fit. On the other hand, material properties of a soft lens have a significant effect on fitting behaviour, comfort, durability, etc.
- Water contents of 25 - 79% means material properties vary greatly and a lens series needs to be designed with the relevant properties in mind.
- Significance of material properties often leads lens designers to develop *material-specific* lens series.

While general concepts can be carried across to a range of materials, the specifics of a particular material must be used when designing a series utilizing it.

9



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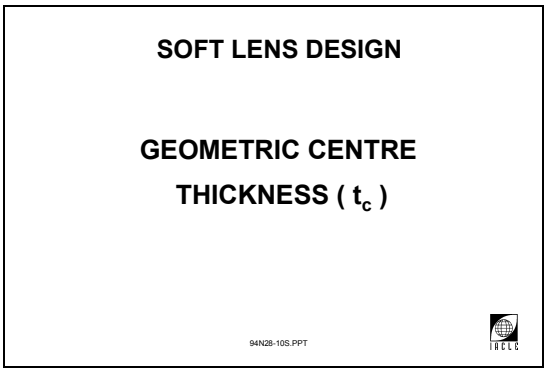
With a Thin Flexible Soft Lens Material, Design is *Almost* Irrelevant

Because of the conformance possible with a flexible material, especially with thin lenses, lens design becomes much less significant because anterior eye shape largely dictates final on-eye lens shape. The physical properties of such lenses cannot resist the external forces applied to them, especially lid forces.

III.B Centre Thickness

10



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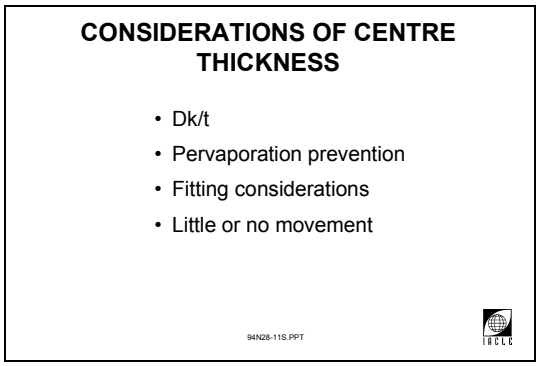
Soft Lens Design: Geometric Centre Thickness

Once the material is selected, soft lens design proper *begins* with lens thickness, especially geometric centre thickness (t_c).

11



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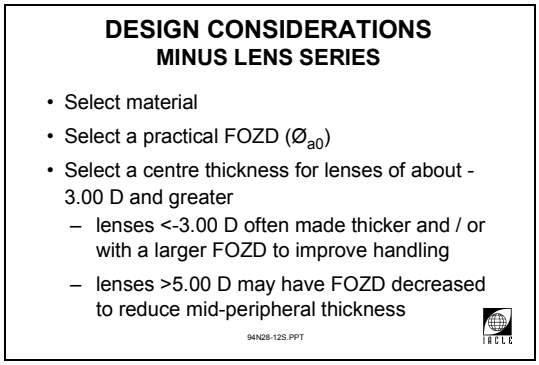
Centre Thickness Considerations

- Dk/*t* considerations
  The cornea's O_2 requirements must be met under the conditions of intended lens usage, e.g. daily wear (DW), flexible wear (FW), or extended wear (EW).
- Pervaporation prevention
  If a high water material is used in a thin lens design, pervaporation corneal desiccation may result.

  Fitting considerations. If the lens is too thin there may be excessive flexing, and it may not remain on the cornea.

  If the lens is too thin but remains on the cornea, it may move little or not at all because of conformity.
- This decreases dispersal of metabolic waste and discarded epithelial cells from under the lens. Overall lens performance and acceptability suffer. The lens may not be tolerated in the longer term.

12



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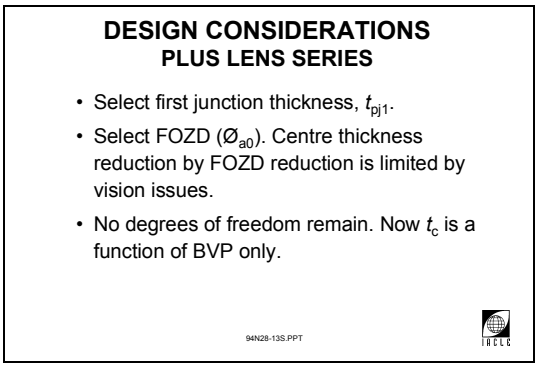
Design Considerations: Minus Lens Series

- Select material
- Select a practical FOZD ($\varnothing_{a0}$). While a large FOZD is desirable, other limitations apply and may need to be considered, especially in high plus and minus Rxs. For example, a designer may choose to reduce FOZD from 8.00 to 7.75 or even 7.5 mm for BVPs of +5.00/-6.00D and higher, in the interests of centre thickness and first peripheral junctional thickness respectively.
- Select centre thickness for lenses of about –3.00 D and greater.
  - for minus lenses in the range 3.00 to 6.00 D, the lens series can be defined by a constant centre thickness
  - above –6.00 a small reduction may be possible. However, this is done infrequently.

- Note:
  - lenses of lower minus power (<2.00D) are often made thicker and/or with a larger FOZD to improve handling
  - While higher powered lenses may have FOZD decreased to reduce mid-peripheral thickness (see above), such a decrease is limited by vision issues. The latter may be governed by pupil size under conditions of reduced illumination.

13



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Design Considerations: Plus Lens Series

- Select a practical first junction thickness, t_{pj1} . While zero/near zero will give the thinnest geometric centre thickness, these figures are not practical. Nor do they result in a durable product.
- Manufacturing difficulties may also influence the choice since there are limitations on the thinness and the profile of the first front junction at the edge of the optic zone. This junction cannot be the sharp simple intersection of two curves. A blend of these two curves must be created.
- Select FOZD ($\varnothing_{a0}$). Centre thickness reduction by FOZD reduction is limited by vision issues. Significant FOZD reductions will not be tolerated by most wearers except those with small pupils. For a stock lens company catering for the 'average' wearer, this presents a special difficulty.
- No degrees of freedom remain. Now t_c is a function of BVP *only* and nothing the designer can do can alter this situation.
  - for this reason, the design and physiology of plus lenses represents a challenge to contact lens designers and the CL industry.

Current difficulties/limitations may explain why plus lenses are less popular. Plus lenses are under-represented in the wearer population compared with the incidence of hyperopia in the population at large. It would seem that many practitioners view contact lenses as a myope-only vision correction option.

III.C Water Content and Thickness

14

WATER CONTENT

Low H_2O	20-40%
Medium H_2O	41-60%
High H_2O	>60%

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Water Content

Since most *low water* lenses are HEMA (water content 37.5 - 39%), this material virtually defines this category.

The *medium water* category contains most of the remaining common lens materials. Almost all material chemistries are represented in this group.

High water materials are now relatively less common. However, they were more common in the past. A limited range of material chemistries are represented in this category. They exhibit some unique advantages and disadvantages. Usually, deposit susceptibility and lower durability limit the application of the majority of materials in this group. The category is likely to remain uncommon because future materials are expected to have lower rather than higher water contents.

While the US FDA has divided materials into low and high water classes only, the high water category commencing at 50% starts too low, given that HEMA is almost 40%. This division was probably based on the desire for simplicity. However, in terms of chemistry a good case exists for 54% to be the upper limit of the low water category, if a two-category classification is required.

Water contents of current materials range from 25% - 79%.

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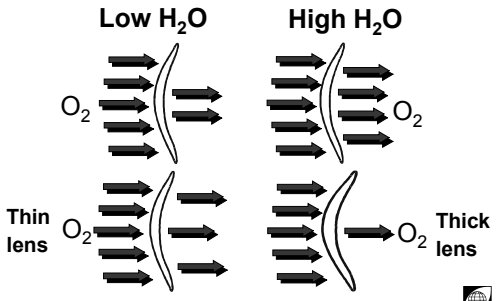

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Diagrams Representing the O_2 Performance of Low/High Water and Thick/Thin Lenses.

The number of arrows to the right of the lens profile is intended to convey a qualitative measure of the O_2 availability under the lens. However, too literal an interpretation of this diagram may be misleading.

16

TRANSMISSIBILITY (Dk/*t*)

- Dk ∝ H_2O content
- O_2 and CO_2 transmissibilities ∝ $\frac{1}{t}$
- Therefore, corneal respiration is best served by a thin high water lens. However, pervaporation can then occur

94N28-16S.PPT

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Transmissibility (Dk/*t*)

The oxygen permeability is proportional to the water content, i.e. Dk ∝ H_2O content. As a first-order approximation, the relationship is direct (linear).

The thicker a lens is, the lower are its O_2 & CO_2 transmissibilities,i.e.

Transmissibility $_{(O_2 \& CO_2)} \propto \frac{1}{t}$ and $= \frac{DK_{(O_2 \& CO_2)}}{t}$

Therefore, corneal respiration is best served by a thin, high water lens, however this sor tof lens is also subject to pervaporation

17

PERVAPORATION

If lens too thin, corneal dehydration may result

- Due to bulk flow of water through lens and instability of water flow at surface
- Subject to individual variation
- Worse with higher water content
- Results in corneal dehydration from water loss to air via lens
- Dehydration produces epithelial desiccation staining - pervaporation staining

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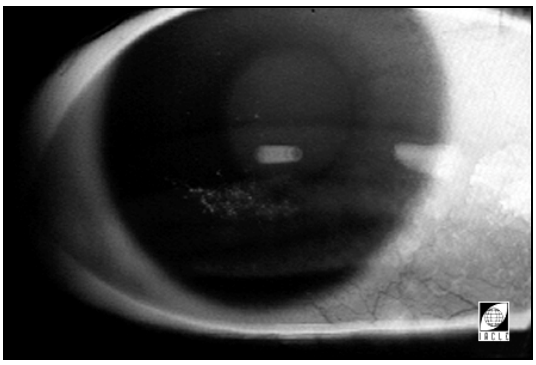

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Pervaporation

- If the lens is too thin, corneal dehydration may result due to bulk flow of water through lens and instability of water flow at the lens surface (Fatt, 1989). This dehydration:
  - is subject to individual variation
  - is worse with higher water contents
  - results in corneal dehydration from water loss to air via lens
  - produces epithelial desiccation staining – this is sometimes called pervaporation staining.

Water lost to the atmosphere from the anterior lens surface is replaced with water from the back of the lens. This in turn taps the supply in the tears. When this source is exhausted, water is extracted from the cornea and pervaporation-induced desiccation staining of the superficial epithelium can be demonstrated objectively (see slide 18).

19

HIGH WATER CONTENT LENSES

- Lose more water than low water lenses (% of total) on eye
- Lose water even when worn in a high-humidity environment
- Experience on-eye lens shrinkage which affects TD and BOZR. These affect fit and need to be taken into account

94N28-18S.PPT

2L494N28-18

High Water Content Lenses:

- Lose more water than low water lenses (% of total) on eye.

Either in absolute terms or when expressed as a percentage of its total lens mass, a high water lens loses more water.

- Lose water even when worn in a high-humidity environment.

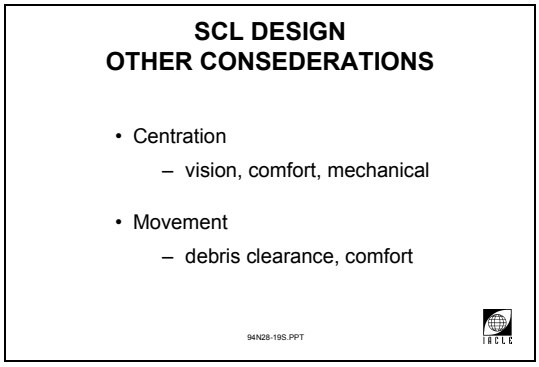
It has been demonstrated that, even in a high-humidity atmosphere, high water lenses lose water when on the eye. This is probably due to the higher ‘on-eye’ temperature and possibly other eye environment factors such as pH and tonicity.

- Experience ‘on-eye’ lens shrinkage which affects TD and BOZR. These affect fit and need to be taken into account.

To maintain the desired fitting relationship, any ‘on-eye’ shrinkage must be taken into account when selecting trial lenses or ordering final lens parameters. A trial fitting is the best determinant.

III.D Other Design Considerations

20



2L494N28-19

SCL Design

Other Considerations:

- Centration.

  Quality of vision, comfort and mechanical effects of a lens on the eye, depend to some extent on centration. A decentred lens, especially in a higher Rx, can adversely affect the quality of vision. If a lens is significantly decentred, most especially if corneal exposure becomes a possibility, wearer comfort can be a problem. Decentration can also lead to localised elevated bearing pressures, conjunctival indentation and even an altered fit. All may reduce lens acceptability.

  The amount of decentration may also increase with lens age due to increased lid traction caused by progressive lens spoilage.

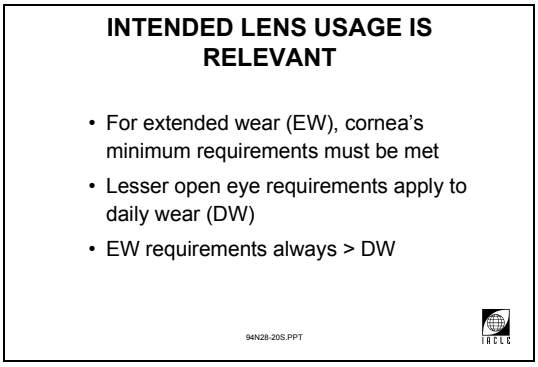
- Movement.

  A minimum amount of movement is required for all soft contact lenses. A principal reason for this is debris removal from under the lens. Such debris includes sloughed-off epithelial cells (corneal and conjunctival), tear components and airborne matter. Tear mixing (oxygen exchange), which has been demonstrated to be minimal, is not a pressing reason for lens movement *per se* to be pursued.

  While too little or no movement is prejudicial to lens tolerance and wearer success in the medium to long term, excess movement usually results in immediate lens awareness/discomfort. As long as the excess movement persists, this awareness/discomfort seldom abates.

IV Physiological Considerations

21



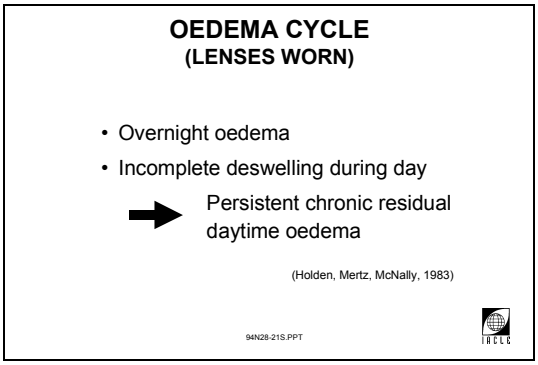
2L494N28-20

Intended Lens Usage is Relevant

Why?

- If extended wear (EW) is envisaged, the cornea's minimum requirements during eye closure must be met. This appears to be impossible with current hydrogel materials and lens designs.
- Lesser open-eye requirements apply to daily wear (DW). Where possible, it is prudent to deliver the best possible physiological environment under a lens rather than the minimum suggested by current thinking on DW requirements. If an EW lens is practical for daily wear, then it represents a better alternative than a minimalist approach.
- EW requirements always > DW because of, among other things, the significantly reduced O_2 availability in the closed eye (at sea level, 55 mm *versus* 155 mm partial O_2 pressures).

22



2L494N28-21

Oedema Cycle

- Overnight oedema.

  Corneal oedema results from prolonged eye closure and the chronic reduction of O_2 availability under closed lids during sleep. Under these circumstances, especially if a contact lens is worn, the overall corneal thickness increases. This is largely due to water imbibition and the reduced capacity of the endothelial pump to maintain corneal deturgescence. This corneal swelling is somewhat less at the limbus because of physical limitations imparted by the anatomical 'clamping' of its periphery (Bonanno & Polse, 1985). The poorer the physiological performance of a lens worn during sleep, the greater the increase in corneal thickness.

- Incomplete deswelling.

  Once a certain level of overnight swelling is exceeded, the cornea is incapable of thinning itself sufficiently during the day to return its thickness to baseline levels while wearing the contact lens. The incompletely thinned cornea then exhibits an apparent residual daytime level of corneal oedema. This is a quantitative measure of the corneal deprivation induced by the lens.

23

Overnight lens wear
→ corneal oedema
• Less O_2 available
• Dependent on Dk/*t*
On eye opening
→ corneal deswelling
• More O_2 available
– hydrogel 8% (Dk/*t*)
– RGP 10-11%
– (Dk/t and tear pump)

94N28-22S.PPT

2L494N28-22

Overnight Lens Wear

- Corneal oedema.

  Oedema depends largely on O_2 availability. Overnight, during eye closure/sleep, O_2 availability is at its lowest. The O_2 transmissibility of the lens indicates the magnitude of the negative contribution the lens makes to the condition the cornea is exposed to during eye closure.

- On eye opening.

  Upon eye opening, the partial pressure of O_2 nearly triples. The level of hypoxia is reduced and corneal function endeavours to return to normal levels. The endothelial pump increases its fluid removal rate and the cornea thins. In soft lenses, the oxygenation is almost totally dependent on the Dk/*t* of the lens, whereas with RGPs, the oxygenation is aided by an effective tear pump in addition to Dk/*t* considerations.

24

PREVENTING OEDEMA

How much O_2 is needed?

9.9% for DW lenses (Dk/*t* = 24)

17.9% for EW lenses (Dk/*t* = 87)

(Holden, Mertz, 1984)

94N28-23S.PPT

2L494N29-23

Preventing Oedema

Criteria derived by Holden & Mertz (1984) suggest the critical oxygen transmissibility and EOP values required for daily and extended contact lens wear.

They found an *equivalent oxygen percentage* (EOP) of 9.9% or a Dk/*t* of 24.1 was required for DW.

EW has a much greater requirement (17.9% O_2 or a Dk/*t* of 87).

These figures (DW and EW) are difficult to meet with present materials and manufacturing technology. In view of these difficulties, a compromise based on the level of overnight swelling which can be reversed on awakening while lens wear continued, was also presented. A Dk/*t* of 34.3, or an EOP of 12.1%, was suggested.

Since the H-M (1984) criteria were published, the use of correction factors in the polarographic technique and the introduction of the coulometric method of Dk determination, has resulted in significant changes (downwards) being made in accepted Dk values for all materials (e.g. HEMA was approximately 7.9 - 8.5 Dk/*t* units*, now 3.8 - 4.5 Dk/*t* units). Although Fatt (1989) expressed reservations about the use of the coulometric method for determining the Dk of hydrogels, further research has overcome the remaining difficulties and the technique is now accepted widely.

It is probable that the EOP values are more realistic since they are relative values. However, Holden & Mertz used data from Hill's comparisons of Dk/*t* and EOP to derive their EOP data.

The critical oxygen issue is still the subject of research and it seems likely that even more stringent criteria may eventuate.

* Dk/*t* units:
$(\text{cm} \times \text{mL}_{[O2]})/(\text{sec} \times \text{mL}_{[\text{lens}]} \times \text{mmHg}) \times 10^{-9}$

25

TO ACHIEVE ZERO DAYTIME OEDEMA

H_2O Content	DW	EW	Compromise EW
38%	0.033	0.009	0.023
75%	0.166	0.046	0.117

94N28-24S.PPT

2L494N28-24

Lens Thicknesses to Prevent Oedema

The following average lens thicknesses are from the original publication by Holden-Mertz (1984). It is likely that they will change following further research into Dk measuring techniques.

Daily wear:

- 38% water lenses: 0.033 mm.
- 75% water lenses: 0.166 mm.

Extended Wear:

- 38% water lenses: 0.009 mm.
- 75% water lenses: 0.046 mm.

Compromise figures for Extended Wear:

- 38% water lenses: 0.023 mm.
- 75% water lenses: 0.117 mm.

While these thicknesses are physiologically desirable they are impractical because of manufacturing and wearing difficulties.

26

HYDROGEL LENSES

All lenses currently available cause >8% overnight oedema

→ chronic hypoxia

Intermittent extended wear

(1-2 nights per week is maximum advisable)

94N28-25S.PPT

2L494N28-25

Hydrogel Lenses

On average, all current soft lenses cause more than 8% O/N oedema which the cornea is unable to eliminate completely during the open-eye phase. The residual is a measure of the level of chronic hypoxia produced by these lenses.

Conservatively, EW should not be recommended or prescribed if it can be avoided. If not, a 1-2 nights per week schedule at most should be advised, along with a recommendation for regular aftercare visits.

27

LIMITATIONS OF CENTRE THICKNESS IN TRANSMISSIBILITY CONSIDERATIONS

Limitations:

- t_c for minus lenses overestimates Dk/*t*
- t_c in plus lenses underestimates Dk/*t*
- Best estimate is average thickness

94N28-26S.PPT

2L494N28-26

Limitations of Centre Thickness When Considering Transmissibility

Limitations:

- Centre thickness for minus lenses overestimates their transmissibility, since the rest of the optical zone is thicker than the centre. In the case of higher powered lenses the differences can be quite marked.
- Centre thickness in plus lenses underestimates the transmissibility, since the centre is the thickest part of the lens.
- Some researchers advocate the 'average' lens thickness should be used as a more realistic indication of overall physiological performance.
- Some advocate the 'average' of the central 6 mm (for minus lenses) as being a fair indication of performance while others suggest the central 10 - 12 mm of the lens.
- The most rigorous approach suggests the thickest point on the lens should be used for Dk/*t*. This approach presents a 'worst case scenario'.

28

TEAR MIXING

Studies have shown:

- little tear mixing under soft lenses
- corneal swelling at any point is related to Dk/t_{local}, hence local thickness is the only relevant dimension

94N28-27S.PPT

2L494N28-27

Tear Mixing

Studies have shown:

- Little tear mixing under soft lenses.

  It has been shown by experiment and clinical observation that there is little useful tear mixing under a soft contact lens. This means that oxygenated tears do not find their way to areas of lower oxygenation, hence there is little compensation for any local hypoxia.

- Corneal swelling at any point is related to Dk/t_{local} because of the lack of tear mixing under a soft lens. Hence local thickness is the ONLY relevant lens dimension.

29

REASONS FOR POOR TEAR MIXING UNDER A SOFT LENS

- Conformance of lens to eye
- Lens thickness and profile
- Material properties
- Lack of lens movement

94N28-28S.PPT

2L494N2828

Reasons For Poor Tear Mixing Under a Soft Lens

Reasons for poor tear mixing under soft lenses include:

- Lens thickness/lens profile/BVP.

  Conformance results in a thin, approximately parallel, tear film with little aqueous phase being present. This results in a more viscous tear film, because it consists mainly of lipids and mucin. The lens profile, which is affected by lens design as well as BVP, influences local lid-induced pressures under both static (rest) and dynamic (blink) conditions.

- Material properties.

  Material rigidity is directly related to its water content. Higher water lenses conform more closely than low water lenses.

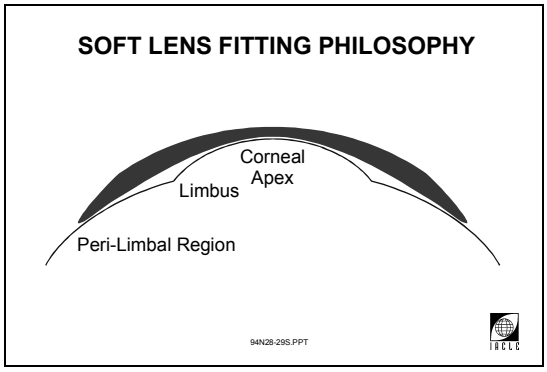
- Lack of lens movement.

  Lens movement, especially with a thin tear film containing little water, has little effect on the physiological conditions under a soft lens.

V Fitting Characteristics

V.A Fitting Characteristics - BOZR

30



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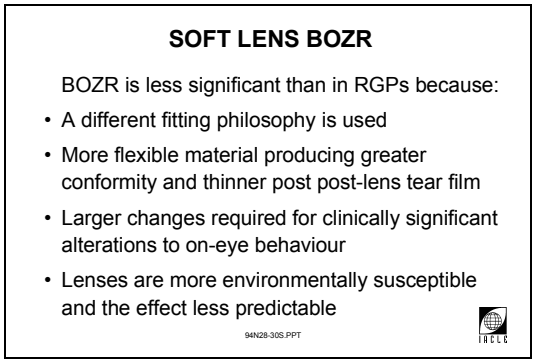
Soft Lens Fitting Philosophy

When reduced to the essentials, soft lens fitting is based on a 'three-point touch' approach. This diagram really only applies to a soft lens immediately after insertion and before the first blink. The latter will result in the lens being forced to conform more closely to the anterior eye topography.

31



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Soft Lens BOZR

BOZR is less significant than in RGPs because:

- A different fitting philosophy is used.

  In RGPs, an alignment between lens back surface and cornea is sought. In soft lenses, a 'three-point touch' philosophy is pursued. The three points are peri-limbal conjunctiva, corneal apex, peri-limbal conjunctiva.

- More flexible material results in greater conformity and a thinner post-lens tear film.

  On-eye lens shape is determined largely by anterior eye topography rather than the lens shape as manufactured. The more flexible the material, the less significant is its manufactured shape. Conformity automatically means a thin post-lens tear film. Using rigid PMMA lenses, Hayashi (1977) has calculated that during a blink the tear film compresses only slightly (calculated at about 3% of its thickness). No equivalent data for soft lenses is available. However, but it is safe to assume that the thinning is *greater* since higher bearing pressures can be developed locally (by lid margins for example). This is because the lens's flexibility means the pressure is not applied over the whole of the lens area, but can be concentrated in a relatively small area.

- Larger changes are required for clinically significant alterations to 'on-eye' behaviour.

  Largely because of this conformity, as well as the different fitting philosophies, large changes in soft lens parameters are required to produce clinically significant alterations to lens behaviour. Typically, a soft lens BOZR needs a change of 0.3 mm whereas an RGP is sensitive to a change of 0.05 - 0.1 mm.

  Soft lenses are more environmentally susceptible and the effect less predictable, e.g. pH, tear tonicity, temperature. Hydrogel lens parameters vary significantly with environmental changes.

Since most changes in the environment are not obvious, it is more difficult to predict what a soft lens will do under the generally unknown (unmeasured) conditions of the external eye.

32

SOFT LENS BOZR

- Visco-elastic forces induced on decentring aid lens self-centring
- Initial fitting relationship is lost due to conformity, osmotic equilibration, lid pressure and elastic forces induced
- Lens shape most dependent on anterior eye topography

94N28-31S.PPT

2L494N28-31

Soft Lens BOZR cont'd...

- Visco-elastic forces induced on decentring aid lens self-centring.

  Elastic potential energy imparted to the lens on decentring will tend to recentre the lens as soon as possible.
- Lens shape is most dependent on anterior eye topography.
- Once the soft lens is forced to conform to the shape of the anterior eye, the significance of all other factors is reduced. The initial fitting relationship is further lost due to osmotic equilibration, lid pressure and elastic forces induced. Over time, osmotic equilibration and regular blinking remove the lens even further from its *in vitro* characteristics.

33

MATERIAL RIGIDITY

$$\text{Rigidity} \propto (\text{thickness})^3$$

$$\text{Rigidity} \propto \text{Elastic Modulus (E)}$$

$$\text{Rigidity} \propto \frac{1}{\text{water content}}$$

94N28-32S.PPT

2L494N28-32

Material Rigidity

- Rigidity $\propto$ (thickness)^3.

  Rigidity is proportional to the cube of the thickness.
- Rigidity $\propto$ Elastic Modulus (*E*).

  Rigidity is directly proportional to the Elastic Modulus (Young's Modulus) of the lens material.
- Rigidity $\propto$ 1/water content.

  Rigidity is inversely proportional to the water content.

34

ELASTIC FORCES

- Hydrogel lenses are deformed by the lid during blinking
- Lens aligns more closely with anterior eye topography
- Visco-elastic forces are induced in the lens
- After blink, lens relaxes but process lags behind the retreat of lids
- Force to move lens $\propto \frac{1}{\text{tear film thickness}}$

94N28-33S.PPT

2L494N28-33

Elastic Forces

- Hydrogel lenses are deformed by the lid during blinking.

  Since a 'three-point touch' fit does not align with the cornea, the first blink after lens insertion will achieve, at least partially, alignment due to lid pressure.
- The lens aligns more closely with anterior eye topography.

  The pressure applied by the lids force conformance to the 'new' topography. From this shape it seeks to return to its more relaxed (lower energy state) shape.
- Visco-elastic forces are induced in the lens.

  When a lens is displaced from its central location, it rests on the flatter peri-limbal and scleral zones. Elastic potential energy is imparted to the lens when it deforms to its new shape. Its apparent diameter also increases due to the flattening.

- After the blink, the lens relaxes. However, the relaxation process lags behind the retreat of the lids.

  The soft lens does not return to its pre-blink shape immediately. Rather, the process is slower with a delayed onset. The lag is called *hysteresis* and is a physical property of the lens material.

- Force to move lens ∝ 1/tear film thickness.

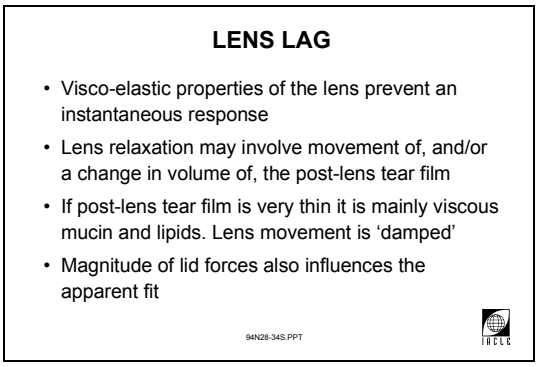
  The force required to slide a lens laterally is inversely proportional to the tear film thickness under the lens. Thin tear films found under very conforming lenses mean large forces are required to move the lens on the eye.

  Clinically, the lens is said to be 'tight' because the lack of blink-induced lens movement is interpreted as being a symptom of a lens whose sag height is excessive. If the lower lid margin is used to push up the lens, it may reveal that lens movement is quite easy to achieve and that the lens is not actually excessively 'tight'.

  Clinically, these signs are seen typically with ultra-thin low water and thin high water lenses. Thin edges reduce the lid/lens interaction even further.

  The lower lid margin push-up test is a better indicator of lens tightness when lens movement appears to be limited.

35



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Lens Lag

- Visco-elastic properties of the lens prevent an instantaneous response.

  This is a physical property of the lens material - see the discussion of hysteresis in the previous slide.

- Lens relaxation may involve movement of, and/or a change in volume of, the post-lens tear film. The tear film has its own visco-elastic properties.

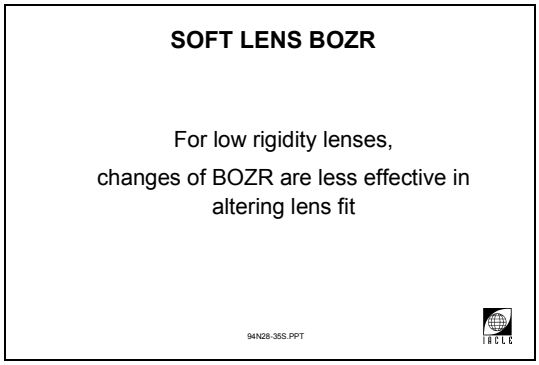
  For a deformed lens to return to a more relaxed state, tear fluid displaced previously by a blink may need to be restored. This may be difficult, since a conforming lens edge/conjunctiva combination may provide an effective seal that prevents a return flow of the tear fluid.

- If the post-lens tear film is very thin then it consists mainly of mucin and lipids, both of which are more viscous. Since the post-lens tear film is already less labile than the pre-lens tear film, any increase in tear viscosity will dampen the film's responsivity to negative pressure under the lens. This in turn dampens lens movement.

- Magnitude of lid forces also influence the apparent fit.

  'Tight' lids influence lens movement more and a qualitative estimate of this eye characteristic should be made to determine what role the lids might play in apparent lens fit. A trial fit with a lens approximating that which is to be delivered is the most valid means of accounting for this factor.

36



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Soft Lens BOZR

In lenses of low rigidity, changes of BOZR are less effective at altering apparent lens fit than in lenses of greater rigidity. Low rigidity lenses result in greater conformance to anterior eye geometry and a thin post-lens tear film. Since the actual lens shape (i.e. its *in vitro* shape) in low-rigidity materials has little influence on fitting behaviour, changing it has only a minimal effect.

V.B Fitting Characteristics - FOZR

37

FOZR

The upper lid covers more of a soft lens than an RGP lens. This influences:

- Lens resting position (static position)
- Movement induced by a blink
- Front surface design needed to optimize lens position and blink-induced movement

94N28-36S.PPT

2L494N28-36

Front Optic Zone Radius (FOZR)

The upper lid covers more of a soft lens than an RGP lens. This influences:

- The lens resting position (static position).

  Lid tonus, particularly of the upper lid, constitutes a constant force on a soft contact lens. The ramp-like edge shape of a soft lens will result in a force, approximately parallel to the eye surface, which attempts to squeeze the lens from under the lid (likened to squeezing a fresh watermelon seed between thumb and forefinger). To a lesser extent the lower lid does the same.

  The balance of these forces, in addition to forces within (visco-elastic) and around the lens (surface tension, negative squeeze pressures under etc.), will decide the resting (static) position of the lens *in situ*. Gravity plays only a small part in soft lens dynamics.

- The movement induced by a blink.

  If a lid margin positions well over a soft lens, its effect on lens movement will be less than one which covers only a little of the lens.

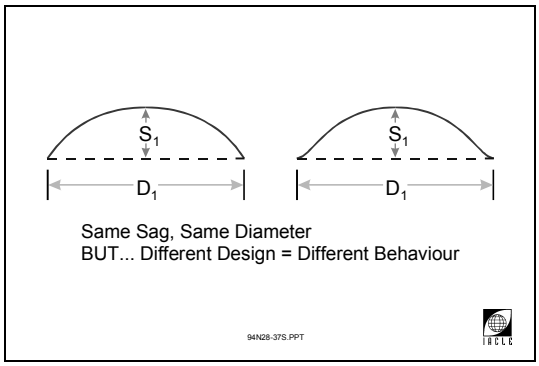
  The interaction of the lids with the actual edge is significant to lens movement and if most of the edge is already covered then the effect of lid/lens interaction is reduced accordingly.

- The front surface design needed to optimize lens position and blink-induced movement.

  By keeping the lens as thin as possible, the front surface profile as low as possible and the surface as continuous (stepless) as possible, the lid/lens interaction is reduced further.

V.C Altering Lens Fit

38



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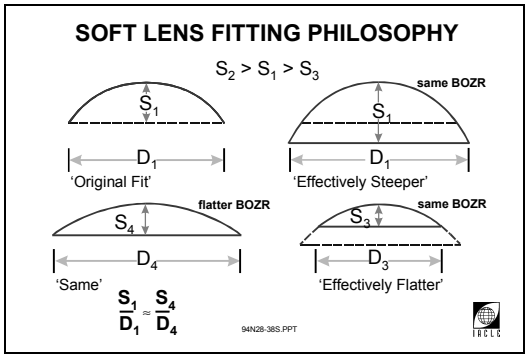
Sagittal Height

It is inappropriate to use sagittal heights in isolation without reference to the back surface design (at least) since assumptions of behaviour based only on a sagittal height value can be misleading.

Sometimes the term sagittal depth is used rather than sagittal height. There is no difference and usage is a matter of personal preference.

39



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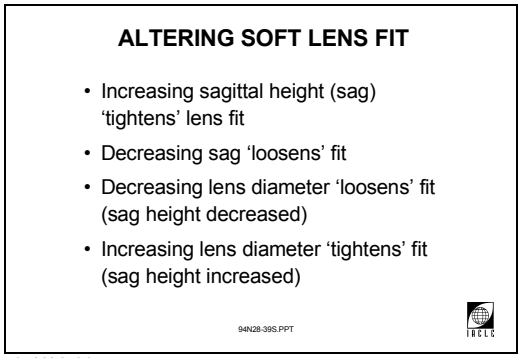
Effects of Sagittal Height and Diameter on Lens Fit

To alter the fit of a lens:

- The diameter can be left unaltered and the sag changed by altering the BOZR.
- The diameter can be altered and the BOZR changed in such a manner that the sag is left unchanged.
- Both the diameter and sag can be changed.
- By increasing the sag height independent of diameter, the fit of the lens becomes effectively *steeper* and, predictably, *tighter*.
- By decreasing the sag height independent of diameter, the fit of the lens becomes effectively *flatter* and, predictably, *looser.*

40



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VI Design Factors

VI.A Back Surface Designs

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BACK SURFACE DESIGNS

- Single curve (moncurve)
- Bicurve, second curve often 0.8-1.0 mm flatter than BOZR about 0.5-0.8 mm wide
- Blended multiple spherical curves (multicurve)
- Aspheric

94N28-41S.PPT

2L494N28-40

Back Surface Designs

- Single curve (monocurve).

  The simplest design but not commonly used.
- Bicurve, second curve often 0.8 - 1.0 mm flatter than BOZR about 0.5 - 0.8 mm wide.

  A common design because it performs satisfactorily clinically and is easy to design and make. While more elaborate designs are available, no clinical studies have demonstrated that they are superior to the simple bicurve.
- Blended multiple spherical curves (multicurve).

  Relatively uncommon and probably a legacy of RGP design thinking. Clinically, the flexibility of soft lenses and the 'three-point touch' fitting philosophy do not require complex peripheral back surfaces.
- Aspheric.

  Relatively uncommon. Surface shape may be a continuous single conic section (conicoid) or a progressive-change complex of conics. Despite the underlying mathematical complexity, the actual surface appears simple and transitionless.

42

BACK PERIPHERAL CURVES

- Presence or absence of back peripheral curves is insignificant physiologically

  (Tomlinson & Soni, 1980)
- Changes in back peripheral curves, especially radical edge lift, affect lens movement substantially

  (Tomlinson & Bibby, 1980)

94N28-42S.PPT

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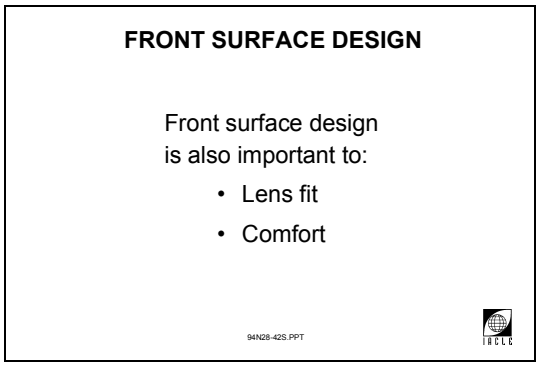
VI.B Front Surface Designs

43



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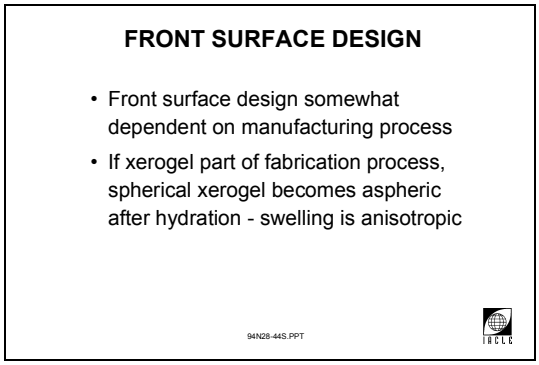
Front Surface Design

Because the front surface is not in contact with the cornea, it tends to be ignored. However, front surface design is not only important to lens fit and on-eye behaviour. It can also influence the comfort of the lens. This is especially true in cases of higher Rxs because of their greater thicknesses.

44



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Front Surface Design

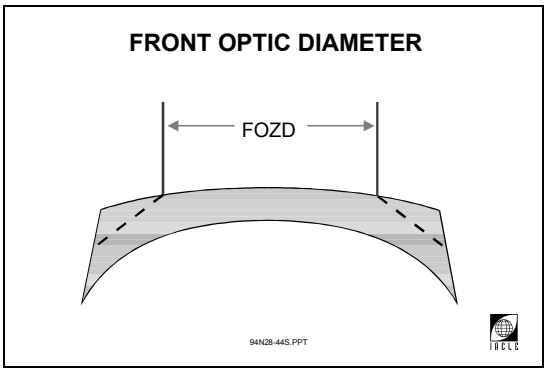
- Front surface design is somewhat dependent on manufacturing processes.

  Not all processes can create all front surface shapes, and final front surface design may need to be a compromise if the manufacturing process to be used cannot create the shape originally desired.

- If a xerogel is part of the fabrication process, a spherical xerogel becomes aspheric after hydration. This is because lens swelling is anisotropic.

  In the interests of achieving similar clinical behaviour across the power range, several design variations may need to be applied to bands of BVPs within the range of powers made. Some of the changes incorporated are needed to offset the differing effects of expansion on hydration and the asphericity resulting from hydration.

45



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Front Optic Zone Diameter (FOZD)

Usually the FOZD defines the effective optic zone diameter of a soft lens, especially when used in combination with simple back surface designs. In this diagram, the front peripheral design defines the FOZD, and therefore, the OZD of the lens.

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FRONT SURFACE DESIGNS

- Commonly bicurve, periphery chosen to → thin edge
- Intersection of FOZR and peripheral curve defines FOZD
- Multiple peripheral spherical curves
- Continuous aspheric is uncommon

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Front Surface Designs

- Commonly bicurve, with a peripheral curve chosen to produce a thin edge. In the case of a *plus* lens the peripheral curve on the front surface is *flatter* than the FOZR. A thin edge is dependent on the front and back peripheral curves converging. However, their meeting is prevented by edge design (rounding) and would, in any case, be undesirable because of the thin 'sharp' edge which would result if they did.

  This is true for both plus and minus lenses. Some designs are more complex (excluding edge blending). However, the level of complexity is often dependent on the limitations of the manufacturing process.

- Intersection of FOZR and first peripheral curve define FOZD.
  The use of a small FOZD to reduced centre thickness (plus lenses), or mid-peripheral thickness (minus lenses), is called *lenticulation.*

- Multiple blended peripheral spherical curves.

  Overly complex designs are probably not required. Blending multiple curves is again a legacy of RGP design concepts.

- Continuous aspheric front surface curves are not commonly used. Questions remain about vision quality. Such a lens becomes double aspheric after a blink (conformance to corneal shape). This is unlikely to reduce aberrations.

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FRONT SURFACE DESIGN

Front surface may also include bifocal or multifocal components such as:

- Continuous aspheric surface
- Concentric bifocal
- Flat-top segment

94N28-47S.PPT

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VI.C Edge Design

48

SOFT LENS EDGED DESIGN AND THICKNESS

- Edge positioned under both lids
- Edge has relatively little effect on comfort
- Edge design may be limited by manufacturing/patent issues
- Thickness governed by durability considerations rather than comfort /physiology concerns

94N28-48S.PPT

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Soft Lens Edge Design and Thickness

Less consideration is given to details of edge design than for RGPs because of the size of soft lenses:

- The edge is already under both lids.
- The edge has relatively little effect on comfort.

  Edge design may be limited by manufacturing/patent issues.

  – This is especially true for molded lens products since just two patents cover the methods of lens edge formation during the molding process.

- Edge thickness is governed by durability considerations rather than comfort and/or physiology concerns:

  – too thick an edge may produce discomfort

  – too thin an edge may lead to tearing of the edge. This is often considered to be more important.

VI.D Aspheric Soft Lenses

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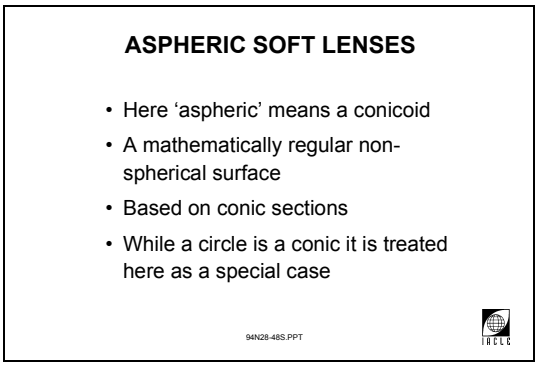

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Aspheric Soft Lenses

- Here 'aspheric' means a conicoid.
- A mathematically regular non-spherical surface/shape.
- Based on conic sections
- Symmetrical solids of rotation of conic sections.
- While a circle is a conic, it is treated here as a special case. Lenses based on a circle are described as spherical.

The description 'aspheric' is used regardless of whether the Rx is spherical or toric.

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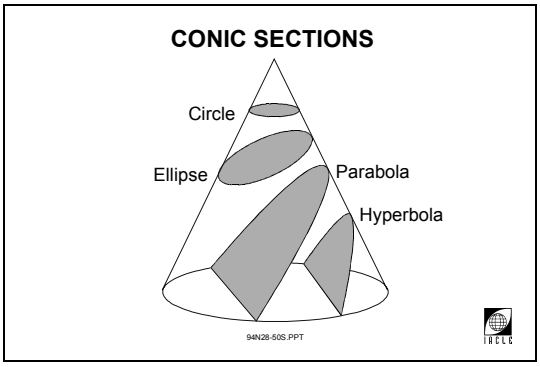

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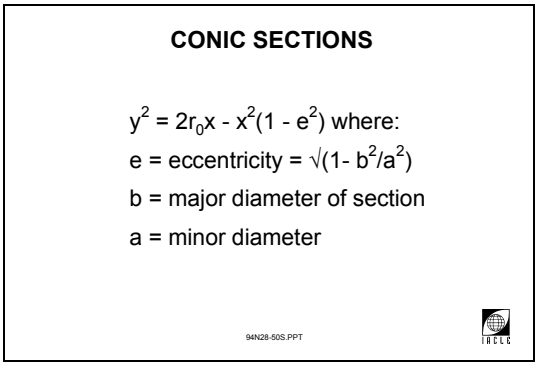

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Conic Sections

Bennett (1968) derived the general equation for a conic section, whose origin (0,0) is at its apex, from the work of Baker, 1943.

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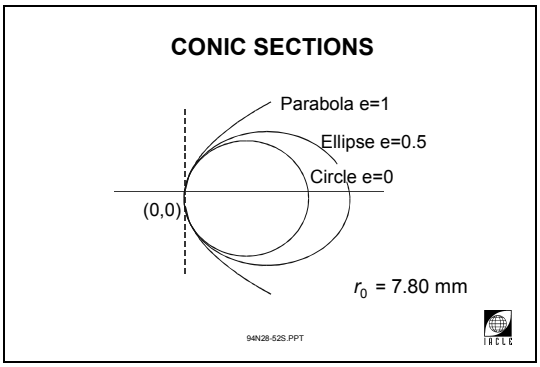

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Conic Sections

Conic sections relevant to soft contact lenses are the:

- Circle.
- Ellipse.
- Parabola.

A further conic, the hyperbola (e>1) also exists. However, it has no relevance to current soft contact lens design and is omitted in the interests of simplicity.

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ECCENTRICITY VALUES OF CONIC SECTIONS

Circle	e = 0
Ellipse	0 < e < 1.0
Parabola	e = 1.0

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Eccentricity Values of Conic Sections

The eccentricity is a description of the flattening (or steepening) rate of the lens periphery. Another factor, 'p', the shape factor, is sometimes used in contact lens or corneal shape literature. Alternatively, 'Q' can also be used.

$p = (1 - e^2)$ and $Q = -e^2 = p - 1$.

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ECCENTRICITY

- As eccentricity increases, peripheral flattening increases exponentially
- $p=(1-e^2)$, p=shape factor, an index of peripheral flattening or steepening

94N28-53S.PPT

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Eccentricity

As eccentricity increases, the rate of peripheral flattening increases exponentially. This is because:

$$p = (1 - e^2)$$

p = 'shape factor', an index of peripheral flattening or steepening
e = eccentricity.

55

WHY ASPHERIC?

- Aspherics attempt to optimize the lens/cornea relationship
- Aspherics reduce local bearing pressure due to peripheral curve/ transition zone discontinuities

94N28-54S.PPT

2L494N28-54

Why Aspheric?

- Aspherics attempt to optimise the lens/anterior eye relationship.

  By using a design that flattens in the periphery, it is possible to have a soft lens which applies a lesser and nearer-to-tangential load to the peri-limbal region of the eye. Unlike an RGP lens, an aspheric soft lens design makes little difference to the loads applied to the cornea.

  By having a design which more nearly approximates the shape of the anterior eye an aspheric soft lens is deformed less when conformance is forced by a blink. This means less elastic potential energy is imparted, recentration may be slower and the lens may move more. This last factor results from the greater displacement needed to deform the lens enough for travel to be limited by elastic forces induced in the lens.

- Aspherics reduce local bearing pressure due to peripheral curve/transition zone discontinuities.

  When the lens design uses discontinuous curves, the junctions require blending. This may result in some zonal bearing pressure differences. Continuous aspheric surfaces do not have this problem.

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FIRST ASPHERIC SOFT LENSES

(Hirst [NZ], early 1970's)

- Con-O-Coid, elliptical back surface
- 2 eccentricities offered
- Spheres and torics

94N28-55S.PPT

2L49428-55

First Aspheric Soft Lenses

Hirst of New Zealand developed this design in the early 1970s.

- Con-O-Coid, elliptical back surface.
- Two eccentricities offered.
- The designs could be incorporated into spherical and sphero-cylindrical prescriptions.
- Companion series of rigid spheres and torics (including bitorics) were developed.
- Hirst worked with Volk in NZ in the 1960s and it is reasonable to assume that Volk had some influence on Hirst's work.

57

CORNEA IS NOT SYMMETRICAL

- Asymmetry is usually not large
- Cornea is considered an ellipsoid (first-order approximation)
- Eccentricities (e) of the cornea:

  H=0.53, V=0.58 (Holden, 1970)

  Flat=0.41, Steep=0.44 (Kiely, *et al*., 1984)

  H and V=0.44 (Guillon, *et al*., 1986)

94N28-56S.PPT

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Cornea is NOT symmetrical

However:

- Asymmetry is usually not large.
- Within clinical significance, the cornea can be considered a conicoid and treated as being symmetrical.
  - First-order approximation, ellipsoid, as was anticipated by Feinbloom. However, the earliest suggestion of an aspheric shape has been attributed to Senff in 1846.
- Corneal asymmetry is not dealt with clinically.

Eccentricities (e values) of the cornea have been found to be:
H=0.53, V=0.58 (Holden, 1970)
Flat = 0.41 & Steep = 0.44 (Kiely et al, 1984)
H & V= 0.44, (Guillon et al, 1986).

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AVAILABLE ASPHERICS

- Few aspheric soft lenses are marketed
- Most have continuous aspheric back curve.
- Production easier with CNC lathes or molding

94N28-57S.PPT

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Few Aspheric Soft Lenses Are Marketed.

Virtually all have a continuous aspheric back curve. Currently, production of such surfaces is easier with computer numerical control (CNC) lathes or molding technology. However, even molding technology is now very reliant on CNC technologies since the latter is used to make the master molds from which the production molds are fabricated.

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SOFT ASPHERICS

- Aspherics require fewer back curve steps to cover range of fits
- Attractive to 'stock lens' companies

94N28-58S.PPT

2L494N28-58

Soft Aspherics

- Aspherics require fewer back curve steps to cover the range of fits required because:
  - fit of aspherics is less sensitive to changes in back curvature due to peripheral flattening
  - conformance produced by a blink deforms an aspheric soft lens less, hence greater change is required in the base curve to produce a clinically significant alteration in lens fit
  - Compared to a spherical lens, alterations in lens diameter result in smaller sagittal height changes. This is because of the peripheral flattening.
- This is attractive to 'stock lens' companies. If only two or three base curves are required to cover a wide range of fits across a broad range of BVPs, the viability of stocking such a lens series is increased.

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ASPHERIC ADVANTAGES

- Better lens/cornea-peri-limbal fitting relationship
- Fewer base curve steps required
- Lens fit less sensitive to lens diameter changes
- Increased lens movement
- Bearing pressure more uniform

94N28-60S.PPT

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ASPHERIC DISADVANTAGES

- Lens shape not optically optimal
- Adverse visual effects of decentred lens greater than with spherical lens
- Visual acuity may not be optimum
- More difficult to manufacture

94N28-61S.PPT

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Aspheric Disadvantages

- Lens shape may not be optimal optically - aberrations may be enhanced by an aspheric shape.
- Adverse visual effects of a decentred lens are greater than with a spherical lens.

  The visual axis of the eye passes through the non-spherical periphery when a lens is decentred, and vision is worse than with a spherical lens under similar circumstances.
- Visual acuity, may therefore not be optimum under general conditions of soft lens use, regardless of whether the lens is centred or not.
- More difficult to manufacture. Because an aspheric surface is not inherently self-generating, aspherics can only be fabricated by a few processes. If molding is to be used the only difficulty is master mold creation. Once this is done, production is no more difficult than a spherical, more conventional design. CNC lathes can also create the desired aspheric surface shapes but at a higher unit cost than simpler alternatives.

62

ASPHERIC DISADVANTAGES

- More expensive to manufacture
- Not as readily available
- Perceived to be more complex
- May decentre and move more than spherical design

94N28-61S.PPT

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Aspheric Disadvantages (cont'd...)

- More expensive to tool-up.

  This can be a barrier to starting aspheric manufacture (soft or RGP). With the competitive market that now exists, the commencement of aspheric lens manufacture is a significant undertaking. This is the case whether a manufacturer is established and extending a product range, or a start-up company aiming to produce an aspheric lens range.

- Not as readily available.

  Some of the reasons for this are related to manufacturing, as detailed above. Additionally, the lack of compelling clinical evidence of the superiority of aspheric soft lenses means there is less demand from prescribers and hesitancy on the part of manufacturers.

- Perceived to be more complex.

  Because they are not considered mainstream by many professionals they are assumed to be more complex or to have more disadvantages than lenses which are routinely used.

- If greater decentration and movement exhibited then more diligence at after-care may be required.

VI.E Lens Design - Limitations

63

Manufacturing process may limit lens design:

Method	Limitations
Lathing	Simple designs only
Molding-Anhydrous	Few, but anisotropic expansion on hydration changes lens shape
Molding-Wet stabilized	Almost none
Spin-casting	Only simple back surface design possible
Molding & Lathing	Lathing limitations
Spin-casting & Lathing	Lathing limitations

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VII Soft Lens Specifications

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RANGE OF SOFT LENS PARAMETERS

TD ($Ø_T$)	12.0	-	15.5 mm
BOZR (r_0)	7.6	-	9.6 mm
Centre thickness (t_c)	.035	-	0.35 mm
F_v Sph	±35 D		
Cyl	0.50	-	20 D
H_2O Content	25	-	79%
O_{ao}	6.5	-	11.5 mm
t_{ER}	0.05	-	0.25 mm

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LENS MASS

Depends on:

- Thickness
- BVP
- Water content
- Diameter

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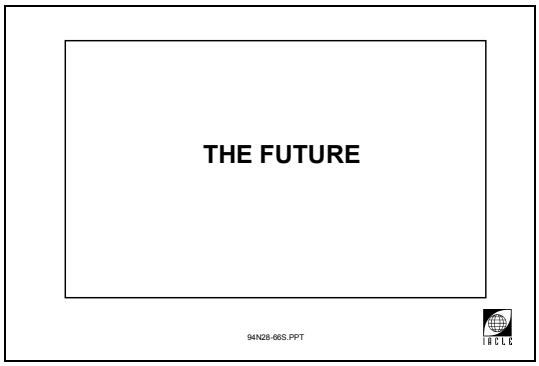
Lens Mass

Seldom considered. Within usual range of water contents the specific gravity varies little. Lens mass therefore depends largely on lens design and BVP.

Thickness is a primary concern for other, more significant reasons (Dk/*t*, comfort, etc) and is usually minimised. BVP is of course not negotiable.

VIII The Future

66



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The Future (*title slide*)

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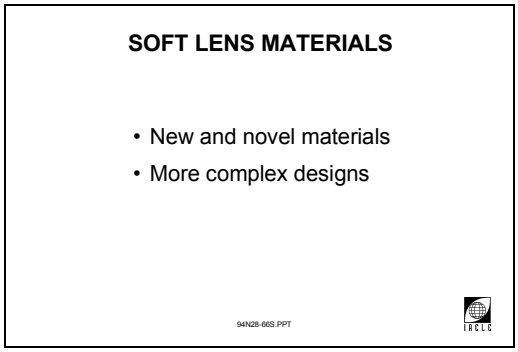

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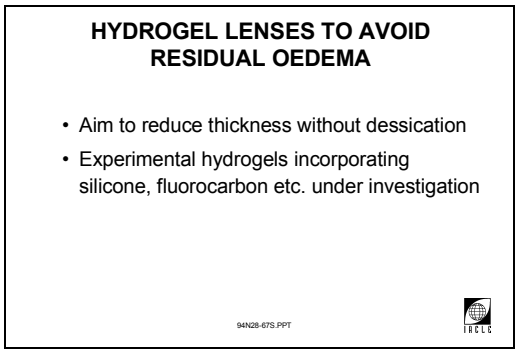
New and Novel Soft Lens Materials

In the future, it is expected that new and novel soft lens materials and designs will be introduced. Optical design is still restricted by the limited freedom available to a lens designer. An avenue which has received little attention is the concept of best-form lens designs. The major barrier to these is lens conformance to the anterior eye altering the final lens shape in an unpredictable (unmeasured) and highly individual way.

A possible innovation might be materials with differing refractive indices in different zones of the lens. Results to date have produced materials with insignificantly different indices. Grafted hybrid one-piece lenses such as the Softperm™ may also evolve with combinations of soft and softer rather than soft and rigid components being attempted.

68



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Hydrogel Lenses To Avoid Residual Oedema

The main thrust of soft lens research has been to improve the physiological performance of the hydrogel materials currently used. The main focus of such research to date has been O_2 performance.

- The aim is to reduce thickness without desiccation of the epithelium.

  Future soft lenses must utilise materials which break the nexus between high O_2 performance and pervaporation staining. Currently, a thin/high water strategy can result in pervaporation staining once a certain thinness is exceeded. The individual variations that are observed clinically make the designer's task even more difficult.

- To improve the inherent O_2 performance of soft lens materials, approaches which owe much to RGP materials research have been made. These include siloxanes, fluorocarbons and perfluoroethers. To date, they have not been successful in that no commercially viable product has been released. Manufacturing and/or wettability difficulties are the main barriers to success.

- Despite research into improving hydrogel lens physiology beyond the hypothetical limits imposed by their water content, no truly novel soft materials have been released commercially. This strongly suggests that a radically different material, perhaps not even a hydrogel, will ultimately be required before any real breakthrough is achieved.

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MEAN OCULAR SURFACE DRYING TIME (SECS)

(Guillon & Guillon, 1990)

Normal eye	25
Soft lens	7
Rigid lens	4

94N28-69S.PPT

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Mean Ocular Surface Drying Time

Guillon, Guillon, (1990), have demonstrated significant differences between drying times of normal eyes and contact lens-wearing eyes. It is believed that these differences will need to be reduced for contact lenses to be problem and symptom-free under normal circumstances.

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LENS SURFACE MODIFICATION

- Make more wettable
- Mimic nature (epithelium/tears)
- Durability of modified surface must match expected lens life

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Lens Surface Modification

One possible way of reducing the tear film disturbance caused by contact lenses is to modify the lens surface characteristics. Such modifications may include:

- Make the lens more wettable.

  It is believed that by making the lens surface more wettable, both the biocompatibility and the comfort will be improved.

- Mimic nature (epithelium/tears).

  It is felt that any surface modification needs to imitate nature, i.e. mimic either the tears or the epithelium so that its compatibility with the eye is assured.

  Durability of modified surface must match expected lens life.

  Any modification of the lens surface must be durable enough to last the life of the lens regardless of how long or short it may be. A failure of the surface will lead to discomfort and incompatibility. Disturbances to vision are also possible.

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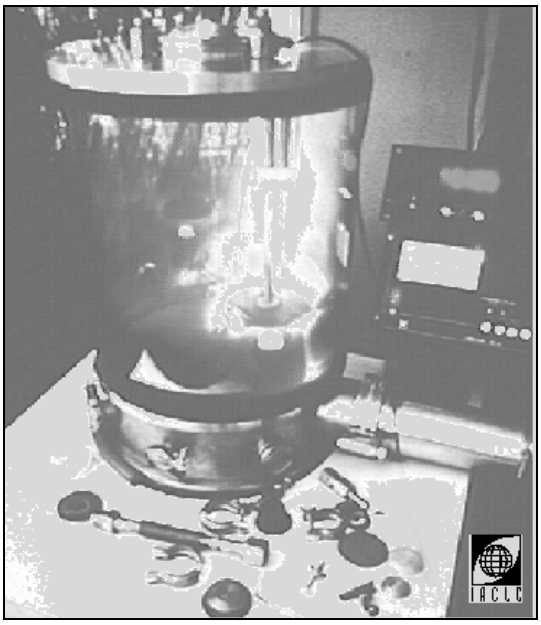

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Gas Plasma Coating Machine

One well-established method of surface modification is to use a plasma discharge technique to modify the surface chemistry or even coat the surface by introducing other chemical species during the process.

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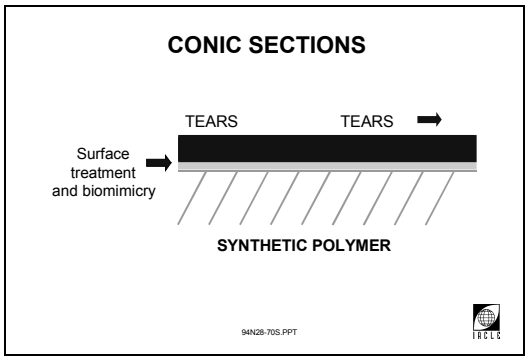

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Diagram of Modified Surface Layers

This diagram shows a modified surface acting as an intermediary between tears and a polymer whose properties may not be ideally suited to contact lens usage.

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The Perfect Lens Design/Material Combination Has Yet to be Created

While a marketing opportunity and/or the technical challenge exists, research into improvements to lens design and materials will be pursued. While perfection is probably unrealizable, significant opportunities to improve the products we currently use still exist.

Tutorial 2.4

(1 Hour)

Soft Contact Lens Design

Quiz

Name:_____ **Date:**_____

1. **Discuss briefly the design considerations for minus lenses.**

_____

_____

_____

_____

_____

2. **Discuss briefly the design considerations for plus lenses.**

_____

_____

_____

_____

_____

3. **What is pervaporation of a soft contact lens?**

_____

_____

_____

_____

_____

4. Give a brief description of the effect of elastic forces on soft contact lens fitting.

_____

_____

_____

_____

_____

5. Overall thickness of a soft contact lens is a major consideration in its design. Why?

_____

_____

_____

_____

_____

References

Baker TY (1943). *Ray tracing through non-spherical surfaces.* P Phys Soc Lond. 55: 361 - 364.

Bennett AG (1968). *Aspherical contact lens surfaces. Part I.* Ophthalmic Optician. 8: 1037 - 1040.

Bennett AG (1968). *Aspherical contact lens surfaces. Part II.* Ophthalmic Optician. 8: 1297 - 1301.

Bennett AG (1969). *Aspherical contact lens surfaces. Part III.* Ophthalmic Optician. 9: 222 - 230.

Bier N, Lowther G (1977). *Contact Lens Correction.* Butterworths, London.

Bonanno JA, Polse KA (1985). *Central and peripheral corneal swelling accompanying soft lens extended wear.* Am J Optom Physl Opt. 62: 74 - 81.

Fatt I (1989). *A predictive model for dehydration of a hydrogel contact lens in the eye.* J Br Contact Lens Assoc. 12: 15 - 31.

Fatt I (1989). *Comparison of the single-chamber polarographic and the coulometric carrier gas procedures for measuring oxygen permeability.* ICLC. 16: 226 - 231.

Holden BA *et al.* (1990). *The Dk project: an interlaboratory comparison of Dk/L measurements.* Optometry Vis Sci. 67: 476 - 481.

Holden BA, Mertz GW (1984). *Critical oxygen levels to avoid corneal edema for daily and extended wear contact lenses.* Invest Ophth Vis Sci. 25: 1161 - 1167.

Lowther GE, Snyder C (1992). *Contact Lenses: Procedures and Techniques.* 2nd ed. Butterworth-Heinemann, Boston.

Mandell RB (1988). *Contact Lens Practice.* 4th ed. Charles C. Thomas Publisher, Springfield.

Phillips AJ, Stone J. (Eds.) (1989). *Contact Lenses.* 3rd ed. Butterworths, London.

Ruben M, Guillon M (1994). *Contact Lens Practice.* Chapman & Hall Medical, London.

Senff R (1846) quoted in: von Helmholtz H (1962). *Treatise on Physiological Optics.* Reprinted by Dover Publications, London.

Tomlinson A, Bibby MM (1980). *Movement and rotation of soft contact lenses. Effect of fit and lens design.* Am J Opt Physl Opt. 57: 275 - 279.

Tomlinson A, Soni SP (1980). *Peripheral curve design and the tear pump mechanism of soft contact lenses.* Am J Optom Physl Opt. 57: 356 - 359.

Unit 2.5

(2 Hours)

Lecture 2.5: Rigid Gas Permeable Contact Lens Design

Tutorial 2.5: RGP Contact Lens Design

Course Overview

Lecture 2.5: Rigid Gas Permeable Contact Lens Design

I. Terminology Relating to Rigid Gas Permeable Contact Lens Parameters
II. Lens Designs
III. Lens Specification for Rigid Gas Permeable Contact Lenses
IV. Lens Requirements
V. Optional Lens Features

Tutorial 2.5: RGP Contact Lens Design

- Quiz

Lecture 2.5

(1 Hour)

Rigid Gas Permeable Contact Lens Design

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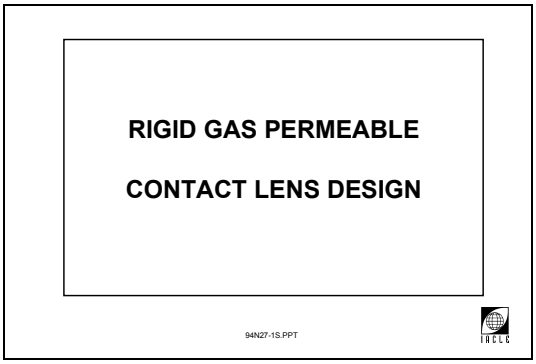
XI Present and Future of RGP Lens Design 229

I Rigid Gas Permeable Lens Design

1



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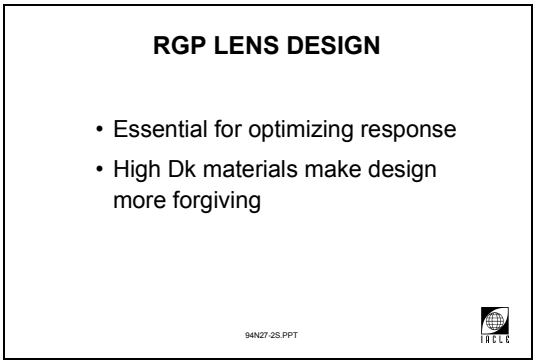

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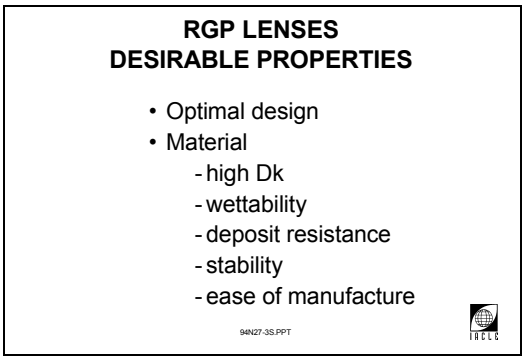
Does Design Matter?

Design issues can never be ignored because design can be used to optimize the ocular response both on an individual basis and for the population at large. However, as RGP material technology has advanced, RGP materials are now much more forgiving in terms of the precision and finesse of fit required. This is due partially to the generally lower rigidity of modern RGP lens materials.

3



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Desirable Properties

The desirable properties of an RGP lens are:

- Optimal design.

  Design is the cornerstone of any contact lens fitting. As materials have improved, the demands on the prescriber have lessened. However they almost certainly will never be eliminated, even when topography measuring systems are interfaced to design and manufacturing systems.

- Material.
  - Dk. The minimum requirements for daily wear (DW) and extended wear (EW) can be met by some RGP materials.
  - Wettability. For both optical regularity and lubricity reasons, a wettable material which will retain a regular tear film is essential for satisfactory ongoing RGP lens wear.
  - Deposit resistance. A deposited lens is not only potentially uncomfortable but the wettability and the regularity of the pre-lens tear film may also be adversely affected.
  - Stability. In the interests of maintaining the parameters of the lens, and therefore lens behaviour, the lens material must be stable. This enables it to resist changes to its chemistry and properties over time, regardless of its environment or treatment.

– Ease of manufacture.
Manufacturing difficulties with a particular material can be a barrier to its usage. If special handling or treatment is required, laboratories may resist using it.
Alternatively, if the material is treated conventionally, an unreliable product may result.

4

DESIRED FITTING

- Moderate edge width and clearance
- Central and mid-peripheral alignment
- Smooth movement
- Centration

94N27-4S.PPT

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Desired Fitting

- Moderate edge width and clearance. A balance needs to be struck between the volume of the tear fluid reservoir at the lens edge and the edge 'stand-off' which can adversely affect comfort.
- Central and mid-peripheral alignment. In general, modern RGP fitting philosophies are based on alignment with the cornea.
- Smooth movement. Lens movement is essential to disperse metabolic and cellular wastes from under the lens. Excess movement can create visual and comfort disturbances. A balance of factors affected by movement will help define the optimal movement characteristics of a fitting.
- Adequate centration. A decentred lens can cause visual anomalies particularly during lowered illumination. Comfort may also be compromised. Since movement is required, this movement should be symmetrical about a central location.

5

DESIRED PERFORMANCE

- Comfortable
- Clear vision
- Adequate wearing time
- Minimal ocular response
- Normal facial appearance

94N27-5S.PPT

2L594N27-5

Desired Performance

A properly performing lens should:

- Be comfortable.
- Provide clear vision which is equal to or better than the vision provided by spectacle lenses.
- Enable adequate wearing time. Patient should be able to wear the lenses during waking hours - an acceptable time is approximately 8-14 hours per day.
- Provoke minimal ocular response - lenses usually affect ocular function but the affect should not be clinically detectable.
- Not affect head posture or ocular appearance such as narrowing of the palpebral aperture or blepharospasm.

6

KEY DESIGN FEATURES

- Back surface design
- Back optic zone diameter
- Front surface design
- Lens thickness
- Edge configuration
- Lens diameter

94N27-6S.PPT

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7

LENS PARAMETERS

ISO TERMINOLOGY

94N27-7S.PPT

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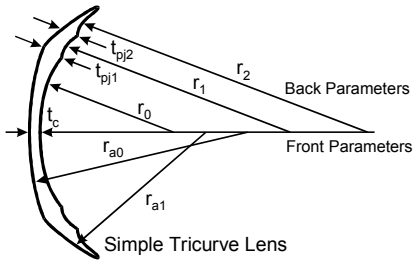
International Organization for Standardization (ISO) terminology is used throughout this lecture.

8

LENS PARAMETERS



94N27-8S.PPT

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Lens Parameters: Front and Back Radii and Thicknesses

Simple Tricurve Lens

The lens parameters, their standardized names and their standardized symbols are included in this diagram.

r_0 = Back Optic Zone Radius

r_1 = Back Peripheral Radius (First)

r_2 = Back Peripheral Radius (Second)

r_{a0} = Front Optic Zone Radius

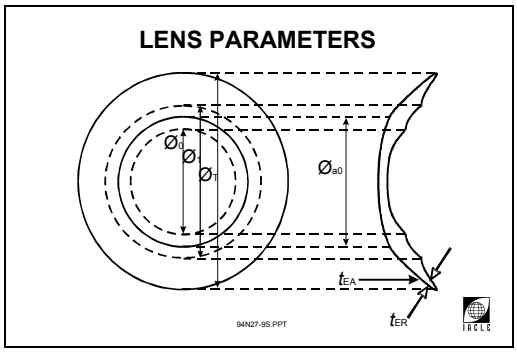
r_{a1} = Front Peripheral Radius (First)

t_c = Geometric Centre Thickness

$t_{p|1}$ = Peripheral Junction Thickness (First)

$t_{p|2}$ = Peripheral Junction Thickness (Second)

9



2L596220-9

Lens Parameters: Diameters and Edge Thicknesses

This diagram shows the relevant diameters along with the two types of edge thickness defined in the ISO standard.

$\varnothing_0$ = Back Optic Zone Diameter

$\varnothing_{o0}$ = Front Optic Zone Diameter

$\varnothing_1$ = Back Peripheral Zone Diameter

$\varnothing_T$ = Total Diameter

t_{ER} = Radial Edge Thickness

t_{EA} = Axial Edge Thickness

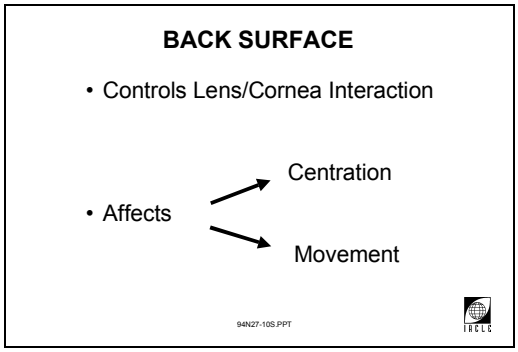
Miscellaneous (not shown on slide)

F_v' = Back Vertex Power

F_v = Front Vertex Power

II Back Surface Design

10

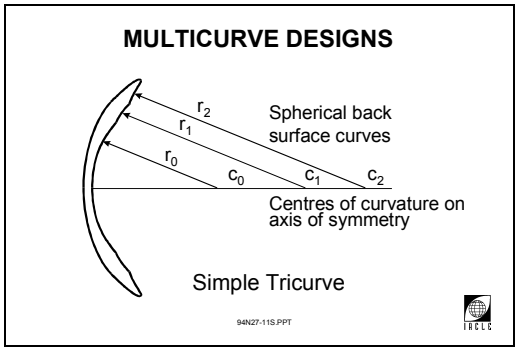


2L594N27-10

The Back Surface

- Back surface design (shape) is the major factor in controlling the lens/cornea interaction. This interaction largely controls the clinical behaviour of a lens which is usually described as the 'fit'.
- This lens/cornea interaction affects the centration of the lens as well as lens movement. Since lens 'fit' is more than just the result of a lens being steeper, flatter or aligned with the cornea, the back surface design outside the back central optic zone is also relevant to final lens behaviour.

11



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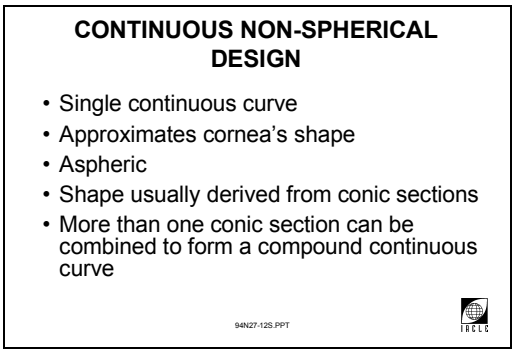
Multicurve Design

This diagram illustrates a series of spherical (i.e. shapes based on a circle) back curves which will ultimately be blended to form a smooth continuous curve. Importantly, because spherical surfaces are the result of the use of a conventional lathe, the centres of curvature of each of these spherical curves lies on the axis of symmetry of the lens (which is also the optic axis of such a lens).

12



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Continuous Non-Spherical Design

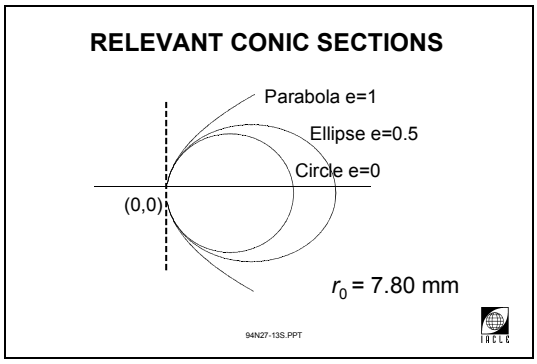
Surface designs (front or back) don't have to be limited to designs based on a circle. The concept of the cornea not being spherical has been accepted for more than a century (Senff, 1846).

The attraction of a continuous single curve which more nearly approximates the cornea's actual shape is obvious. Such surface designs are referred to as 'aspheric' and represent a deliberate attempt to improve on designs which are 'spherical'. (The term 'spheric' is not normally used but is still correct.)

The family of curves from which such surface shapes can be derived, which also includes a first-order approximation to the shape of the cornea, is called *conic sections*.

Conic sections can be combined to form compound continuous curves. Combinations of conic and non-conic sections have also been used. The advent of computers and computer-aided manufacturing means that very complex continuous curves are possible.

13



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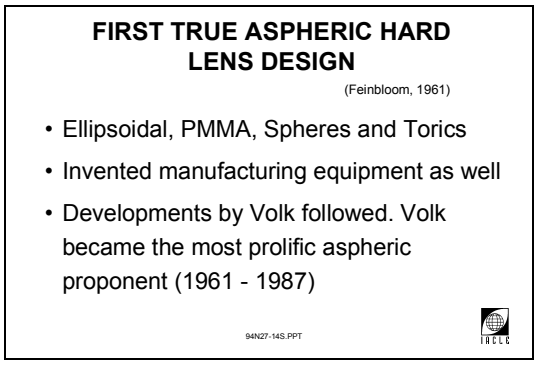
Conic Sections

This diagram shows all conic sections. In this series the circle is considered a special case. The hyperbola has been rarely used in RGP or PMMA lenses and it is believed that no current lens designs incorporate such a shape. The solid formed by the rotation of a conic section about its major axis is called a *conicoid*. The conicoid resulting from the special case of the circle is a *sphere* hence the term *spherical*.

14

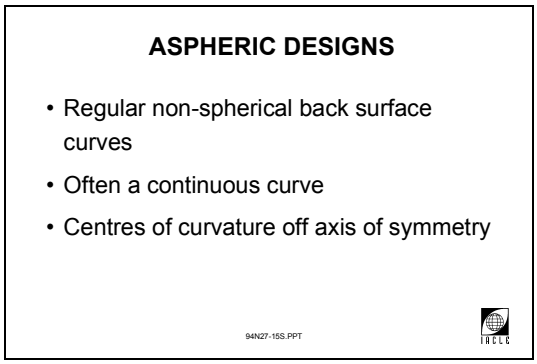


2L594N28-14

First True Aspheric Hard Lens Design

The first true aspheric hard lens design was by Feinbloom in 1961. His lens was ellipsoidal and could be fabricated as a lens with either a spherical or a toric Rx. Because the shapes could not be generated by contemporary equipment, Feinbloom also invented fabrication machinery for the generation of his lens designs. His pioneering work was quickly followed by the work of Volk and Neefe. The former then went on to become the greatest proponent of aspheric lenses for contact lenses and virtually all other clinical purposes (e.g. field lenses for indirect ophthalmoscopy).

15



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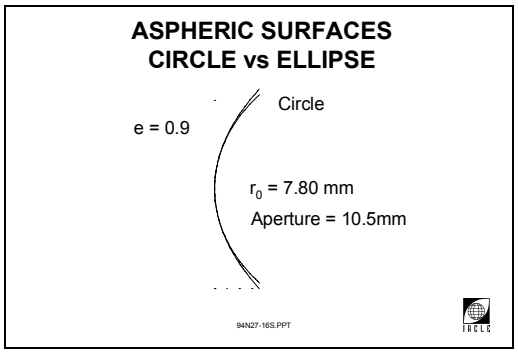
Aspheric Designs

Aspheric lenses incorporate regular non-spherical curves whose centres of curvature appear to be *off* the axis of symmetry (cf. spherical lens designs whose centres of curvature appear to be *on* the axis of symmetry).

Surfaces, especially back surfaces, are often a continuous curve as opposed to surfaces formed by blending discrete curves.

16

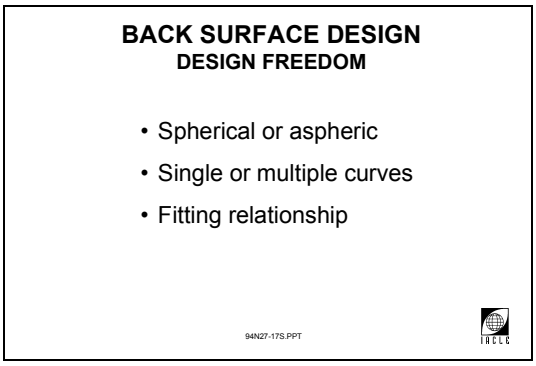


2L596213-16

Aspheric Surfaces

Despite the dramatic diagrams used to illustrate aspheric surfaces and curves which appear in textbooks, the shape differences are anything but dramatic. This diagram compares a circle and an ellipse. Despite the ellipse's larger than normal eccentricity (0.9 *versus* 0.4 to 0.6), and the use of a larger than practical diameter, the difference, especially over a more realistic aperture of say 8 mm, in fact remains quite small.

17



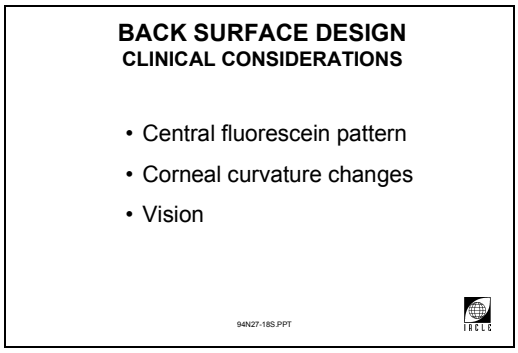
2L594N27-17

Back Surface Design: Design Freedom

While back surface design is somewhat limited by the fact that it must relate to the corneal shape in an acceptable way, there is still some freedom as to the final overall shape. The possibilities are:

- A spherical or aspheric shape.
- Single or multiple curve design.
- Fitting relationships which broadly fall into the following categories:
  - *steeper* than the cornea
  - *aligned* with the cornea
  - *flatter* than the cornea.

18

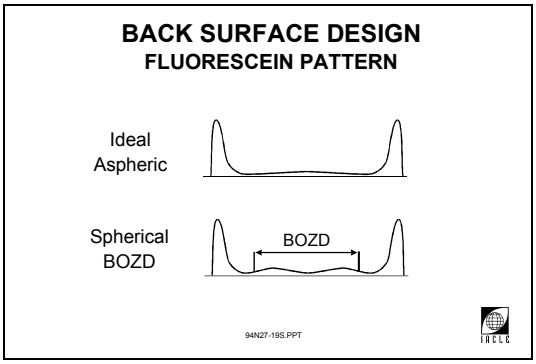


2L594N27-18

Back Surface Design: Clinical Considerations

- Central fluorescein pattern.
  The use of sodium fluorescein is a sensitive technique for comparing the cornea's shape to that of a trial contact lens by highlighting the differences between them.
- Corneal curvature changes.
  When a fitting relationship other than alignment is chosen, the possibility that the lens may alter the corneal curvature and/or shape needs to be considered.
- Lens adherence.
  Virtually all EW RGP wearers will show an episode of lens adherence at some time and it is still not clear what, if anything, can be done to eliminate the occurrence.
- Vision.
  If the corneal shape is normal and regular, the tear lens power, and its influence on the final BVP required, is directly influenced by the BOZR chosen.
  If the cornea is irregular, keratoconic or highly astigmatic, the overall back surface shape, as well as the BOZR, may influence the vision outcome.

19



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Fluorescein Pattern

The fluorescein pattern observed under an RGP lens depends on its back surface shape. The diagrams, representing cross-sectional traces of tear lens thickness under rigid lenses, show the expected patterns from two possibilities.

An aspheric shape ideally aligns with the cornea. As a result, little or no fluorescein is seen anywhere except at the lens edge. The latter is due to the tear reservoir/meniscus deliberately formed at the lens edge.

A spherical BOZD shows the effect of a spherical curve not aligning with the aspheric cornea. The bull's-eye appearance refers to the concentric bright band (ring of fluorescence) surrounding the dark centre (absence of fluorescence) which results. This effect is much less pronounced with a small BOZD) even when the BOZR is altered to compensate for the change in sagittal height.

20

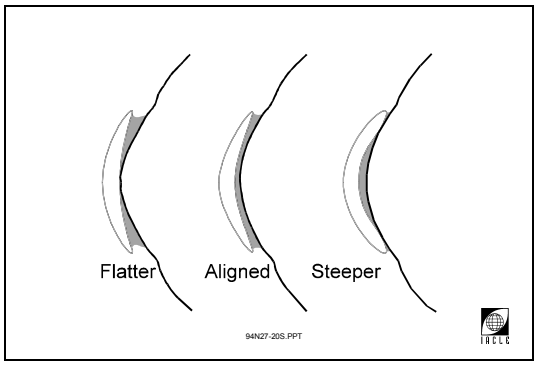

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Diagram of the Three Main Fitting Philosophies

- Flatter.
- Aligned.
- Steeper.

21

BACK OPTIC ZONE RADIUS

- Aspheric
  - better alignment
  - more difficult to manufacture
  - difficult to verify
  - more decentration
- Spherical
  - better vision
  - better centration

94N27-21S.PPT

2L594N27-21

Back Optic Zone Radius:

- Aspheric:
  - better alignment. Cornea is aspheric and better approximations to its shape can be achieved with aspheric back surface designs.
  - difficult to manufacture. While the difference between spherical and aspheric lenses is now smaller due to the wide usage of CNC lathes, it is still slightly more difficult to produce aspheric lenses by non-molding techniques. Molding aspherics is only more difficult at the start-up stage when master tools are being fabricated.
  - difficult to verify. Since current instruments are designed for spherical optics and curves, aspherics represent a challenge to both the industry and practitioners.
- Spherical:
  - studies have shown that spherical surface shapes generally produce superior vision quality (see slide 25).

22

CORNEAL CURVATURE CHANGES
EFFECT OF FITTING PHILOSOPHIES

(n=11)

SPHERICAL	ASPHERIC
K_h -0.26 $\pm$ 0.49 D	-0.19 $\pm$ 0.51 D
K_v -0.61 $\pm$ 0.47 D	-0.20 $\pm$ 0.47 D

$p<0.001$

Negative = a flattening

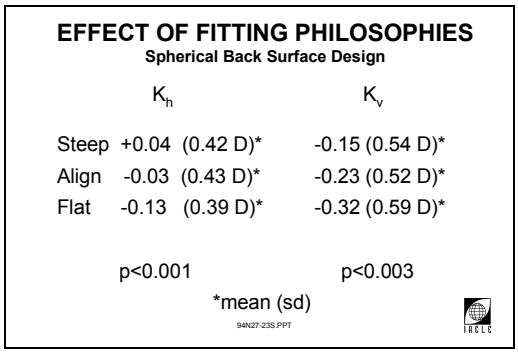
94N27-22S.PPT

2L594N27-22

Corneal Curvature Changes: Effect of Design

In a study of back surface designs, the changes in horizontal and vertical corneal meridians were compared. The greatest changes (flattening) occurred with spherical lenses in the vertical meridian. The horizontal meridian with spherical lenses, and both meridians with aspheric lenses, changed by lesser amounts.

23



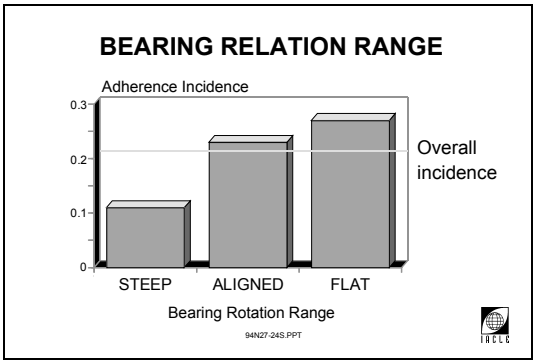
2L594N27-23

Corneal Curvature Changes: Effect of Fitting Philosophies (Spherical Back Surfaces)

The changes in corneal curvature (horizontal and vertical) induced by lenses with spherical BOZRs and fitted according to the three fitting philosophies, were compared in a CCLRU study.

This table shows that the vertical meridian is generally more affected regardless of the fitting philosophy used (steeper, aligned, flatter). Somewhat paradoxically, even with a steep lens, the vertical meridian still flattened slightly (–0.15 but with a substantial SD). Only in the horizontal meridian with a steep fit was a curvature *increase* recorded. Even then it was only slight, albeit with a significant SD. The data also suggests that flatter fits are more effective at altering corneal curvature. This may also be relevant to lens adherence.

24

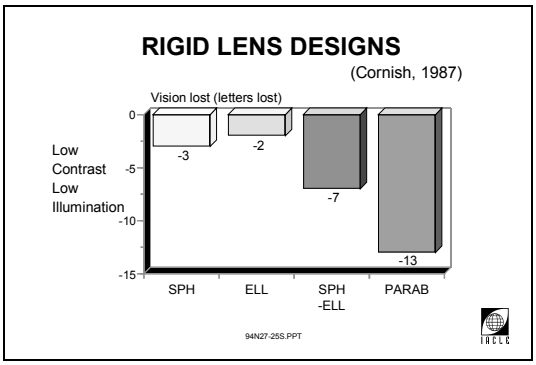


2L594N27-24

Lens Adherence: Bearing Relation Range

When the relationship between RGP lens adherence (lens binding to the cornea) and the fitting relationship is examined, it appears that when the lens is fitted steeper than K, the incidence of adherence is lower but still not zero. While adherence with 'aligned' and 'flatter' fits differs little, there is a tendency for the flatter fits to result in a greater incidence of adherence.

25

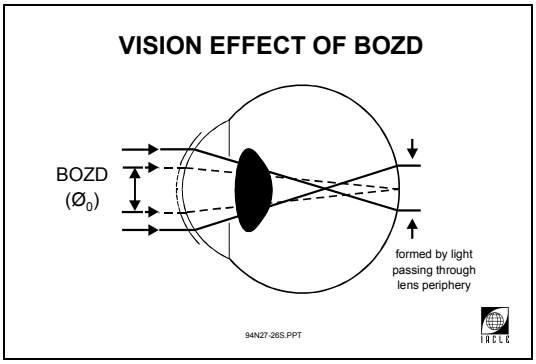


2L594N27-25

Rigid Lens Design and Vision Quality

The effect of back surface shape on vision quality is demonstrated in this graph. While spherical and elliptical shapes produced little loss of quality, a combination of them resulted in a greater decrease in vision. For manufacturing convenience, RGP lenses with aspheric back surface designs often have spherical front surfaces, a combination this graph suggests is undesirable. The parabolic surface shape performed poorly.

26



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Vision Effect of Back Optic Zone Diameter

The effects on vision of a BOZD ($Ø_0$) which is smaller than the entrance pupil size (the image of the anatomical pupil formed by the optics of the cornea and anterior chamber) are illustrated in this diagram. Once the BOZD is exceeded by the entrance pupil diameter, light is refracted by the optic zone, the first curve junction and the lens periphery. In this circumstance, vision quality, including image contrast, is decreased.

27

BACK OPTIC ZONE RADIUS
SUMMARY

- K changes according to fitting relationship
- Steep fitting lenses
  - less adherence?
- Larger optic diameter
  - better vision but poorer alignment

94N27-27S.PPT

2L594N27-27

Optimal Back Surface Design: Summary

Assuming the lens back surface design is spherical and an *alignment* fitting is sought, the following summarizes the optimum fluorescein fitting pattern of a centred RGP contact lens resting on a spherical cornea:

- Alignment or a very slight tendency towards apical clearance over the central 7 – 8 mm.
- Mid-peripheral alignment about 1 – 2 mm wide.
- Edge clearance about 0.5 mm wide.
- An obvious tear meniscus at the lens edge.

The actual dimensions (pattern widths) depend on:

- Total lens diameter (TD).
- Corneal topography (toricity, *p*-value and regularity).
- Actual lens back surface design (including BOZD, etc.).

III Back Surface Mid-Periphery

28

BACK SURFACE MID-PERIPHERY
DESIGN FREEDOM

- Width
- Radius
- Shape
- Number of curves

94N27-28S.PPT

2L594N27-28

Back Surface Mid-Periphery

Design Freedom:

- Width. The width of the curve(s).
- Radius. The radius/radii of the curve(s).
- Shape. The shape or form of the surface, i.e. conical, spherical, aspheric.
- Number of curves.

29

BACK SURFACE MID-PERIPHERY

Requirement:
- Align the flattening cornea

Affects:
- Tear flow
- Stability of the fit
- Corneal mid-peripheral shape
- Centration

94N27-29S.PPT

2L594N27-29

Back Mid-Periphery

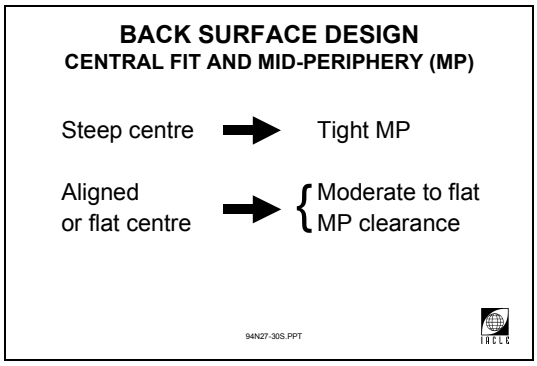
Requirement:

- Should align flattening cornea.
  Since the cornea flattens peripherally, the lens secondary and peripheral zones must have curves which are flatter than the BOZR, preferably flattening progressively. This can be achieved by a series of flattening blended spherical curves, or by a continuous aspheric curve such as an ellipsoid or a paraboloid which would match the corneal shape.

Affects:

- Stability of fit.
  If the mid-peripheral curves are significantly flatter than this corneal region, excessive clearance, an unstable fit and excessive movement will result.
- Tear flow.
  This area of the lens can cause a restriction of tear flow if the bearing area is localized (narrow) by sealing off the back optic zone region. This is also likely to produce a tight fit and entrapment of debris or air bubbles within the optic zone area.
- Corneal peripheral shape.
  As with the central region, corneal shape can be affected by the lens fitting relationship. Harsh and localized bearing on the mid-peripheral band may cause corneal indentation.
- Centration.
  If the mid-peripheral zone is flatter than the cornea resulting in excessive edge lift, the lens is more likely to decentre.

30



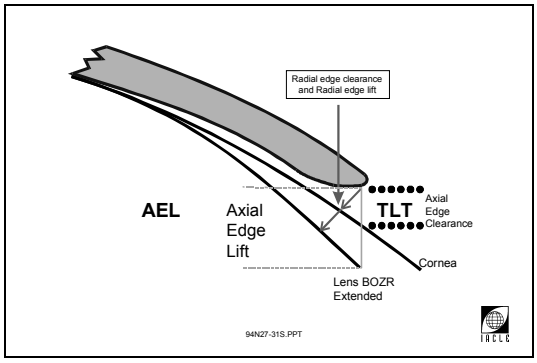
2L594N27-30

Central Fit and Mid-Periphery

A steep central fit may produce a tight mid-peripheral fit unless multiple curves are used and the optic zone diameter is reduced.

An aligned or flat central fit can result in moderate or excessive mid-peripheral clearance.

31

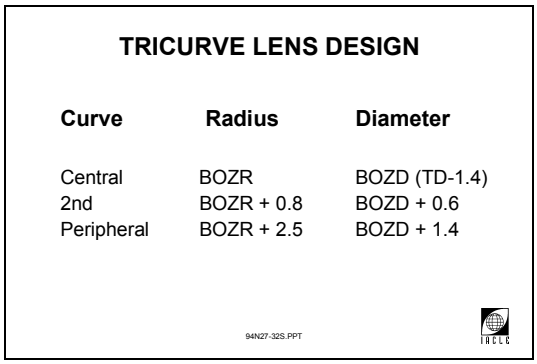


2L594N27-31

Axial Edge Lift, Radial Edge Lift, Tear Layer Thickness

This diagram illustrates the terms Axial and Radial Edge Lift and Clearance as well as the Tear Layer Thickness (TLT). While this diagram refers to the lens edge, the concept of the 'extension' of the base curve (BOZR) to form a reference surface applies to all lens zones, i.e. central, mid-peripheral, peripheral and edge zones. Note that the term 'lift' refers to a *lens* and not the lens/cornea fitting relationship. The terms axial and radial *clearance* are used to describe the distance between the lens and the cornea for each of the lens zones.

32



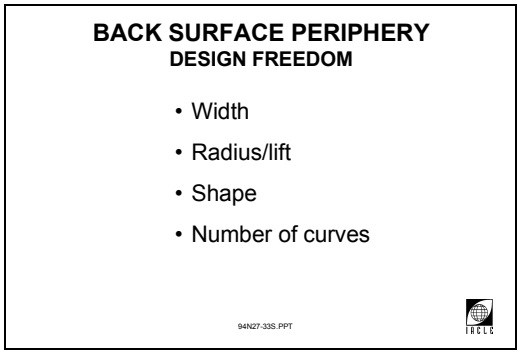
2L594N27-32

Tricurve Lens Design

This typical, simple tricurve design (i.e. optic and two additional curves) shows that the second curve has a radius 0.80 mm *flatter* than the BOZR for a width of 0.30 mm. The optic zone has a diameter 1.4 mm less than the total diameter (TD) of the lens. Many variations of this design are used. However, the principle of progressively flatter curves over discrete widths is common to all. This allows the mid-peripheral curve to either align with the flattening paracentral region of the cornea or have minimal clearance over this zone. Interestingly, the ISO draft standard deals only in zone diameters whereas manufacturers prefer to deal in zone widths. Diameters are presented here.

IV Back Surface Periphery and Edge Design

33



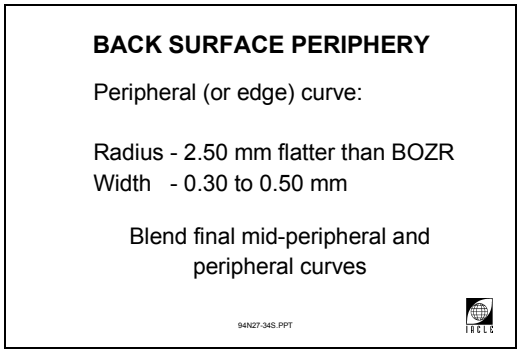
2L594N27-33

Back Surface Periphery

Design Freedom:

- Width.
  The width of the peripheral curves.
- Radius/lift. The flatter a peripheral curve is in relation to the cornea, the greater will be the edge stand-off. It can be measured axially or radially as shown in slide 31.
- Shape. The shape or form of the surface, i.e. spherical, aspheric.
- Number of curves.
  Either a single continuous curve, or multiple curves blended into a smooth surface, may be used as the back peripheral design.

34



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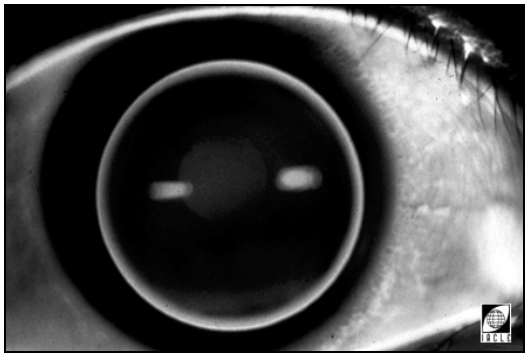
Back Surface Periphery

In order to optimise this section of lens design, the peripheral curve, regardless of its form (spherical or aspheric), should be flatter than the corneal radius in order to have corneal clearance. The clearance when observed with fluorescein should appear as a band with its intensity increasing towards the periphery.

An almost ideal fluorescein fitting pattern is presented in slide 35. It demonstrates the little or no fluorescein pattern under the central and mid-peripheral zones of the lens indicating corneal alignment, the edge clearance desired, the tear meniscus at the lens edge and good lens centration.

35



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36

BACK SURFACE PERIPHERY

Affects:

- Peripheral fluorescein appearance
- Centration
- Tear exchange
- Lens fit
- 3 & 9 staining

94N27-35S.PPT

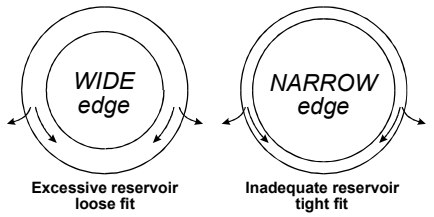
2L594N29-35

Back surface periphery affects:

- Fluorescein pattern at the periphery of the lens, e.g. a flat and wide peripheral curve will result in excessive edge clearance producing a bright band of fluorescein.
- Centration is usually compromised by excessive edge clearance.
- Tear exchange is greater with a wide and flat peripheral curve.
- Excessive edge clearance will result in an unstable fit with excessive lens movement.
- 3 & 9 o'clock staining may result from excessive or inadequate edge clearance.

37

EDGE WIDTH AND TEAR RESERVOIR



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Edge Width and Tear Reservoir

This diagram shows the competing issues involved in selecting edge widths. While a wide edge will increase the volume of tears stored in the edge reservoir, the stability of lens fit may be adversely affected. A balance between these forces is required.

38

EDGE CONFIGURATION DESIGN

- Position of apex
- Roundness
- Blend of junctions
- Thickness

94N27-37S.PPT

2L594N27-37

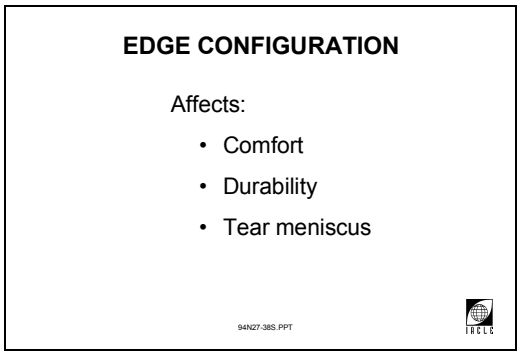
Edge Configuration

Design Freedom:

- Position of apex. The apex of the edge profile can be biased towards the back or front or remain central.
- The edge of the lens should not exhibit any 'high' points.
- Blend of Junctions.
  The topography of the lens just inside the lens edge influences the edge profile, thickness, junction angles etc. The blend from the final peripheral curve to the edge finish is critical to what edge design is possible.
- Thickness.
  This is difficult to quantify because of the multitude of ways it can be measured. Traditionally the radial thickness at some point a fixed distance in from the edge apex is used.

  The distance and the tools used to measure thickness vary greatly. A precision profilometer is an alternative to this technique but such devices are uncommon, expensive and not widely accepted at this time.

39



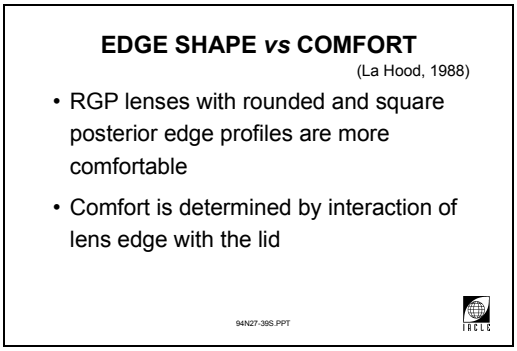
2L594N27-38

Edge Configuration

Edge Configuration can affect:

- Comfort.
  Generally the thinner, rounder and smoother the better. It has been shown when the edge apex is biased towards the back of the lens, the comfort is optimized (La Hood, 1988)
- Durability.
  Making a lens too thin creates a risk of lens fragility. Making it too thick may influence comfort adversely.
- Tear meniscus.
  The edge clearance, apex location and material wettability largely define the tear meniscus at the lens edge.

40



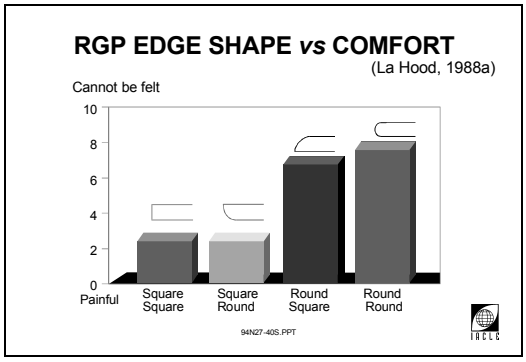
2L594N26-39

Edge Shape *versus* Comfort

As a result of studies of comfort *versus* edge shape it was found that:

- RGP lenses with rounded and square posterior edge profiles are more comfortable. This suggests that as long as the apex is not biased towards the anterior surface, the actual shape is less significant.
- Comfort is determined by the interaction of lens edge with the lid and to a lesser extent the interaction of the lens with the cornea. However when the lids are manually retracted, the wearer of an RGP lens usually reports decreased sensation from the lens.

41

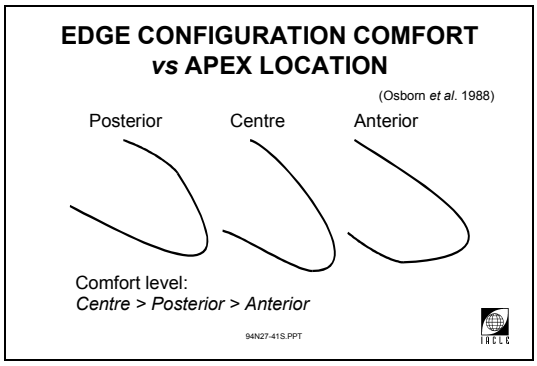


2L594N27-40

RGP Edge Shape *versus* Comfort

This graph shows the comfort ratings found for each of the edge profiles trialed in the study. A depiction of each profile appears above the relevant bar on the graph.

42

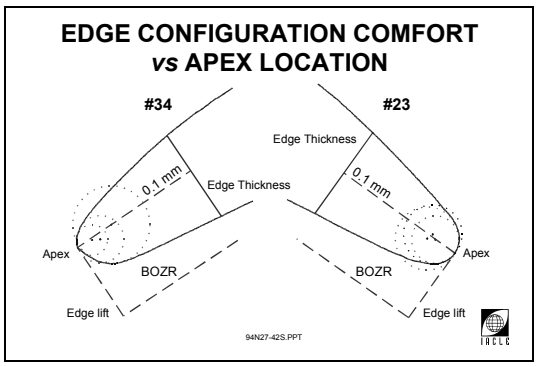


2L596220-41

Comfort *versus* Apex Location

In a detailed study of custom fitted lenses, Orsborn found a centrally located edge apex was more comfortable than either a posterior or anterior location. An anterior location was the least comfortable.

43



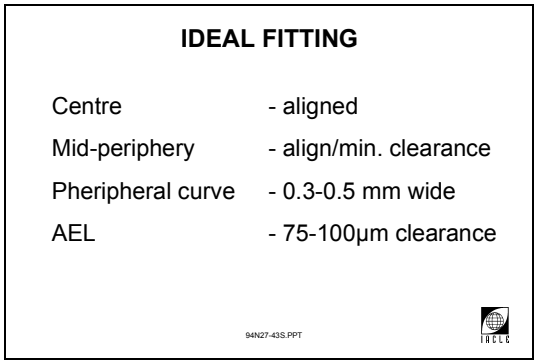
2L596213-42

Numerical Edge Analysis

With a high precision profilometer, numerical data on the actual edge shape can be achieved. While applicable to clinical practice, the real role of such an instrument is in manufacturing, lens design and quality assurance/control.

	Lens #34	Lens #23
Edge thickness 0.1 mm	142.2 µm	145.9 µm
Edge thickness 0.5 mm	189.3 µm	194.3 µm
Edge lift	112.2 µm	113.5 µm
Edge taper	73.3%	73.1%
Apex position	43.7% cent.-ant.	51.9% central
Radius anterior	34.3 µm	46.4 µm
Radius apex	22.7 µm	34.5 µm
Radius posterior	56.5 µm	43.0 µm

44



2L594N27-43

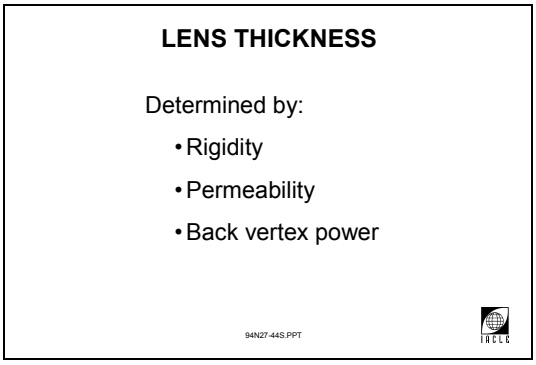
Ideal Fitting

Based on the foregoing, the ideal fit of an RGP can now be described.

- Centrally the lens should align with the cornea.
- The mid-periphery should be aligned with the cornea or have minimal clearance from it. Excessive bearing pressure in this region may restrict tear flow under the lens and/or affect the cornea itself.
- The peripheral curve, which is usually 0.3 to 0.5 mm wide, should result in an axial edge lift of approximately 0.10 mm. This lift is dependent on the other back surface parameters as well.

V Lens Thickness

45



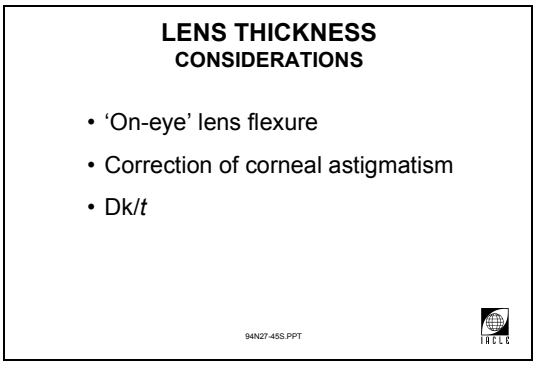
2L594N27-44

Lens Thickness

Lens thickness is largely determined by:

- Rigidity of the lens material. Lenses made from less rigid materials need to be made thicker when fitted to an astigmatic cornea if they are to resist becoming toric themselves by conformance.
- Permeability. As some highly permeable materials are more flexible, lens thickness may have to be increased compared with less permeable materials.
- Back vertex power (BVP). BVP is a significant determinant of lens thickness, especially in the optical zone.

46



2L594N27-45

Lens Thickness

Considerations:

- 'On-eye' lens flexure.
  A lens needs to be thick enough to resist flexure while being thin enough to deliver the potential physiological benefits inherent in higher Dk materials.
  Some materials show a direct relationship between Dk and flexibility, i.e. the higher the Dk the greater the flexibility. This often means in practice that any gains from increasing the Dk are offset by the need for a thicker lens having an acceptable level of flexure, i.e. Dk/*t* does not increase by as much as is suggested by the increase in the Dk of the material used. However, Cornish *et al .,* (1991) found that over the Dk range 0 – 140, Dk and flexibility were independent properties. Therefore, at least for the materials tested, the oxygen transmissibility can be increased without the need to increase lens thickness to maintain the level of lens rigidity desired.
- Correction of astigmatism.
  The dominant use of RGPs in many practices is for the correction of corneal astigmatism with a spherical lens. If the lens flexes on an astigmatic cornea, then less than the 90% of astigmatism (which is normally corrected by such lenses) will be corrected.
- Dk/*t*.
  Since Dk/*t* is a measure of the oxygen transmission through the lens, *t* is an important determinant of oxygen availability especially for low to moderate Dk materials.

47

Dk/*t* of various materials at standard power (-3.00 D) and centre thicknesses (t_c).

	t_c(µm)	Dk/t_c
Quantum II	150	94
Breath 'O' HCL	170	80
Equalens II	150	77

94N27-46S.PPT

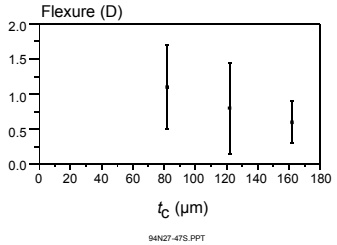
2L594N27-46

Dk/*t* of Various Materials at Standard Power and Centre Thickness

Historically, the contact lens industry has used –3.00 D as a standard BVP. Each material requires a characteristic thickness to resist clinically significant flexure on a toric cornea. This table shows typical thicknesses for some common materials along with the resultant Dk/t_c. The table clearly shows that high Dk values are not the final arbiter of oxygen conditions under a lens.

48

'ON-EYE' FLEXURE *vs* t_c
CORNEAL Cyl = 1.82 ± 0.74 D



94N27-47S.PPT

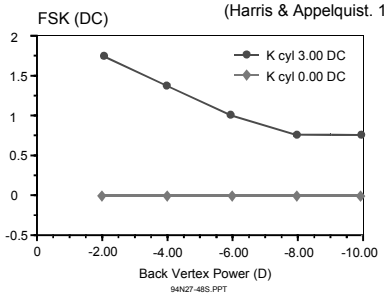
2L594N27-47

'On-Eye' Flexure *versus* t_c

This graph shows the lens flexure which occurs at varying lens thicknesses when fitted to a population of astigmatic corneas whose toricity was 1.82 ± 0.74 D. From the data, it can be surmised that a thickness of >0.16 mm is required to resist flexure of a clinically significant level.

49

FLEXURE & LENS POWER
(Harris & Appelquist. 1974)



94N27-48S.PPT

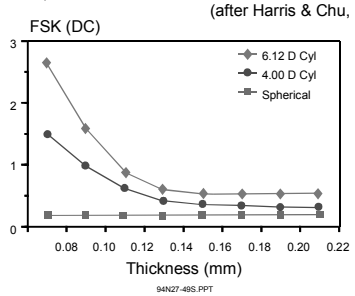
2L594N29-48

Flexure and Lens Power

Because of the effect BVP has on overall lens thickness, it too is a clinical consideration. This graph shows the effect BVP has on lens flexure on a 3.00 D corneal cylinder. Obviously there is no effect when a lens is placed on a spherical cornea.

50

FLEXURE, LENS THICKNESS & CORNEAL CYL
(after Harris & Chu, 1972)



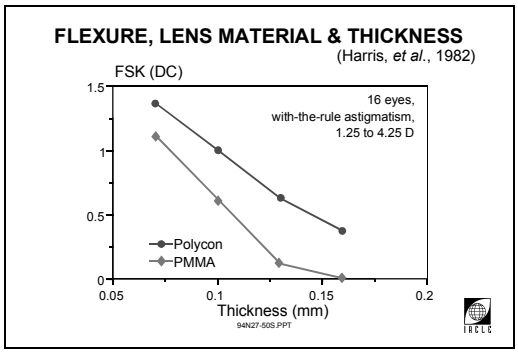
94N27-49S.PPT

2L594N29-49

Flexure, Lens Thickness and Corneal Cylinder

This composite graph clearly shows the effect progressively increasing corneal cylinder has on lens flexure *in situ*. The material used was PMMA. It shows that about 0.16 mm centre thickness is required to resist flexure on the larger cylinders. Interestingly, in the case of the 6.12 D cylinder, even 0.22 mm thickness still exhibited an 0.50 D flexure.

51



2L594N29-50

Flexure, Lens Material and Thickness

This graph shows the flexure differences which can be attributed to the physical property differences of materials. The more flexible Polycon™ material needs to be thicker to resist on-eye flexure.

VI Front Surface Design

52

FRONT SURFACE DESIGN

Controlled by:

- BVP

Design Freedom:

- FOZD
- Front peripheral curves
- Their radii and widths

94N27-51S.PPT

2L594N27-51

Front Surface Design

The front surface of the lens and the thickness profile is largely controlled by the BVP required and whether the front surface is spherical or aspherical.

The only options that may be exercised are:

- FOZD.
  This is usually made large enough to accommodate most pupil (entrance pupil) sizes without resulting in an excessive mid-peripheral thickness. In higher powers, the FOZD may be reduced slightly as a compromise between mid-peripheral thickness and the effects a large pupil size may have on vision.
- Number of peripheral curves on the front surface, their radii and widths.

53

LENTICULATION

Affects:

- Centre thickness
- Lens mass
- O_2 transmission
- Comfort

94N27-53S.PPT

2L594N27-52

Thickness Profile/FS Design

The front surface design affects:

- Vision.
  Apart from FOZD *versus* pupil size issues, there is also the question of the 'form' of the lens. While it is desirable that a lens be of 'best form' design, contact lenses do not offer this freedom because their form is dictated by corneal shape. Spherical or aspheric shapes also differ in their vision quality with spherical probably performing a little better (see slide 25).
- Lid interaction. This in turn will influence comfort, movement and centration. The profile thickness of the lens will also affect lid interaction.

54

LENTICULATION

Affects:

- Centre thickness
- Lens mass
- O_2 transmission
- Comfort

94N27-53S.PPT

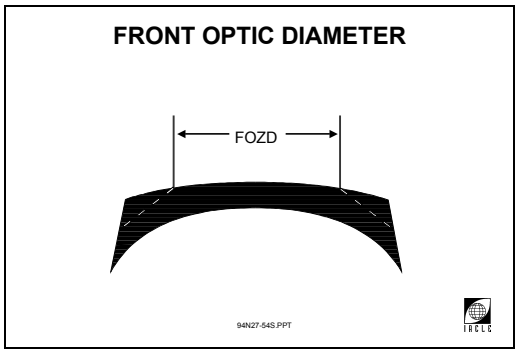
2L596N27-53

Lenticulation

Lenticulation affects:

- Centre thickness.
  In plus lenses only.
- Lens mass.
  This is true for all lenses.
- O_2 transmission.
  This is true for all lens types. It is especially true for the optic zones of plus lenses, and for the effects on *average* lens thickness of all lens types.

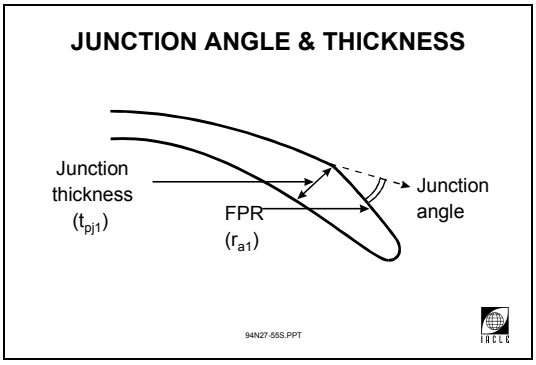
55



2L594N28-54

Lenticulation defines the FOZD of a lens. Unlike most soft lenses, the FOZD does not necessarily define the practical optical zone diameter on RGP lenses, and often the BOZD is smaller than the FOZD.

56



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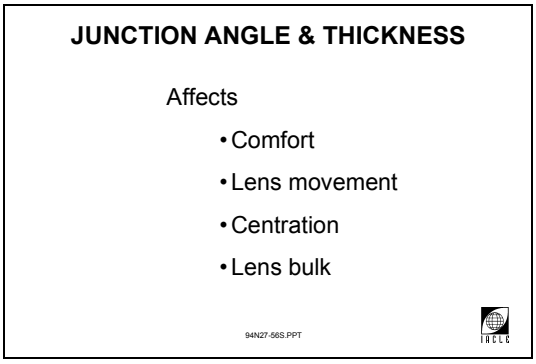

2L594N27-56

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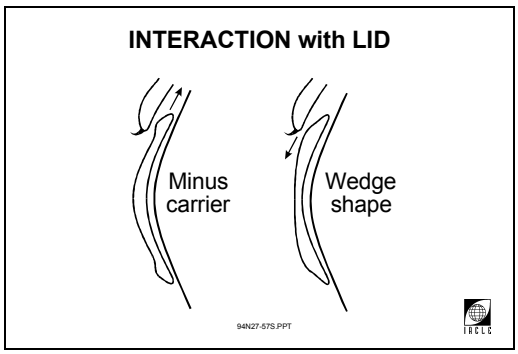

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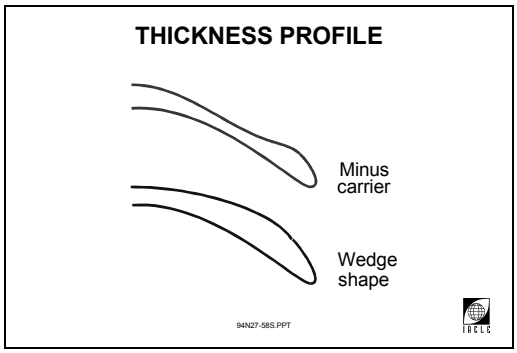
Interaction with Lid

Sometimes, outcomes which are generally considered undesirable can be harnessed for the benefit of the wearer. If a combination of lid interaction and gravity result in excess movement and inferior decentration, a so-called *minus carrier* can be incorporated into the design of the front surface's periphery to try to use the upper lid as a lens elevator. A blink will then raise the lens rather than displace it inferiorly.

A variation of this theme is the Korb 'lid attachment' fitting philosophy. This uses a thinner lens design (to decrease lens mass) and a modification of the edge design (especially the front surface) in the outer 1 mm to provide a broader band of contact with the upper lid. The lens is fitted flatter (flattest K + 0.15 - 0.70, average +0.25) than usual in diameters which are towards the smaller end (8.6 - 9.4 mm) of the normal range. The intention is for the lens to be 'attached' to, and move with, the upper lid.

59



2L596220-58

Thickness Profile

This is a diagrammatic representation of two possible edge profiles, one a conventional type, the other a ‘minus carrier’ aimed at lens elevation on blinking.

VII Lens Diameter

60

DIAMETER

Determined by:

- Corneal diameter of population (stock lenses)
- HVID of patient
- Inter-palpebral aperture
- Lens power (minus/plus)

94N27-59S.PPT

2L594N27-59

Lens Diameter (Total Diameter, TD, $Ø_T$)

Lens diameter (total diameter or $Ø_T$) is determined by:

- Corneal diameter (or HVID) of the population when stock lenses are involved.
- HVID of the patient when a custom fitting is being pursued.
- Lens power (BVP) (plus and minus).
  When it is likely that the lens will decentre (high plus: gravity and lid interaction, high minus: lid interaction and some gravity) it may be necessary to increase total diameter in the interests of a larger FOZD/BOZD. This is to ensure that a useful amount of the optic zone covers the pupil.

61

LENS DIAMETER

Affects:

- Centre of gravity
- Stability
- Option to have larger BOZD/FOZD
- Comfort
- 3 & 9 staining

94N27-60S.PPT

2L594N27-60

Lens Diameter

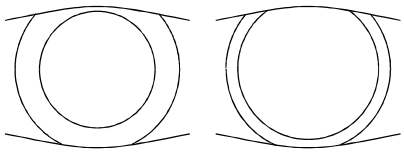
Lens diameter affects:

- Centre of gravity.
  This is shown diagrammatically in slides 63 and 64.
- Stability.
  In general the fit of larger lenses is more stable because the locating forces are highly dependent (direct relationship) on the lens circumference, and larger lenses have less corneal space available in which to move.
- The option to have a larger BOZD/FOZD.
- Comfort.
- 3 & 9 o'clock staining.
  If an area is susceptible to desiccation staining, one possible solution is to cover it with the lens by increasing the lens diameter until this is achieved.

62

LENS DIAMETER *and* COMFORT

Better comfort with larger TD?



94N27-61S.PPT

2L596220-61

Lens Diameter and Comfort

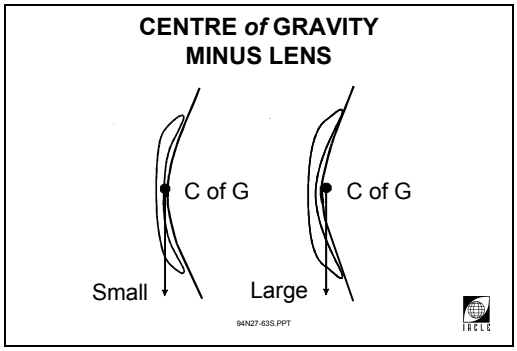
Better comfort with larger TD?

There is a theory that because a larger lens diameter places more of the lens edge under the lids while they are in their resting position, the overall comfort of an RGP lens is enhanced.

While this is a factor in the greater comfort of soft lenses, the contribution of larger RGP lens diameters to comfort has only recently been demonstrated. Williams-Lyn *et al.,* (1993) showed that larger diameter (10 mm *versus* 9.5 and 9.0 mm) RGP lenses were more comfortable. (They also showed that steeper fitting lenses were *less* comfortable).

VIII Centre of Gravity

63



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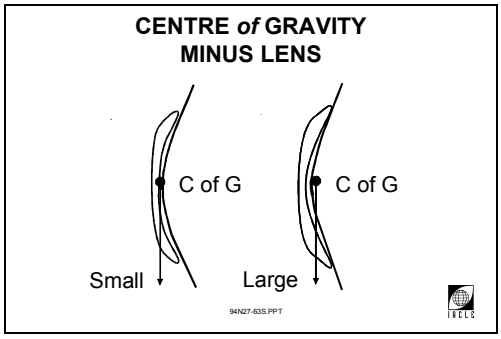
Centre of Gravity: Plus Lenses

This diagram illustrates the effect lens design, especially the lens periphery and lens diameter, can have on the location of the centre of gravity of plus lenses. The more anterior the centre of gravity (C of G) is located, the less stable will be the fit because of the greater mislocation force (rotational moment) produced by gravity.

64



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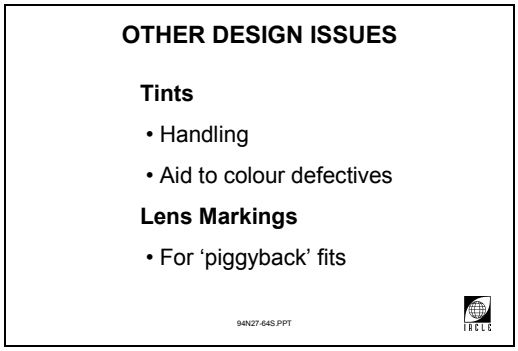
Centre of Gravity: Minus Lenses

This diagram illustrates the effect lens design, lens diameter and overall thickness profile can have on the location of the centre of gravity of minus lenses. The more anterior the centre of gravity is located, the less stable will be the fit because of the greater mislocation force (rotational moment) produced by gravity. Further, the contribution of the greater lens mass resulting from a larger diameter cannot be ignored as it is also a mislocating force.

IX Other Design Issues

65



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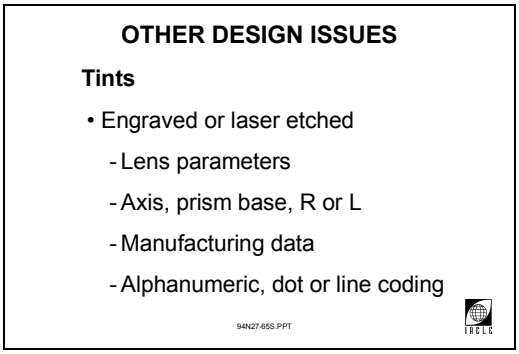
66



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Other Design Issues

Tints:

- Handling.
  Tints are usually incorporated to improve the visibility of a lens during handling. RGP lens tints are usually not effective as cosmetic tints because considerably less than the whole of the iris is covered by the average lens. Lens movement may make this shortcoming even more apparent.
- For colour defectives.
  Lenses such as the X-Chrom (Zeltzer, 1971) or the JLS lens (Schlanger, 1985) are used by colour defectives to help overcome their confusion of colours. Their function is to introduce a brightness difference to assist in colour differentiation. They are uncommon.

- Special edge design.
  In those rare cases in which a 'piggy-back' RGP/soft lens combination is to be used, the RGP 'rider' lens may be edge finished to facilitate its 'fit' in the recess machined in the front of the soft 'carrier' lens.

- Lens Markings.
  Lens data such as BOZR, TD, the intended eye (R or L), the base of any prism incorporated, the cylinder axis, the 6 o'clock lens position, manufacturing data such as company logo, batch #, series, etc. can all be engraved or laser marked on an RGP lens's front surface. Markings may be alphanumeric or a series of dots, lines or depressions.
  Many manufacturers choose not to mark lenses because they have reservations about the adverse effects such markings may have on lens durability or its susceptibility to deposits.

X Role of the Manufacturer

67

ROLE OF MANUFACTURER

Accurately reproduce what was ordered

- Dimensions
- Power
- Edge shape
- Blending

Manufacture with craftsmanship

94N27-66S.PPT

2L594N27-66

68

ROLE OF MANUFACTURER

RGPs delivered to practitioner should be in best possible condition, including:

- Thorough post-manufacturer cleaning with recommended solvent and/or cleaner
- Soaking in wetting solution

94N27-67S.PPT

2L594N27-67

Role of the Manufacturer

A manufacturer is expected to reproduce the lens order accurately. The expectations are:

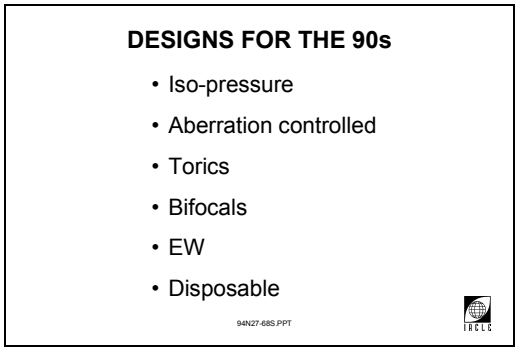
- Dimensions.
- Power (BVP).
- Edge shape.
  This lecture has dealt with this issue in some detail and its importance should now be apparent.
- Blending.
  Apart from this as a design issue, it is also affected by the level of 'craftmanship' applied to the lens finishing steps.

Craftmanship should be demonstrated by a manufacturer at all stages of lens creation and it should be one of the practitioner's criteria for selection of a manufacturer once a design has been chosen.

The manufacturer should deliver to the practitioner a cleaned, accurate and appropriately stored RGP lens. For initial comfort and microbiological reasons, the lens should ideally be delivered in an RGP storage solution.

XI Present and Future of RGP Lens Design

69



2L594N27-68

Designs for the 90s

- Iso-pressure. A design which will apply a uniform 'benign' pressure to the whole of the corneal area covered by the lens.
- Aberration-controlled design which will minimize the lens-induced aberrations. This may not be achievable since contact lenses offer designers few degrees of freedom. Since shape cannot be altered significantly, it is probable that a variable refractive index across a lens is one of the few possibilities. Results to date have not been encouraging.
- Torics.
  Torics and bitorics, which have been available for decades, are relatively reliable products which will improve as manufacturing technology becomes more advanced.
- Bifocals.
  Translating implanted-segment bifocals appear to be the most successful type of contact lens bifocal and this will probably continue.
- Extended Wear (EW).
  Generally, the oxygen transmissibility (Dk/*t*) of RGP lenses is significantly greater than that of hydrogels. Currently, the only materials which could satisfy the Holden-Mertz criteria are RGPs. Successful extended wear is more likely to involve RGP materials than the current hydrogels. New hydrogels being developed may reach the criteria.
- Disposable.
  AS RGP materials have become more sophisticated, they have tended to exhibit some of the deposit/spoilage characteristics of hydrogels. Protein treatments are now required for a significant number of wearers. Like hydrogels, disposing of the lens is one solution to this problem. Higher manufacturing costs are currently a barrier to disposability.

Tutorial 2.5

(1 Hour)

Rigid Gas Permeable Spherical and Toric Lens Design

Quiz

Name:_____ **Date:**_____

1. Which features of an RGP lens can affect the gravitational force?

_____

_____

_____

_____

_____

2. List the lens parameters that are critical to control lens centration.

_____

_____

_____

_____

_____

3. What lens parameters play a role in providing adequate tear exchange?

_____

_____

_____

_____

_____

4. What design features provide better centration and movement in lenses with a high BVP?

_____

_____

_____

_____

_____

References

Baker TY (1943). *Ray tracing through non-spherical surfaces.* P Phys Soc Lond. 55: 361 - 364.

Bennett AG (1968). *Aspherical contact lens surfaces. Part I.* Ophthalmic Optician. 8: 1037 - 1040.

Bennett AG (1968). *Aspherical contact lens surfaces. Part II.* Ophthalmic Optician. 8: 1297 - 1301.

Bennett AG (1969). *Aspherical contact lens surfaces. Part III.* Ophthalmic Optician. 9: 222 - 230.

Bier N, Lowther G (1977). *Contact Lens Correction.* Butterworths, London.

Cornish R (1988). Unpublished data.

Cornish *et al.* (1991). *Relationship between material Dk, flexibility and correction of astigmatism with RGP lenses.* Optometry Vis Sci. Suppl. 68: 145P.

La Hood D (1988). *Edge shape and comfort of rigid lenses.* Am J Optom Physl Opt. 65: 613 - 618.

La Hood D (1988a). Unpublished data.

Lowther GE, Snyder C (1992). *Contact Lenses: Procedures and Techniques.* 2nd ed. Butterworth-Heinemann, Boston.

Mandell RB (1988). *Contact Lens Practice.* 4th ed. Charles C. Thomas Publisher, Springfield.

Orsborn GN, Zantos SG, Medici LA, Godio LB (1988). *The influence of apex location, edge thickness, and edge lift on the comfort of rigid contact lenses.* Am J Optom Physl Opt. Suppl. 65: 73P.

Phillips AJ, Stone J (Eds.) (1989). *Contact Lenses.* 3rd ed. Butterworths, London.

Ruben M, Guillon M (1994). *Contact Lens Practice.* Chapman & Hall Medical, London.

Schlanger JL (1985). *The JLS lens: An aid for patients with color vision problems.* Am J Optom Physl Opt. 62: 149 - 151.

Senff R (1846) quoted in: Helmholtz H von (1962). *Treatise on Physiological Optics.* Reprinted by Dover Publications, London.

Williams-Lyn D, MacNeill K, Fonn D (1993). *The effect of rigid lens back optic zone radius and diameter changes on comfort.* ICLC. 20: 223 - 229.

Zeltzer H (1971). *The X-Chrom lens.* J Amer Optom Assoc. 42: 933 - 939.

Unit 2.6

(18 Hours)

Lecture 2.6: Contact Lens Verification

Practical 2.6.1: RGP Contact Lens Verification

Practical 2.6.2: Soft Contact Lens Verification

Practical 2.6.3: Modification of RGP Lenses

Practical 2.6.4: Inspection of Special Lenses

Tutorial 2.6: RGP Lens Modification

Course Overview

Lecture 2.6: Contact Lens Verification

I. Verification of Rigid and Soft Contact Lens Parameters

II. Principles and Features of Instrumentation Used in Verification

Practical 2.6: Contact Lens Verification

- Rigid Gas Permeable Contact Lens Verification
- Soft Contact Lens Parameter Verification
- Modification of Rigid Gas Permeable Lenses
- Inspection of Special Lenses

Tutorial 2.6.3: Rigid Gas Permeable Contact Lens Modification

Video and Discussion

Lecture 2.6

(1 Hour)

Contact Lens Verification

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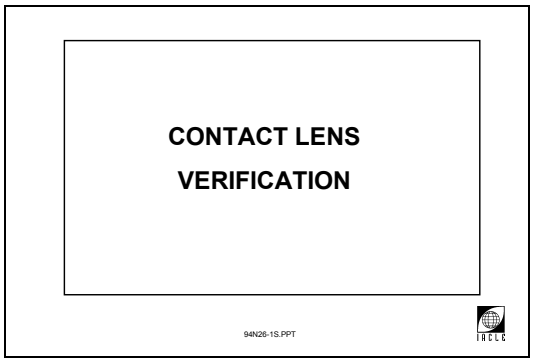
II Parameters Requiring Verification and Instruments Used **240**
II.A Radii of Curvature 240
II.B Lens Power Verification 254
II.C Verification of Linear Parameters 257
II.D Edge Profile Verification 263
II.E Lens and Surface Quality Assessment 267

I Introduction

1



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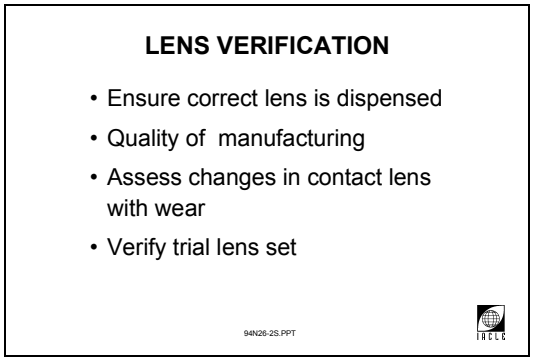
Contact Lens Verification

Contact lens verification undergoes two stages, laboratory and clinical. The parameters verified are essentially the same for both but there may be more parameters verified in the laboratory because of manufacturing, quality control and differences in accessibility to equipment. This lecture is an attempt at discussing the more common techniques and equipment plus other techniques that may be utilised as an alternative.

2



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Lens Verification: Why Verify Contact Lens Parameters?

Contact lenses ordered from a laboratory warrant verification by the optometrist for the following reasons:

- Contact lenses are manufactured by laboratories to meet the prescriptions provided. However, Holden (1976) has shown that laboratory measurements of soft contact lens parameters vary significantly from clinical measurements.
- Although quality control standards are followed by most manufacturers, practitioners should provide them with feedback on the manufacturing quality of the lenses they supply.
- Dimensional changes in both RGP (rigid gas permeable) and SCLs (soft contact lenses) are documented in the literature.
- Fatt (1983) showed that the flexure of RGP lenses on-eye is more dependent on lens dimensions and the lens-cornea bearing relationship than on material elasticity.
- Fatt also cited several factors that cause SCL parameters as marked on the vial to differ from the actual lens parameters:
  - inaccuracy of the linear swell factor
  - variation of the swell factor from point to point in the lens
  - variation in the swell factor along the different axes
  - failure of the manufacturer to maintain a truly dehydrated lens button while lathe cutting the lens.
- To ensure that proper over-refraction and trial fitting examination has been conducted, the accuracy of trial sets used in the clinic should be determined.

II Parameters Requiring Verification and Instruments Used

II.A Radii of Curvature

3

What should be verified?

- Radii of curvature
- Power
- Linear parameters
- Edge profile
- Lens quality

94N26-3S.PPT

2L694N26-3

What Should be Verified?

Rigid and soft lenses have similar parameters which require verification by the practitioner. The following important lens parameters should match the prescription ordered:

- Radii of curvature.
- Power.
- Linear parameters.
- Edge profile.
- Lens quality.

The lecture will be presented in order of the parameters listed above and the instrumentation that may be used for their verification.

4

LENS VERIFICATION

Measure hydrated lenses

94N26-4S.PPT

2L694N26-4

Lens Verification: Measure Hydrated Lenses

Rigid and soft contact lenses should be hydrated in a soaking solution for 12 - 24 hours before verification procedures are conducted.

5

RADII OF CURVATURE

- Back optic zone radius (BOZR)
- Back peripheral curve radii (BPCR)
- Front optic zone radius (FOZR)
- Front peripheral curve radii (FPCR)

94N26-5S.PPT

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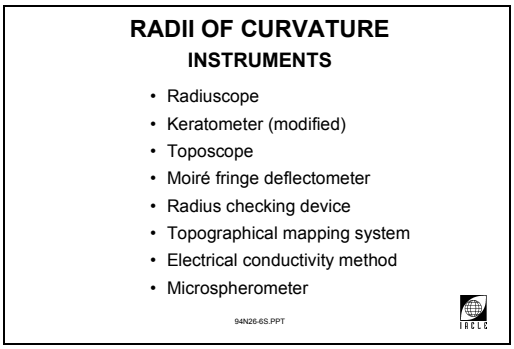
6



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Radii of Curvature: Instruments

The use of the following instruments and their underlying optical principles will be discussed in the order presented below for both rigid and soft contact lens measurements:

- Radiuscope: Drysdale's principle.
- Keratometer (modified): Purkinje image formation.
- Toposcope: Moiré fringe pattern formation.
- Moiré fringe deflectometer: Moiré fringe pattern formation.
- Radius checking device: Thick lens system.
- Topographical mapping system.
- Electrical conductivity: BOZR as a function of sag and chord diameter.
- Microspherometer: BOZR as a function of sag and chord diameter.

7

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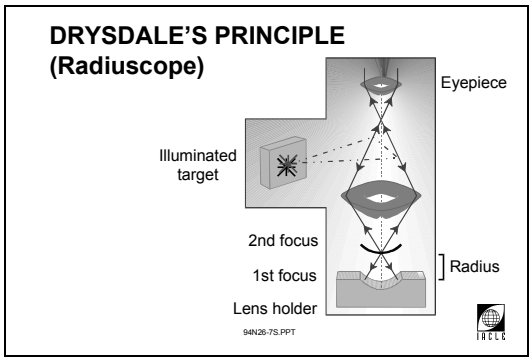
Radiuscope

Monocular and binocular radiuscopes are available from different optical supply companies.

8



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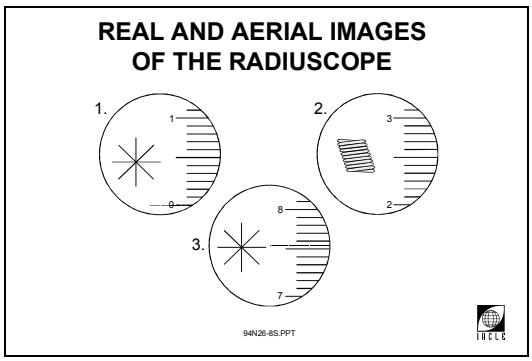

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Drysdale's Principle

Drysdale's principle is based on the theory that when a curved reflecting surface such as a contact lens is positioned so that the real image created by the instrument (which becomes the aerial object for the lens surface) is located at its centre of curvature, an image will be formed in the same plane as the aerial object.

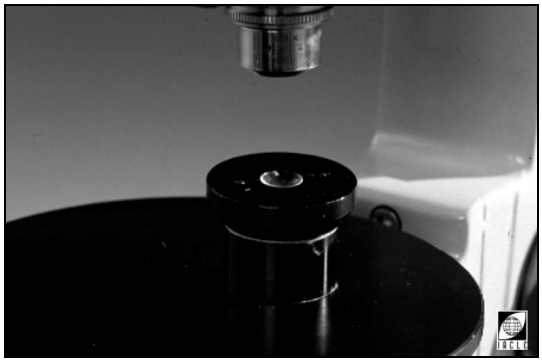
The real image/aerial object is formed at the first focal plane and an aerial image is formed at the second focal plane, both places being at the centre of curvature of the lens.

The distance between the real image at the lens surface and the aerial image is equivalent to the radius of curvature of the lens surface.

Slide 9 illustrates the real and aerial images seen through the radiuscope:

1. Real image (first focus).
2. Filament focus - between first and second images.
3. Aerial image (second focus).

10



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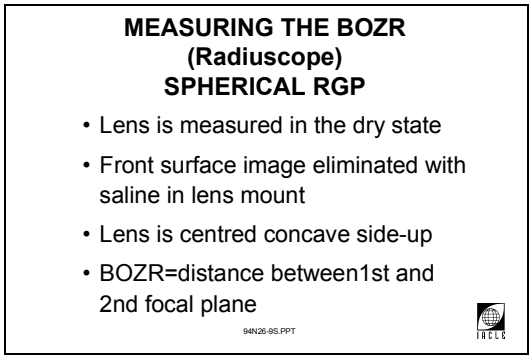

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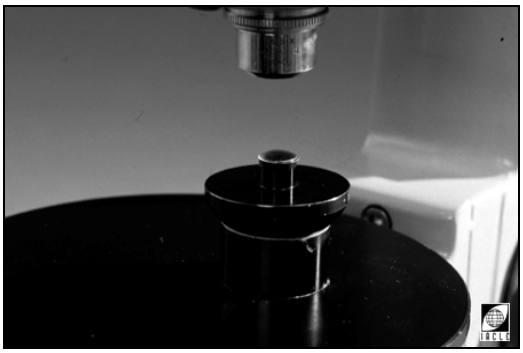
Measuring the BOZR with the Radiuscope

Spherical RGP

- Spherical RGP lenses are measured in the dry state after hydration overnight in the soaking solution.
- The lens is positioned concave side up on the lens mount. This mount has been filled with water or saline solution so that there is just a thin liquid interface between the lens and mount. This eliminates the image formed by the front surface (convex) of the lens. To ensure precise measurements, the concave surface of the lens should be kept dry.
- The mires or spoke pattern is first focused and set at zero. A second set of mires or spoke pattern is located by rotating the drum. The distance between the first and second focal position is taken as the BOZR as read off the scale.

12



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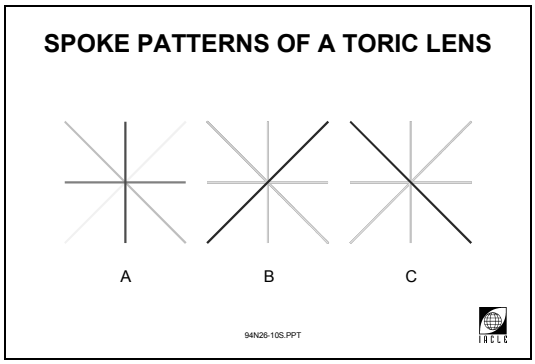
Measuring the FOZR with the Radiuscope

Spherical RGP

The same procedure as that used for measuring the BOZR is followed for determining the FOZR, except that the lens is centred convex side up on the appropriate lens mount. The scale is reversed so that the aerial image will be focused before the real image.

13



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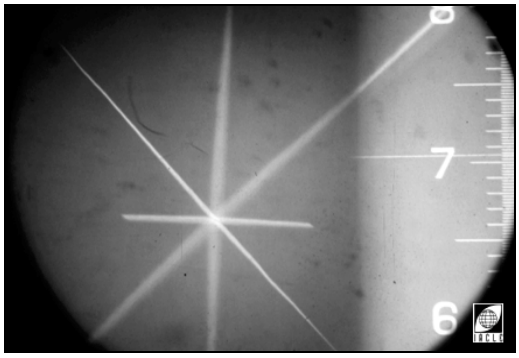
Measuring a Toric Surface with the Radiuscope

When viewing the aerial image of a toric lens, either none of the lines of the spoke pattern are focused (13A), or one line is clearer (13B). In either case, the lens must be rotated and/or the radiuscope adjusted until one line is focused (13B).

This reading is noted. The line at 90° to this line is then brought into focus and its reading noted (13C).

14



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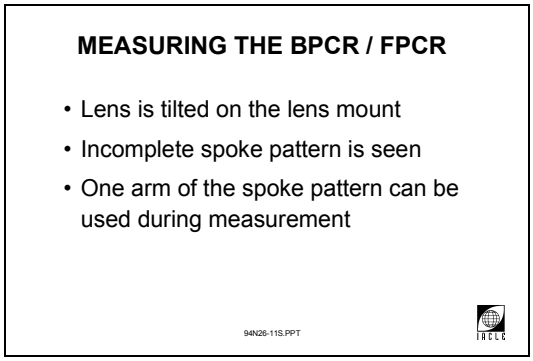
Slide 14 shows an actual picture of the spoke pattern that is observed when one line is in focus (135°) with a reading of 7.05 mm. The line at 45° will be the other principal meridian of the toric surface. Basically, the same method is used for measuring the FOZR.

15



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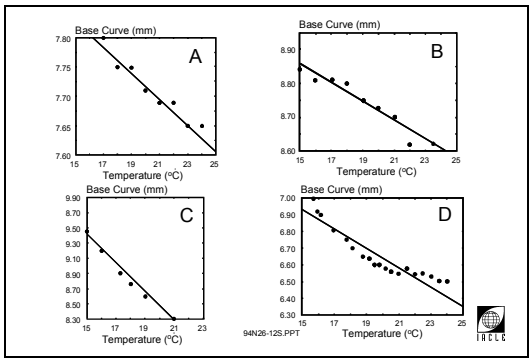
Measuring the BPR/FPR with the Radiuscope

The back and front peripheral radii are measured with the radiuscope by tilting the lens on the appropriate lens mount. Because of the narrow surface area that is being measured, the spoke pattern will show only one line to be clearly in focus.

16



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Verification of the Radii of Curvature

SCL

In measuring SCLs there are important considerations which must be taken into account:

- Measurement of SCLs in a wet cell environment can also be affected by the pH and tonicity of the saline solution. Lenses should be measured in 0.9% saline solution.
- Most SCL should be measured in 15 - 25°C at an average of 20°C or room temperature. Increased temperature on- or off-eye causes the lens to shrink. Chaston and Fatt (1981, 1982) showed that a significant change in the base curve of high-water content lenses occurred over a temperature range of 15 - 37°C.

17

BOZR MEASURING METHODS
SCL

- Immersion
- Air checking (semi-dehydrated state)

94N26-13S.PPT

2L694N26-13

BOZR Measurement Methods

There are two main methods of measuring the BOZR of SCLs:

- The immersion technique, which involves measurement in saline solution in a wet cell system.
- Air checking, which requires the SCL to be dabbed with a lint-free cloth and measured in a semi-dehydrated state. The critical duration of such air-checking is approximately one minute depending on ambient temperature and humidity. This is rarely practised.

18

MEASURING THE BOZR:
IMMERSION (Radiuscope)
SCL

- Requires a wet cell filled with saline solution
- The readings are multiplied by the refractive index of saline to calculate the BOZR

94N26-14S.PPT

2L694N26-14

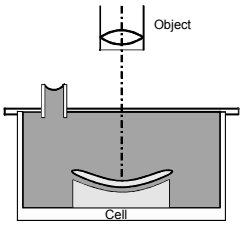
Measuring the BOZR of SCLs: Immersion

Radiuscope

Chaston (1977) measured the BOZR of SCLs with the radiuscope using a wet cell made from PMMA. The wet cell is constructed with a black base and made to sit on the base plate of the radiuscope. The readings are multiplied by the refractive index of saline to get the BOZR. The same procedure is used for measuring RGP lenses.

19

PRINCIPLE OF BOZR MEASUREMENT
WITH THE RADIUSCOPE



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20

ULTRASONIC MEASURMENT OF THE BOZR (AMS OPTISON): IMMERSION

- SCL is placed in a wet cell with a transducer
- Sound waves are reflected off the back surface of soft contact lenses
- Measures the Chord Related Radius (CRR) and sag

94N26-16S.PPT

2L694N26-16

Ultrasonic Measurement of the BOZR of SCLs (AMS Optison): Immersion

- Port (1982) reported a technique of measuring the BOZR of SCLs by using high frequency sound waves focused by a transducer.
- The lens is set on a cylinder of known diameter. A radius estimate called the Chord Related Radius (CRR) is calculated which is a function of the sag height.
- The formula for computing the BOZR is given below:

21

ULTRASONIC MEASUREMENT OF THE BOZR (AMS OPTISON): IMMERSION

Formula for computing the BOZR:

$$CRR = \frac{d^2}{8s} + \frac{s}{2}$$

94N26-17S.PPT

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$$CRR = \frac{d^2}{8s} + \frac{s}{2}$$

where:

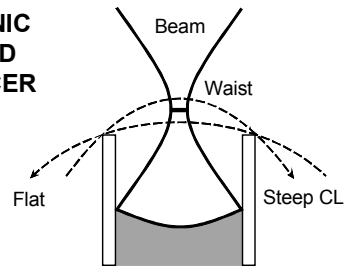
CRR = chord related radius

d = diameter of cylinder

s = sagitta

22

ULTRASONIC BEAM AND TRANSDUCER



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23

MEASURING THE BOZR AS A FUNCTION OF THE SAG AND CHORD DIAMETER: AIR CHECKING (Radiuscope)

- Uses a special lens mount with a known diameter
- Radiuscope provides readings of lens thickness and front surface curvature

94N26-19S.PPT

2L694N26-619

Measuring the BOZR of Spherical SCLs as a Function of the Sag and Chord Diameter: Air Checking

Radiuscope

- Parelhoff and Weissman (1986) modified the lens mount of the radiuscope to allow air-checking of SCLs.

For their technique, the lens mount is constructed with a stage so that the lens can be measured within the depth of field of the radiuscope. The lens is set on an unpolished button of 11.9 mm diameter (chord diameter). This diameter accommodates the back optic zone diameter (BOZD) of most SCLs.

24

MEASURING THE BOZR AS A FUNCTION OF THE SAG AND CHORD DIAMETER: AIR CHECKING (Radiuscope)

Formula for computing the BOZR:

(Parelhoff & Wessman, 1986)

$$h = r - (r^2 - y^2)^{1/2}$$

94N26-20S.PPT

2L694N26-20

- The lens is set concave side up and its thickness is measured after calibrating the radiuscope from the height of the stage/button.
- The lens is then turned concave side down and its apex is located and focused.
- The BOZR is then computed based on the formula below (Parelhoff and Weissman 1986):

$$h = r - (r^2 - y^2)^{1/2}$$

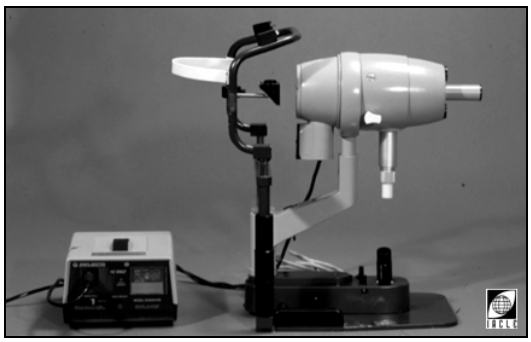
where:

h = sagittal depth

r = base curve

y = 1/2 chord length (11.9/2)

25



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Keratometer

The keratometer which is used for measuring corneal curvature can also be used to measure the BOZR of a contact lens by using special attachments.

Principle of the Keratometer (Stone and Phillips, 1989)

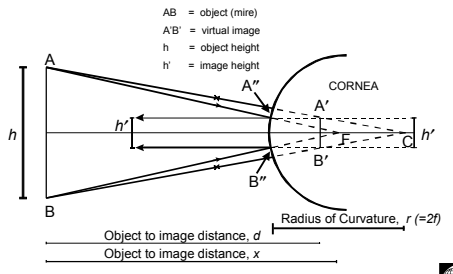
Illuminated object mires are reflected from the front surface of the cornea which acts as a convex mirror.

Measures the image size of the reflected image (Purkinje Image 1) formed by the cornea of an object of known linear size.

NOTE: A more in-depth discussion is found in Unit 1.2.

26

OPTICAL PRINCIPLE OF KERATOMETRY



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27

MEASURING THE BOZR (Keratometer) SPHERICAL RGP

- Keratometer set-up is modified with a lens holder and prism or mirror attachment
- Values derived are less than the actual radii
- The same procedure for measuring the cornea is used for contact lenses

94N26-22S.PPT

2L694N26-22

Measuring the BOZR of Spherical RGP Lenses

Keratometer

- Use of the keratometer to measure RGP lenses requires a lens holder and prism or mirror attachment. Its function is to allow the image formed by the contact lens surface to be reflected into the keratometer.
- Because the keratometer is designed to measure convex surfaces, the back surface readings will be less than the actual radii.
- The procedure followed is the same as that for measuring the cornea.

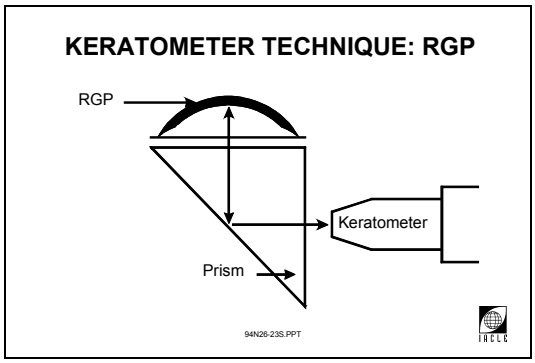
28

2L60227-96

Types of Lens Holders/Attachments for Keratometry of RGP Lenses

- Lens mount plus silver surfaced mirror.
- Lens holder with depression.
- Right-angled prism with aluminium backing.

29



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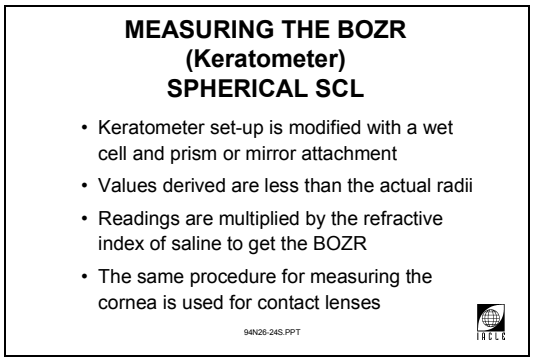

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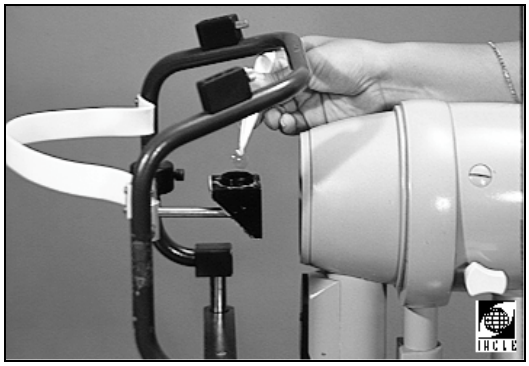
Measuring the BOZR of Spherical SCLs

Keratometer

- A further modification of the prism or mirror attachment is made by designing a wet cell for the SCL.
- The measured BOZR is less than the actual radius and has an error value of about 0.03 mm. The BOZR can be derived by multiplying the measured value by the refractive index of saline.
- The procedure followed is the same as that used for measuring the cornea.

31



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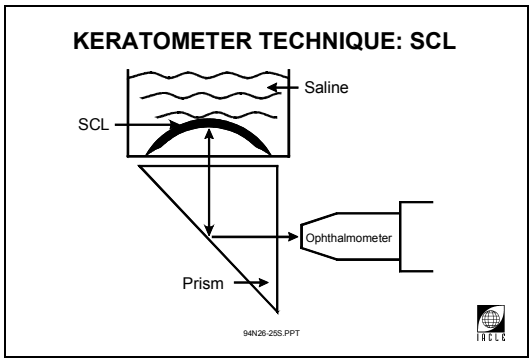

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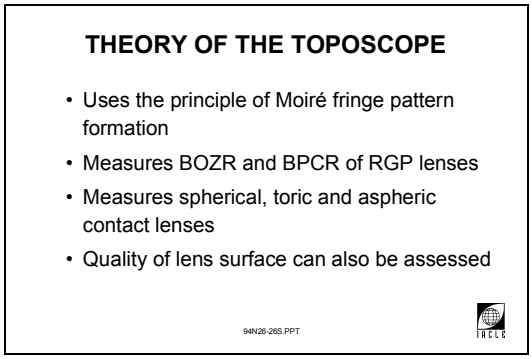

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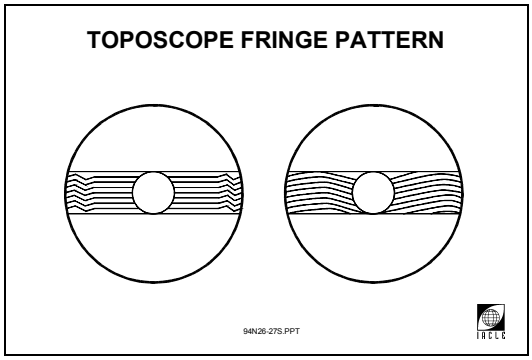

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Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Toposcope

The toposcope was one of the earliest instruments used to examine the quality and back surface curvature of RGP lenses. The toposcope allowed measurement of spherical, toric and aspheric contact lenses. The fringe pattern generated by the toposcope gave a meaningful representation of the quality of the lens surface.

Theory of the Toposcope

- Although the toposcope is no longer manufactured, the principle of Moiré fringe pattern formation underlying the instrument is still used in current instrumentation.
- The Moiré pattern is formed by superimposing sets of lines from that projected on the surface of the lens and at the eyepiece at different orientations.
- Magnification is adjusted so that the fringe pattern aligns with the central index seen in the field of view of the toposcope. The degree of magnification change is translated as the radius of curvature. The radius of curvature is read off the magnification dial of the instrument.

35

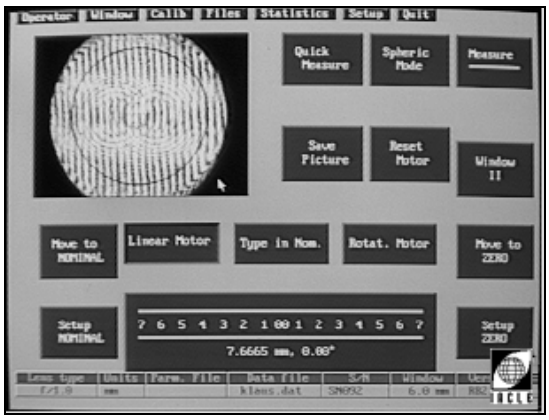
2L60203-96

Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Moiré Fringe Deflectometer (Brass 2™)

Rotlex Optics Ltd. (1994) have developed a computer generated analysis of the BOZR using the principle of Moiré fringes. This analysis is performed by a device known as the Moiré fringe deflectometer. The deflectometer (the Brass 2™) is utilised as a quality control instrument in contact lens manufacture and research for the assessment of lens parameters.

36



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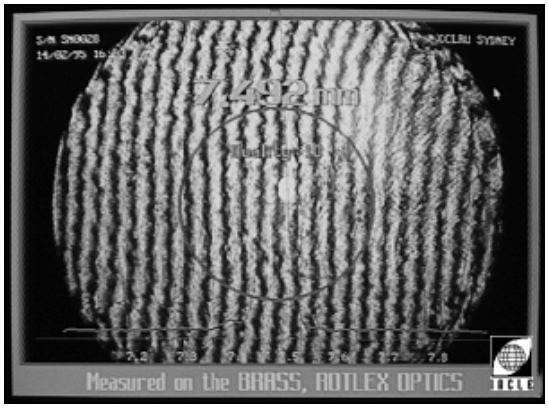
37



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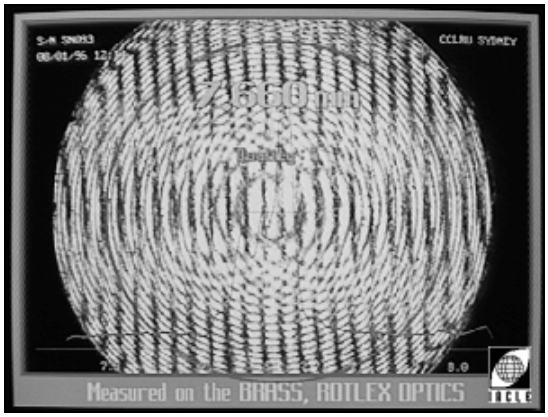
38



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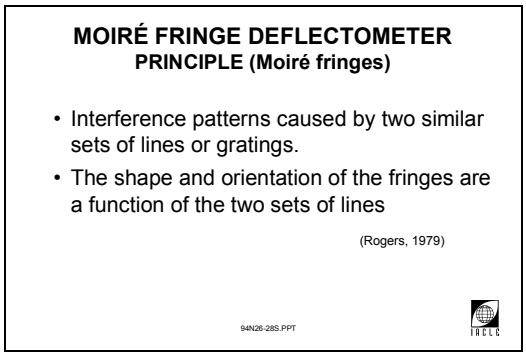
Features of the Moiré Deflectometer (Brass 2™)

The Brass 2™ Moiré deflectometer is now the most advanced technology available for contact lens manufacturing quality control. It has the following capabilities:

- Measures spherical, toric and aspheric RGPs and SCLs.
- Measures zonal and annular radii of curvature.
- Optical quality of the lens surface can be assessed from the appearance of the fringe pattern. The image of the fringe pattern is converted and saved in an electronic format so it can viewed with the computer monitor as seen in slides 35 and 36. Slides 37 and 38 show good and bad quality lens surfaces, respectively.
- Provides a graphical representation of quality across the lens surface as well as its overall rating scale.

39



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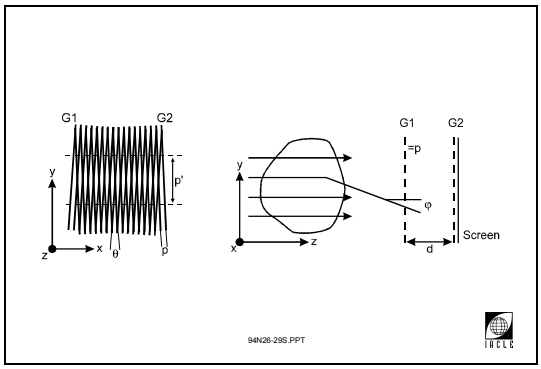
Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Principle of the Moiré Fringe Deflectometer

- Fringe patterns are formed when two sets of lines or gratings interfere with a collimated light source that passes through the lens.
- The shape and orientation of lens fringe patterns are a function of the two sets of lines (Rogers, 1979). The collimated light source that passes through the lens is distorted and causes the image of the first grating to be distorted at the second grating (Rotlex Optics Ltd., 1994).

40



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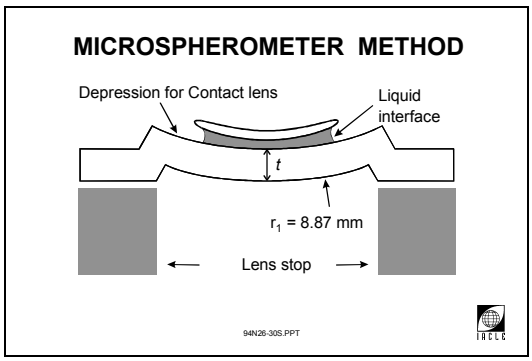
41



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Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Radius Checking Device (R-C Device)

Sarver and Kerr (1964) used the principle of the thick lens system to design the R-C Device whose refractive index is the same as the lens material. The contact lens floats on a liquid interface which has the same refractive index as the lens material. The R-C device is used in conjunction with the focimeter and lens thickness gauge.

Theory of the R-C Device

- Made of plastic with refractive index of 1.49.
- Radius of curvature of the device is flatter than most contact lenses.
- Liquid used has a refractive index of 1.49.
- Thickness of the liquid lens is negligible.
- Device, liquid and lens compose a ‘thick lens’ system.

42

THEORY OF THE RADIUS CHECKING DEVICE

(Sarver & Kerr, 1984)

Formulae for computing the BOZR:

$$F_v = \frac{F_2}{1 - \frac{t_1 + t_2}{1000} F_2} + F_1$$

$$r_2 = \frac{(1-n)(1000)}{F_v + F_1} + \frac{(t_1 + t_2)(1-n)}{n}$$

94N26-31S.PPT

2L694N26-31

Slide 42 shows the formulae used to compute the BOZR (Phillips and Stone, 1989).

where:

n = index of refraction of the 'thick lens' system.

F_1 = front surface power of the device.

t_1 = thickness of the device (mm).

t_2 = thickness of the contact lens measured with a thickness gauge (mm).

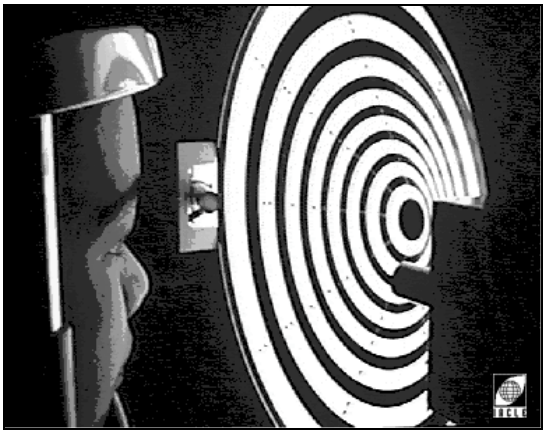
F_2 = back surface power of the contact lens (D).

r_2 = back surface radius of the contact lens (mm).

F_v = front vertex power of the 'thick lens' system measured with the focimeter (D).

Alternatively, a calibration table (see Sarver and Kerr, 1964) may be used to determine r_2, by subtracting the calibrated value of the 'thick lens' power from the calibrated value of the contact lens thickness.

43



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Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Topographical Mapping System

By combining the features of the photokeratoscope and a built-in camera, polaroid images of the cornea are captured and viewed with a computer monitor. The computer software which forms part of the system performs complicated algorithms and digitises the polaroid image of the cornea to arrive at a topographical map of the cornea.

Theory of the Topographical Mapping System

- Computerised topographical mapping systems or videokeratoscopes have been evaluated by El Hage and Bacigalupi (1992) who consider them to be useful instruments for measuring contact lenses. Unlike the keratometer, the videokeratoscope locates points in space and thus does not assume the surface to be of any specific shape.
- To use the instrument, a special lens holder is required to position the lens in front and at the plane of the headrest.

44

THEORY OF THE EH-270 CCT

(EL Hage & Bacigalupi, 1992)

- Does not assume the surface measured to be of any specific shape
- Requires a special lens holder to position the lens in front of the instrument
- Measures BOZR, BPCR, BOZD and BPCW of RGP lenses

94N26-32S.PPT

2L694N26-32

45

PRINCIPLE OF THE ELECTRONIC DEVICE TO MEASURE RADIUS OF CURVATURE

(Hamano & Kawabe, 1978)

The device is based on electrical current generated by an electro-conductive needle when it touches the surface of the soft contact lens

94N26-33S.PPT

2L694N26-33

46

THEORY OF THE ELECTRONIC DEVICE

(Hamano & Kawabe, 1978)

- BOZR (inner radius) measurements are a function of the sag and chord diameter
- Inner radius is determined by the digital read-out attached to the electroconductive needle
- Thicker lenses are less affected by vaporization than thinner ones

94N26-34S.PPT

2L694N26-34

Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Electrical Conductivity Method

SCL materials are hydrophilic and electro-conductive. Hamano and Kawabe (1978) have developed a device that uses a needle to transmit electrical current to a read-out device when it touches the lens surface.

Theory of the Electronic Device

A study by Hamano and Kawabe (1978) on an electronic device to measure the inner radius of soft contact lenses demonstrated the following:

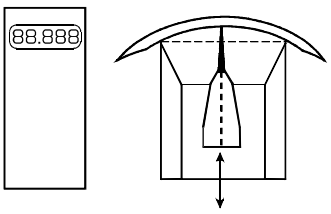
- BOZR (inner radius) measurements are a function of the sag and chord diameter.
- Inner radius is determined by the digital read-out attached to the electro-conductive needle.
- There were indications that thicker lenses are less affected by vaporisation than thinner ones.

47

2L60031-96

48

MICROSPHEROMETER METHOD



94N26-35S.PPT

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Other Methods for Measuring the Radius of Curvature of RGP and SCLs

Microspherometer

Manual and electrical microspherometers both use tactile probes to touch the inner surface of the lens which is positioned on the support ring. Internal validity and the systematic errors that occur during use of the instrument are of major concern, especially with the manual microspherometer as explained below.

49

THEORY OF THE MICROSPHEROMETER

- Manual and electrical types
- Measures SCL by tactile probe that touches the inner lens surface
- Difficulty in determining when the probe touches the lens
- Systematic errors (Forst, 1973):
  - deformation caused by surface tension while lens sits on the support ring
  - deformation caused by pressure of lens probe

94N26-36S.PPT

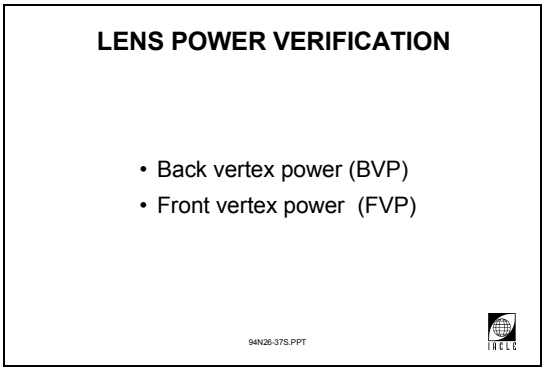
2L694N26-36

Theory of the Microspherometer

- The major problem with the device is determining when the probe is touching the surface of the lens. Accurate assessment of this depends on the skill of the technician.
- Forst (1973) compared various microspherometer methods of measuring the BOZR. The microspherometer had the following systematic errors:
  - deformation caused by surface tension while the lens is seated on the support ring
  - deformation caused by pressure of the lens probe.

II.B Lens Power Verification

50



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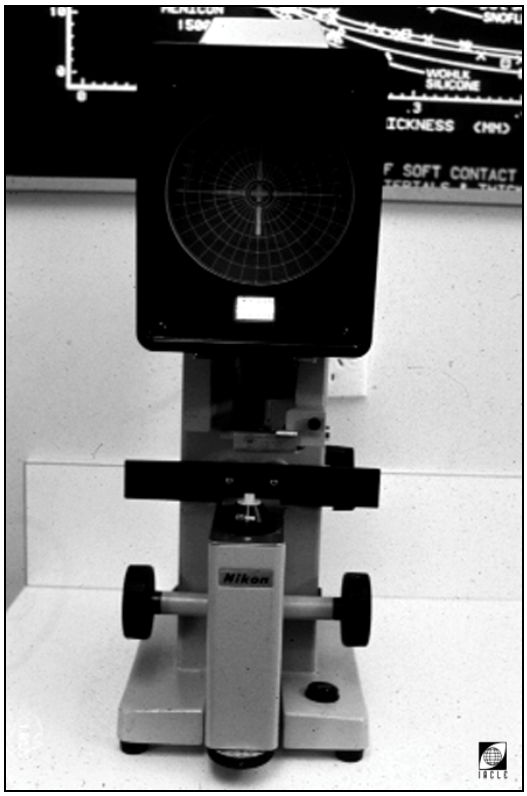
Lens Power Verification

- Front and back surface radii of curvature.
- Centre thickness.
- Refractive index.

From these parameters, the front and back vertex powers of contact lenses can be calculated. The *focimeter*, otherwise known as the lensometer, simply and accurately measures the focal lengths of lens surfaces.

51



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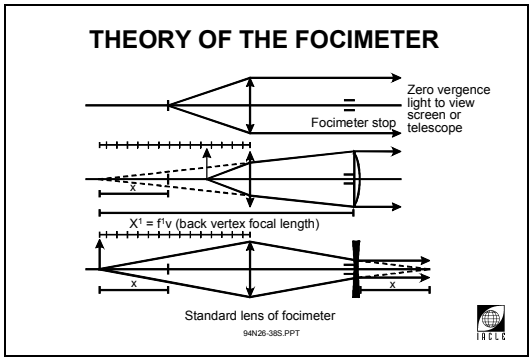
Focimeter

52



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53

POWER
BACK VERTEX POWER

- Focimeter (Lensometer) (aperture =4mm)

Tolerances:

± 0.12 D within ± 10.0 D
± 0.25 D over ± 10.0 D

94N26-39S.PPT

2L694N26-39

Back Vertex Power

The parameter usually referred to by laboratories as a measure of the power of contact lenses is the back vertex power (BVP).

The focimeter provides accurate measurements of BVP within the following tolerances:

- ± 0.12 D within ± 10.0 D
- ± 0.25 D over ± 10.0 D

54

MEASURING THE BVP (Focimeter)
SPHERICAL RGP

- Lens is cleaned and dried
- Lens must be centred concave side down on the focimeter stop
- Reading is taken off the power drum/scale after focusing the mires
- Back vertex focal length is measured from the plane of the focimeter stop

(Stone & Phillips, 1989)

94N26-40S.PPT

2L694N26-40

Measuring BVP of Spherical RGP Lenses

Focimeter

The following standard procedure measures spherical RGP lenses:

- Lenses are cleaned and dried, and centred on the focimeter support, concave side down.
- The mires are focused and the reading is taken off the power drum/scale.

A slight variation of the power drum reading from the actual focal length occurs because the focimeter measures BVP from the plane of the focimeter stop (Stone and Phillips, 1989). This error can be minimised by reducing the aperture at the focimeter stop.

55

MEASURING THE BVP (Focimeter)
TORIC RGP

- Power for each meridian is measured
- Cylinder value is derived from measuring the difference in meridional powers
- Amount of prism incorporated can be measured against concetric rings (=1Δ)

94N26-41S.PPT

2L694N26-41

Measuring BVP of Toric RGP Lenses

Focimeter

- The same procedure is used to measure toric lenses, except that the power for each meridian is measured.
- The amount of cylinder can be derived from the difference in meridional powers measured.
- As some toric lenses may be prism ballasted, the amount incorporated can be measured by using the concentric rings or similar graduations. These are usually equivalent to 1 Δ of displacement.

56

MEASURING THE BVP (Focimeter)
SPHERICAL / TORIC SCL

- Lens is dabbed with a lint-free cloth/tissue
- Same procedure as for RGP lenses

94N26-42S.PPT

2L694N26-42

Measuring BVP of Spherical and Toric SCLs

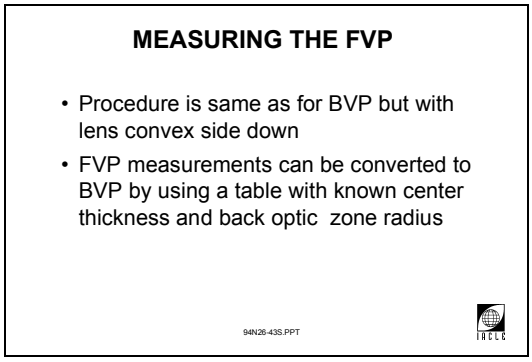
Focimeter

- The SCL is measured by air-checking it with the focimeter.
- The lens is dabbed with a lint-free cloth/tissue to remove excess water.
- The SCL is centred on the focimeter support and the procedure used to measure RGP lenses is followed.

An SCL can also be measured by immersing the lens in saline contained in a wet cell. Because the lens power is measured in saline, the value has to be multiplied by four (approximately) to calculate the true lens power in air. Yumori and Mandell

(1981) have calculated more precise correction factors for lenses of varying thicknesses, powers and sagittal depth. The values range from 4 - 6x factors.

57



2L694N26-43

Measuring FVP of RGP and SCLs

Focimeter

- The procedure used to measure BVP is used for FVP, except that the lens is centred concave side up on the focimeter support.
- Alternatively, FVP measurements can be converted to BVP by referring to a table containing centre thickness and back optic zone radius readings. Such a table can be found in the appendix section of *Contact Lenses* by Phillips and Stone (1989).

II.C Verification of Linear Parameters

58

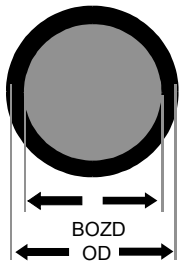
LINEAR PARAMETERS TO BE VERIFIED: RGP

- Lens diameters
  - back optic zone diameter (BOZD)
  - total diameter
  - peripheral curve width (PCW)
- Lens thickness
  - centre thickness (ct)
  - edge thickness

94N26-44S.PPT

2L694N26-44

59



Tolerances of BOZD:

No blend	- ±0.10
Light	- ±0.20
Medium	- ±0.30
Heavy	- ±0.40

94N26-45S.PPT

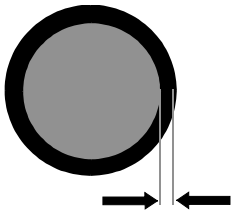
2L694N26-45

Tolerances for the BOZD Based on Transition Blend Weight

As a heavier blend is applied on an RGP lens the distinction between the optic zone and the periphery becomes less distinct. Measurements of the BOZD is accepted within measured tolerances based on the weight of the blending of transition zones:

No blend	-	±0.10 mm
Light	-	±0.20 mm
Medium	-	±0.30 mm
Heavy	-	±0.40 mm

60



94N26-46S.PPT

2L694N26-46

61

TOTAL DIAMETER

Instruments:

- Measuring magnifier 10x
- V gauge
- Projection magnification with scale

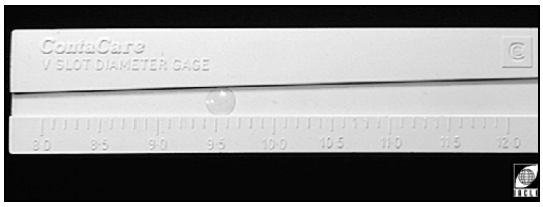
94N26-47S.PPT

2L694N26-47

Total Diameter Verification of RGP Lenses

The total diameter (TD) of a contact lens can be measured with a variety of instruments. The most commonly used clinical and laboratory instruments are listed in slide 61.

62

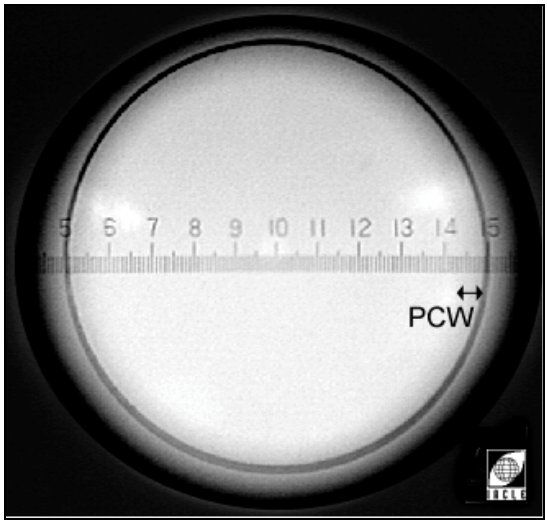


2L60213-96

V-Gauge

The slot gauge or V-gauge is a simple, cheap device available to practitioners. It provides a satisfactory verification of lens diameter for clinical purposes. The rigid lens is slid along the V-channel (angle of 1.5°) and the diameter is read off the millimetre scale.

63

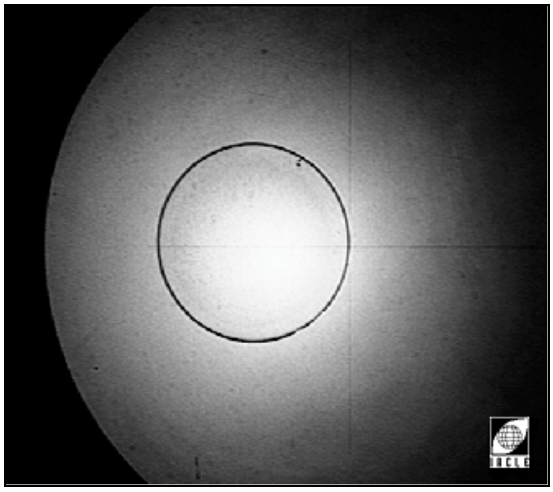


2L60214-96

Magnification Loupe (10x)

The Peak™ 10x loupe has a graticule in millimetre scale and a magnifying lens to allow an enlarged and accurate reading of the total and zonal diameters of a rigid lens. The illustration shows a rigid lens as seen through the loupe. This device offers a practical method of in-office verification of lens diameters, intermediate and peripheral curve widths.

64



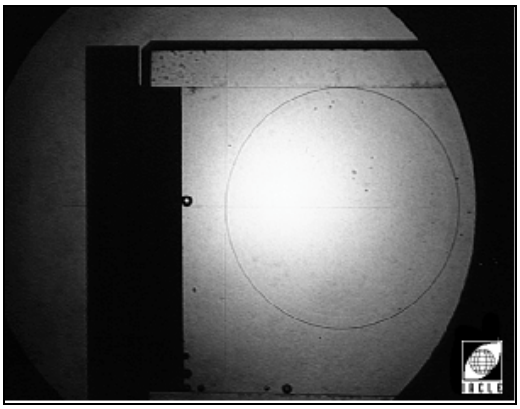
2L60217-96

Projection Magnifier with Electronic Micrometers

Projection magnifiers with electronic micrometers (e.g. Heidenhain gauge) are used mostly by laboratories for quality control and by institutions for contact lens research. They give magnified and accurate measurements of the total and zonal diameters to less than one-hundredth of a millimetre. Measurement can be done in conjunction with lens inspection of rigid and soft (in wet cell) lenses (see slides 64, 65 and 81).

NOTE: The Moiré fringe deflectometer (Brass 2™), introduced earlier, can also provide total lens diameter measurements.

65



2L60218-96

66

PERIPHERAL CURVE WIDTH (BICURVE LENS)

- Measuring magnifier 10x
- Calculation: $\frac{TD - BOZD}{2}$

94N26-48S.PPT

2L694N26-48

Peripheral Curve Width Verification of RGP Lenses

The PCW can be measured with most of the above-mentioned instruments.

Where direct measurements may be difficult, the PCW can be calculated with the following formula for a bicurve lens:

$$PCW = \frac{TD - BOZD}{2}$$

where:

PCW = peripheral curve width

TD = total diameter

BOZD = back optic zone diameter

67

LESS THICKNESS VERIFICATION: RGP

- Dial thickness gauge
- Electronic thickness gauge
- Radiuscope

  Tolerances: ± 0.02

94N26-49S.PPT

2L694N26-49

Lens Thickness Verification of RGP Lenses

The thickness verification instruments for RGP lenses are the following:

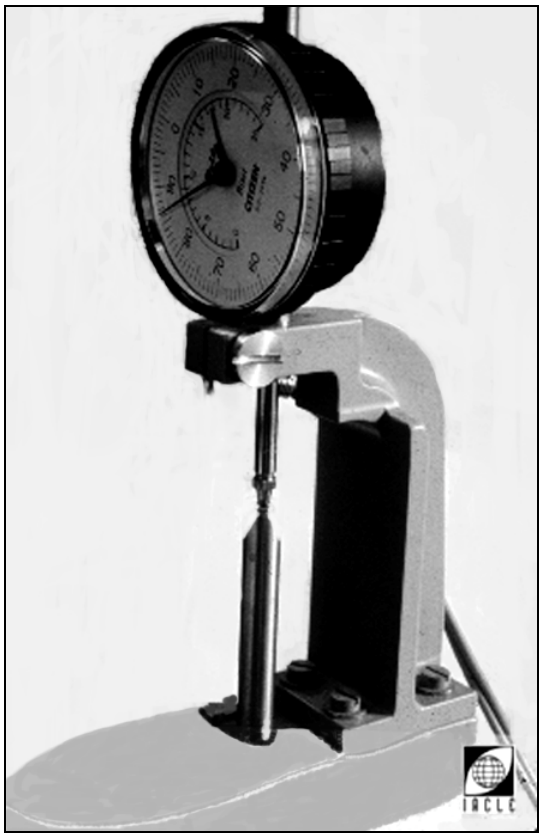
Thickness gauges

The thickness gauge (slide 68) has a dial or electronic digital gauge (Heidenhain gauge). The latter provides greater accuracy and can give readings to more than one-hundredth of a millimetre. RGP lenses must be cleaned and dried before the measurement.

Radiuscope

The radiuscope can measure centre thickness only (not edge thickness). This is done by placing the RGP lens on the lens mount without saline. The front and back surface radii are measured and the distance between both readings is noted. The difference between the focused spoke patterns is taken as the centre thickness. This measurement needs to be adjusted to allow for the refractive index of the lens material. The tolerance for radiuscope measurements is ±0.02 mm.

68



2L61705-96

69

LENS THICKNESS VERIFICATION: RGP

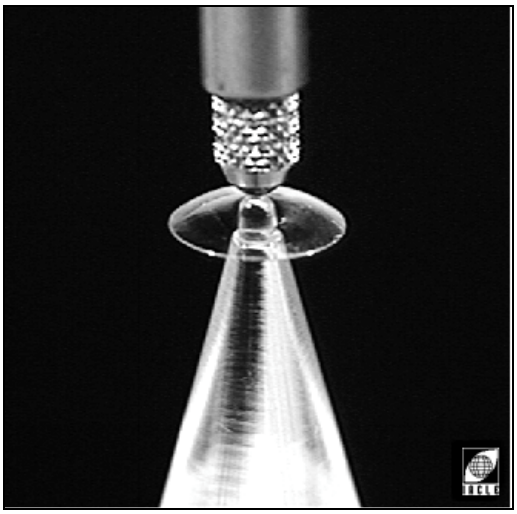
Centre: axial thickness

Edge: radial thickness

94N26-50S.PPT

2L694N26-50

70



2L60223-96

Lens Thickness Verification of RGP Lenses

Lens thickness measurements are taken at the centre and edge. To ensure precise understanding of which thickness parameter is actually being measured, it is important to define the terms used:

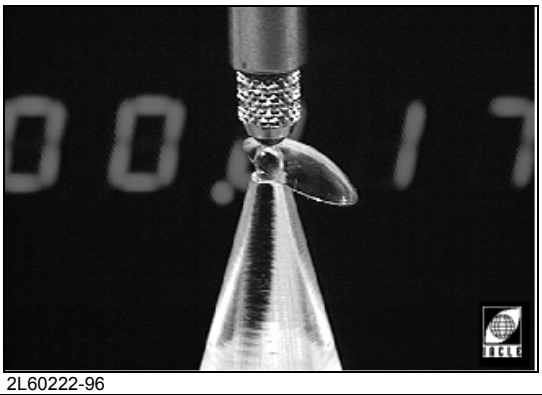
- Centre thickness.

  The lens is positioned so that the optic axis of the lens is parallel or coincident with the spindle of the thickness gauge (see slide 70). This gives a centre thickness measurement. This measurement is also termed the axial thickness. Tolerance is 10%.

- Edge thickness.

  The lens is positioned so that it is tilted on the thickness gauge. This makes the linear thickness measurement approximately coincident with the radius of the lens (see slide 71).

71



2L60222-96

72

LINEAR PARAMETERS TO BE VERIFIED:
SCL

- Lens diameters
  - total diameter
  - FOZD
- Lens thickness
  - centre thickness (ct)
  - edge thickness

94N26-51S.PPT

2L694N26-51

73

LENS DIAMETER VERIFICATION:
SCL (in wet cell)

Instruments:

- Projection magnifier
- Moiré fringe deflectometer
- 10x loupe with graticule

94N26-52S.PPT

2L694N26-52

Lens Diameter Verification of SCLs (in wet cell)

The diameter verification instruments for SCLs are the following:

Projection magnifier

Measures the lens to less than one hundredth of a millimetre using an electronic micrometer (e.g. Heidenhain gauge) which gives a digital read-out. This method requires the lens to be seated in a wet cell with saline solution.

Moiré fringe deflectometer

Lens diameter is measured in a wet cell which sits in the cuvette of the instrument.

10x loupe with graticule

The lens is placed in a wet cell and the loupe is placed in contact with the wet cell. The diameter is read directly from the scale.

74

LENS THICKNESS VERIFICATION:
SCL

(Paramore, 1981)

Instruments:

- Electronic thickness gauge
- Pressure controlled gauge
- Electrical thickness gauge
- Radiuscope (modified)

94N26-53S.PPT

2L694N26-53

75

2L60708-92

Lens Thickness Verification of SCLs

Thickness gauges

A variety of thickness gauges are available in the form of electrical or pressure controlled methods.

The electronic thickness gauge has a dome on which the lens sits (slide 75). The weight of the plunger can cause lower readings as more measurements are taken. Therefore, ‘unsquashed’ and ‘squashed’ readings from the Heidenhain gauge are averaged as the measure of centre thickness.

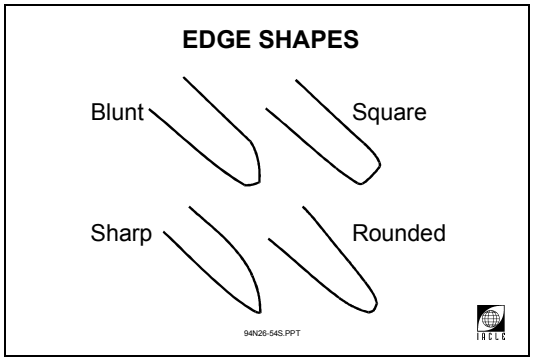
Radiuscope

In 1991, Paramore published a method of measuring the centre thickness of a SCL with the radiuscope using an aluminium base.

The initial measurement involves calibrating and focusing on the polished half of the base. The lens is then centred concave side up so that the second focus is measured for the back surface of the lens against the unpolished half of the base. The difference between these readings is taken as the centre thickness. The accuracy and reliability of the technique is within 0.01 mm.

II.D Edge Profile Verification

76



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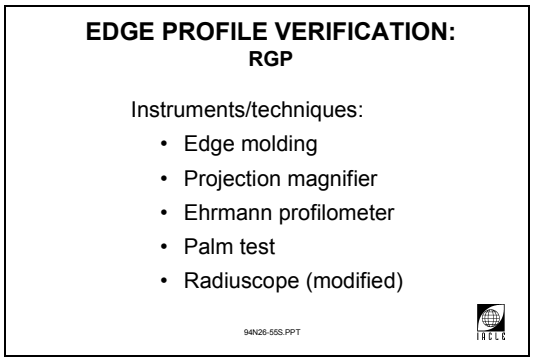
Edge Profile Verification of RGP Lenses

To determine the quality of the lens edge the following edge shapes and defects should be observed:

- Edge shapes

  The edge shapes depicted in the illustration are common examples for descriptive purposes. The ideal shape should be a thin rounded edge.

77



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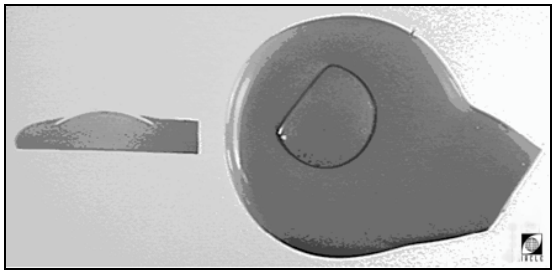
78



2L61060-93

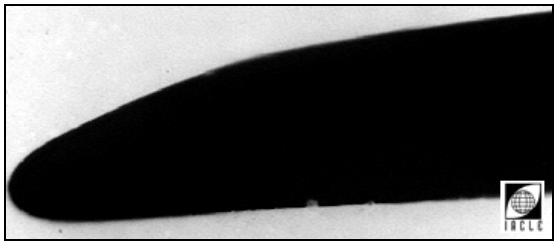
Edge Molding

- The edge profile of a RGP lens can be molded by depressing about 1 mm of the lens edge in plasticine or dental impression material (La Hood, 1988).
- Sections of the mold are cut to give a profile of the lens edge. This is examined with the projection magnifier or a stereomicroscope.

Problems:

- This technique is time consuming and requires skill.
- Sections of the mold may not be accurately cut through the centre. As a result the edge profile seen may not be the true edge shape.

79



2L61435-92

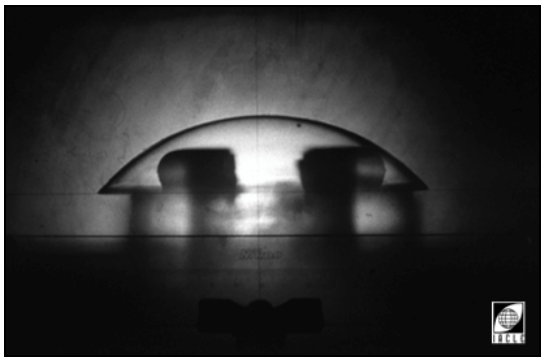
80

2L60707-92

Projection Magnifier

- Provides an optical method of examining the edge profile. The lens is positioned horizontally on a lens mount and increased magnification is used.
- Simultaneous sag height and lens diameter measurements may also be taken.
- Measurements are read off the attached electronic (Heidenhain) gauge.
- A qualitative assessment of the edge profile is made. It is important to recognise that the optical profile seen is not a true section of the lens edge.

81



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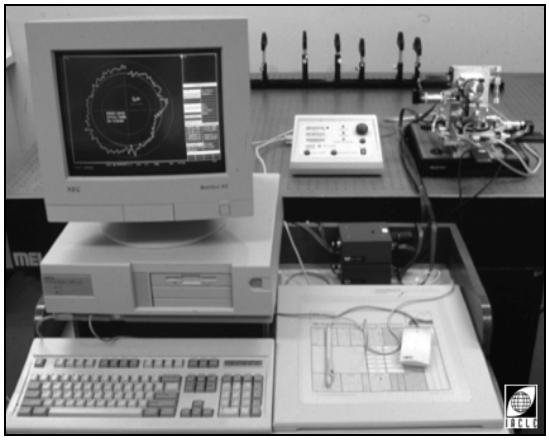
82

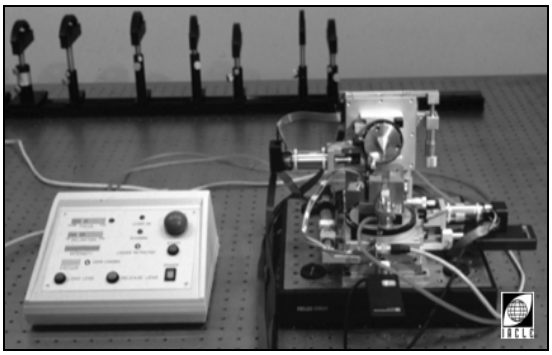


2L62046-94

Ehrmann Edge Profilometer (1995)

- The optical profilometer was developed as a self-guiding laser scanning device. A sensor collects the data points along the lens surface and a numerical data analysis is performed by the computer.
- A specific meridian is chosen and measured, and a profile is generated by the computer.
- Its capabilities include measurement of the lens parameters (BOZR, FOZR, BVP, lens thickness and diameter) and analysis of the edge profile.
- An error curve can be generated which records any of the measurements from the nominal parameters of the lens.

83



2L62045-94

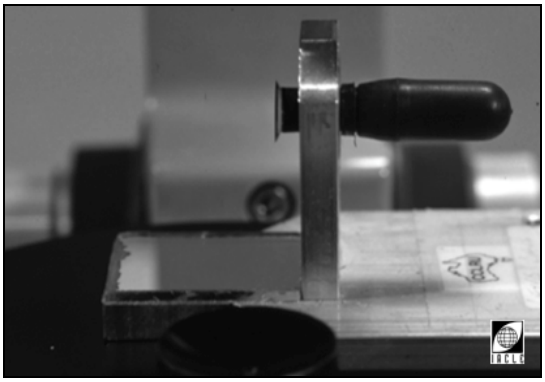
84

2L60211-96

Palm Test

This technique involves making the lens edge glide along the palm and ‘feeling’ the edge. It is a highly subjective technique and its accuracy and reliability are very limited.

85



2L60229-96

Radiuscope (modified)

- Contact lens laboratories have used the radiuscope to look at the edge profile of RGP lenses. A mirror-backed lens mount is required with the lens positioned vertically.
- The radiuscope can give about 10x magnification of the lens edge profile.
- As is the case with the projection magnifier, the edge profile seen through the radiuscope does not give a true profile of the lens edge. However, the display is adequate for examination of edge quality.

II.E Lens and Surface Quality Assessment

86

LENS AND SURFACE QUALITY ASSESSMENT

- Surface defects
- Optical quality
- Lens impurities/deposits

94N26-56S.PPT

2L694N26-56

Lens and Surface Quality Assessment

Before and after being dispensed to a patient, contact lenses must be examined for defects.

87

SURFACE QUALITY

Scratches and lathe marks:

- Can cause: - deposit build up
  - poor wettability
  - surface hydrophobicity
- Indicate overpolishing during manufacture

94N26-57S.PPT

2L694N26-57

Surface Quality

The surface of an RGP contact lens must be checked for scratches and lathe marks as these can cause deposit build-up, poor wettability and surface hydrophobicity. They are indications of manufacturing defects usually associated with over-polishing.

Soft contact lens manufacturing defects include lathe marks and edge defects.

88

LENS AND SURFACE QUALITY ASSESSMENT: RGP AND SCL

Instruments:

- Magnifying 10x loupe
- Projection magnifier
- Contact lens optical quality analyser (CLOQA)
- Dark field microscope
- Moire fringe deflectometer

94N26-58S.PPT

2L694N26-58

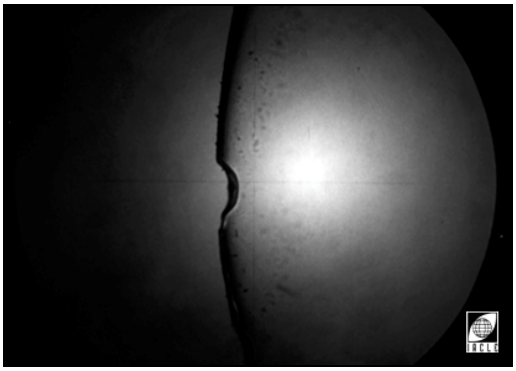
89

2L60212-96

Lens Inspection with a Magnifying Loupe

A 10X loupe, without a graticule, allows the inspection of the surface quality of RGP contact lenses. The lens is placed concave side down against the glass face and the instrument is directed towards the light.

90



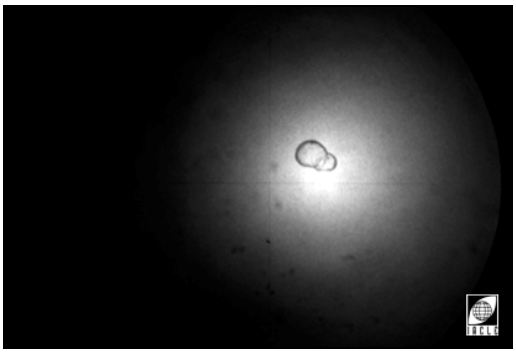
2L60215-96

Edge Defect of RGP Lens Viewed with a Projection Magnifier

This RGP lens was presented by a patient who had complained of minor discomfort during lens wear.

Adjacent to the large chip are smaller chips that would otherwise not have produced the patient's symptoms of discomfort. This demonstrates the need for regular lens examination during patient aftercare visits.

91

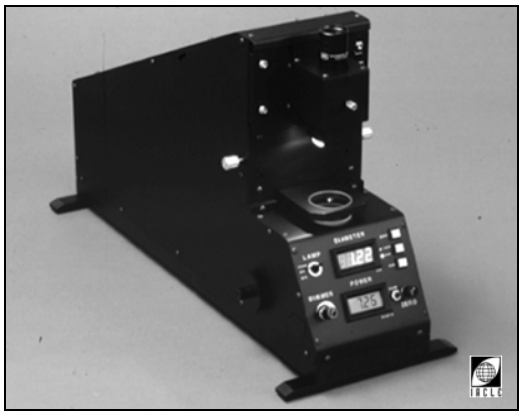


2L60220-96

Lens and Surface Quality Assessment of SCLs

Jelly Bump Observed with 100x Magnification Using the Projection Magnifier

92

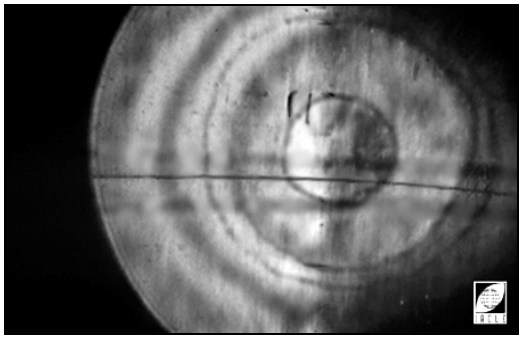


2L61571-96

Contact Lens Optical Quality Analyser (CLOQA)

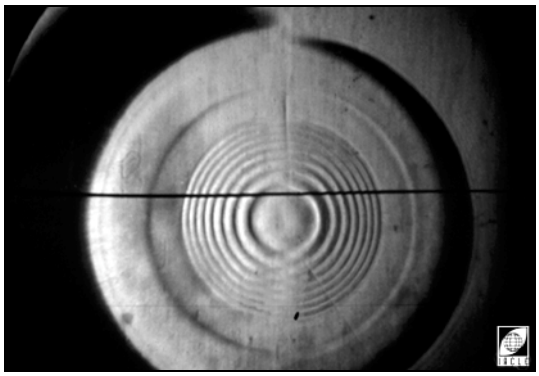
The Contact Lens Optical Quality Analyser is based on the Foucault knife edge principle. This principle is demonstrated by the lens shown (slide 92) where light refracted through the lens undergoes chromatic dispersion. Any optical irregularity caused by lathe marks, variation in the index of refraction, distortion etc., is seen as a chromatic 'shadow' of the lens.

93



2L61980-91

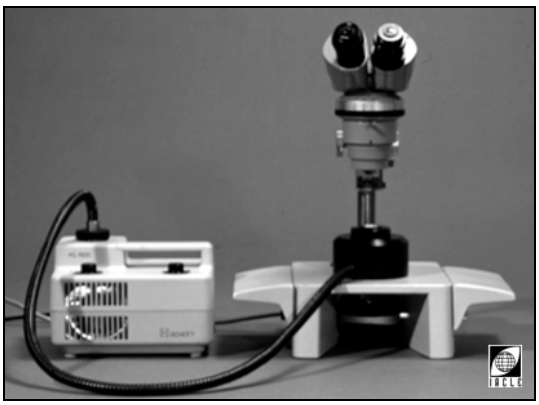
94



2L60831-91

Diffractive Bifocal Seen Through the Contact Lens Optical Quality Analyser (CLOQA)

95



2L60231-96

Dark Field Microscope

Dark field microscopy has been used in surface quality assessment of SCLs. It offers:

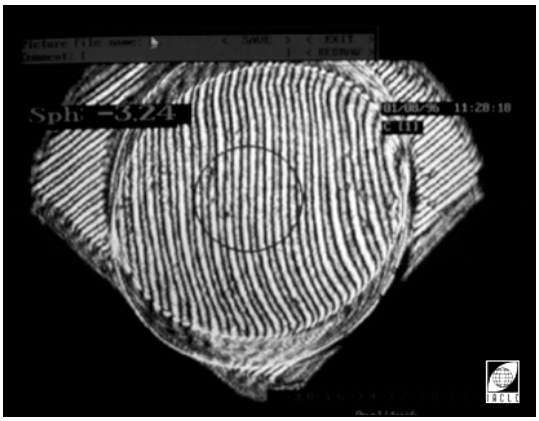
- A wide magnification range of 10 to 100x.
- Variable depth of focus.
- Bright illumination to highlight surface defects and deposit formation.

A camera can be attached to one of the eyepieces by using an adaptor. This enables a photographic record to be made of the lens condition.

96

2L60232-96

97



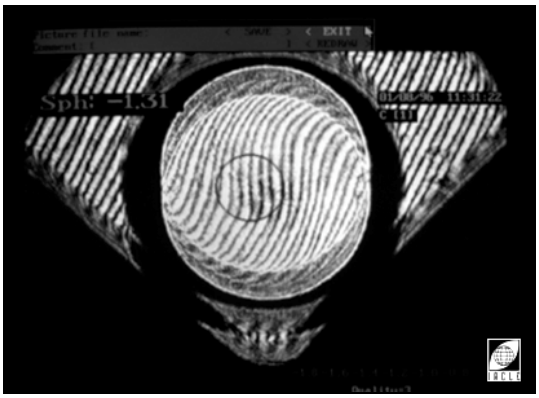
2L60208-96

Moiré Fringe Deflectometer with ConTest™ (Rotlex Optical Ltd., 1995)

The Moiré Fringe deflectometer principle is used in conjunction with the Con Test™ computer program to assess the optical quality of contact lenses.

The lens is positioned in a cuvette and the program generates an image of the Moiré fringe pattern formation through the lens. Lesser distortions in the pattern indicate superior lens quality. The fringe patterns shown in slides 97 and 98 illustrate good and poor lens quality, respectively.

98



2L60209-96

99

COLOUR/TINT

- White background test
- Variation in thickness

94N26-59S.PPT

2L694N26-59

Verification of Colour/Tint of Rigid and SCLs

Many contact lenses are manufactured with handling tints that can be checked against a white background. The depth of the tint will vary with different lens thicknesses. Lenses which are tinted for cosmetic purposes are discussed in Module 8.

100

CONTACT LENS RECORD FORM

Includes:
- Specifications ordered
- Specifications received
- Specification adjustments
- Final specifications

94N26-60S.PPT

2L694N26-60

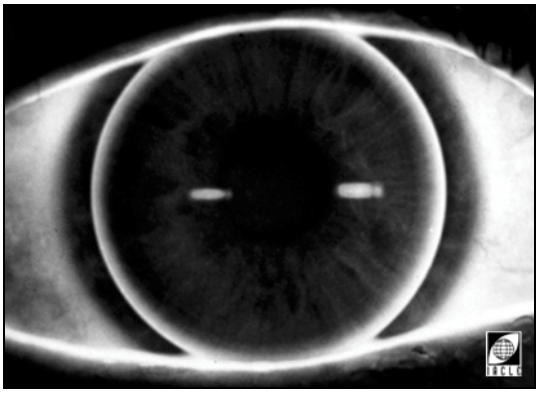
Contact Lens Record Form

The contact lens record form should include:

- Specifications ordered.
- Specifications received.
- Specification adjustments.
- Final specifications.

If the measured parameters of trial lenses used in the clinic are accurate then it will be possible to accurately predict the performance of ordered lenses.

101



2L60300-91

On-eye Fit: The Real Indicator

At the end of the verification process, the real indicator that an accurate and optimal fitting has been achieved is evaluation of the lens *in situ*.

Practical 2.6.1

(3 Hours)

RGP Contact Lens Verification

Setting Up the Verification Equipment

The supervisor will demonstrate how the instruments are set up and operated. The class will be divided into six groups: Each group should rotate and familiarise themselves with each of the instruments and devices. Lenses of known parameters should be labelled and assigned to each station.

The objective is to measure the lenses and attempt to obtain the same readings as those indicated on the labels. Difficulties and inaccuracies should be addressed prior to commencing Practical Session 2.

Station 1: Radiuscope

Station 2: Thickness gauges

Station 3: Focimeter

Station 4: 10x loupe and profile projector

Station 5: Diameter gauges

Station 6: Dark field microscope

Class and Individual Assessment:

- Proficiency in manipulating all the verification instruments.
- Measuring the sample lenses accurately and comparing the parameters with those indicated on the labels.

Setting Up the Verification Equipment

Station 1: Radiuscope

1. Clean, rinse and dry both surfaces of the lens.
2. Place a drop of saline in the depression of the concave lens mount, ensuring that the saline is not higher than the mount's surface.
3. Place the contact lens on the saline in the depression with the concave surface to be measured facing upwards.
4. Position the lens mount on its support on the stage of the instrument. The mount should be level in its support to ensure that the centre of the lens surface is normal to the optical axis of the microscope.
5. Set the voltage selector at 5.0 V (the most commonly used setting).
6. The aperture selector should be in the large aperture position at the back of the instrument.
7. Fully lower the objective of the microscope using the coarse adjustment knob.
8. Centre and position the lens mount so that the green beam of light is reflected from the centre of the contact lens.
9. Adjust the interpupillary distance if using a binocular model. Also adjust the focus of the microscope for each eye separately, using the fine adjustment knob.
10. Look into the eyepiece(s) and observe the scale on the right side of the field. Bring this scale into sharp focus using the scale focusing knob.
11. While looking into the eyepiece(s), turn the coarse adjustment knob to raise the objective until you see light coming into focus forming part or all of a spoke patterned target.
12. Move the stage horizontally until the target is centred in the field of view. This is the 'real' image of the target at the surface of the lens.
13. As the focus begins to sharpen, change to a fine adjustment knob to bring target into critical focus.
14. When the target is clear, use the index adjustment knob to move the index line to zero.
15. Now continue to raise the objective. At one point, the filament will come into focus and this image should be centred within the aperture. Disregard and continue lowering the objective with the coarse adjustment knob.
16. Raise the objective until the upper (aerial) image of the target again comes into view. Raise the objective slightly beyond the point at which the image appears sharpest.
17. Then lower the objective by focusing downward for the final setting so that more accurate readings are achieved.
18. Bring the image of the target into sharp, clear focus by using the fine adjustment knob and record the BOZR from the scale.
19. If a toric surface is being measured, one line of the spoke pattern will appear to be clearer (aerial image). A small rotational adjustment of the mount will aid in refining the focus. Refine the focus using the fine adjustment knob while rotating the mount. This is recorded as the BOZR of one principal meridian. The other principal meridian is measured by turning the fine adjustment knob until the opposite (90° away) spoke pattern comes into clear focus. Record this as the BOZR of the other principal meridian.
20. When measuring the convex radius (FOZR), the positions of the aerial and real images are reversed: the 'upper' image is the real image and the 'lower' is the aerial image. Use the mount with the raised central portion and place the lens convex surface up.

Station 2: Thickness Gauge

1. Zero the measuring device.
2. Lift the plunger gently.
3. Centre the lens on the bottom stop.
4. VERY GENTLY lower the plunger until it rests against the lens.
5. Read off the thickness and record to the nearest 0.01 mm.

Station 3: Focimeter

1. Focus the cross-hairs of the eyepiece.
2. Clean, rinse and dry the lens.
3. A contact lens accessory device can be attached to the focimeter to balance the lens which should have a smaller aperture stop than the lens diameter. Alternatively, mount the focimeter vertically. The lens may be 'balanced' between the thumb and index finger but care should be taken that the reading is not affected by flexing or applying pressure to the lens.
4. Centre the lens within the aperture, back surface down (i.e. concave surface down).
5. Obtain the clear mire image.
6. Record the back vertex power (BVP).
7. Now turn the lens over so that the front surface (convex) is resting against the lens stop.
8. Obtain the clearest mire image.
9. Record the front vertex power (FVP).

Station 4: Loupe and Profile Projector

Loupe

1. Clean, rinse and dry the lens
2. Gently hold the lens between the thumb and index finger.
3. Place the lens on the surface of the loupe containing the micrometer scale.
4. Hold the lens against the surface with the tip of the index finger so that the lens is not obscured from the viewed light source.
5. Gently move the lens until it is centred on the scale to avoid parallax error.
6. Read and record the width of the optical zone, the peripheral curves and total diameter.
7. It may be necessary to move the magnifier back and forth slightly in front of the light source to determine where the separation of the curves exist. Determine the edges of these. If a heavy transition zone blend has been used, it may be more difficult to accurately determine the widths.
8. Record any defects.
9. The profile of the edge can also be viewed by holding the lens flat between the thumb and index finger and viewing through the opposite end of the loupe.

Profile Projector

1. Place the lens on the lens mount.
2. Focus the instrument.
3. Use the required magnification.
4. Examine the edge shape of the lens and draw the profile (sharp, blunt, rounded, square, nicks, chips).

Station 5: Diameter V-Gauge

1. Ensure that the lens and channel are clean and dry to enable free movement of the lens
2. Place the lens at the widest end and allow it to slide freely until it is stopped by the sides of the V-channel.
3. Read and record the diameter of the lens.

Station 6: Dark-Field Microscope

1. Clean, rinse and dry the lens.
2. Gently place the lens on the flat base of the dark field microscope.
3. Adjust the magnification and illumination to examine the lens.
4. Record the appearance of each lens (e.g. surface scratches, tool marks, cracking/crazing, residual pitch, lens deposits).

Spherical RGP Parameter Verification
RECORD FORM

Name:_____ Date:_____

Instructions: Rotate through the following stations in the order shown in the schedule. Follow the procedure outlined for each station and record findings on the form below. For each parameter, record the mean of three measurements.

Station 1: Back and Front Optic Zone Radii (BOZR and FOZR), r_0 and r_{a0}

Use the radiuscope to measure and record the BOZR and FOZR of the lens.

LENS NUMBER___	BOZR (mm), r_0	FOZR (mm), r_{a0}
1.		
2.		
3.		

Station 2: Total Lens Diameter, $\varnothing_T$

Use the slot gauge to read and record the diameter of the lens.

LENS NUMBER	TOTAL DIAMETER (mm), $\varnothing_T$

Station 3: Geometrical Centre Thickness, t_c

Use the thickness gauge to read the thickness.

LENS NUMBER	GEOMETRICAL CENTRE THICKNESS (mm), t_c
1.	
2.	
3.	

Station 4: Edge Profile Inspection

Examine the edge shape of four lenses on the profile projector and draw the edge profile of each lens. Indicate which edge shape will provide the most comfort and which shape will cause the most discomfort to the patient when they blink.

LENS NUMBER	EDGE PROFILE	COMFORT

Station 5: Optic and Peripheral Zone Diameters (loupe)

Use the loupe to measure the optic and peripheral zone diameters of the lenses provided.

LENS NUMBER	OPTIC ZONE DIAMETER (mm)	PERIPHERAL ZONE DIAMETER (mm)

Station 6: Lens Inspection

Use the **10X loupe** to inspect the lenses provided. Record any defects seen.

LENS NUMBER	DEFECTS

Use the **dark field microscope** to examine the lenses. Record the appearance of each lens.

LENS NUMBER	APPEARANCE

Station 7: Front and Back Vertex Powers (F_v, F_v')

Use the focimeter to measure the front and back vertex power of the lenses provided.

LENS NUMBER	FRONT VERTEX POWER, F_v, (D)	BACK VERTEX POWER, F_v', (D)

Toric RGP Parameter Verification

RECORD FORM

Name:_____ Date:_____

Instructions: Rotate through the following stations in the order shown in the schedule. Follow the procedure outlined for each station and record findings on the form below. For each parameter, record the mean of three measurements.

Station 1: Back and Front Optic Zone Radii (BOZR and FOZR), r_0 and r_{a0}

Use the radiuscope to measure and record the BOZR and FOZR of the lens.

LENS NUMBER	BOZR (mm), r_0: 1st PM	BOZR (mm), r_0: 2nd PM

LENS NUMBER	FOZR (mm), r_{a0}: 1st PM	FOZR (mm), r_{a0}: 2nd PM

Station 2: Total Lens Diameter, $\varnothing_T$

Use the slot gauge to read and record the diameter of the lenses provided.

LENS NUMBER	TOTAL DIAMETER (mm), $\varnothing_T$

Station 3: Geometrical Centre Thickness, t_c and Radial Edge Thickness, t_{ER}

Use the thickness gauge to read the thickness of the lens at the centre and 1 mm from the edge. Record and calculate the mean thicknesses of each lens.

LENS NUMBER	GEOMETRICAL CENTRE THICKNESS (mm), t_c	RADIAL EDGE THICKNESS (mm), t_{ER}
1.		
2.		
3.		

Station 4: Optic and Peripheral Zone Diameters

Use the loupe to measure the optic and peripheral zone diameters of the lenses provided.

LENS NUMBER	OPTIC ZONE DIAMETER (mm)	PERIPHERAL ZONE DIAMETER (mm)

Station 5: Front and Back Vertex Power (F_v, F_v')

Use the focimeter to measure the front and back vertex power of the lenses provided.

LENS NUMBER	FRONT VERTEX POWER, F_v, (D)	BACK VERTEX POWER, F_v', (D)
	_____Sph_____Cyl_____	_____Sph_____Cyl_____
	_____Sph_____Cyl_____	_____Sph_____Cyl_____
	_____Sph_____Cyl_____	_____Sph_____Cyl_____

Practical 2.6.2

(3 Hours)

Soft Contact Lens Verification

Setting Up the Verification Equipment

The supervisor will demonstrate how the instruments are set up and operated. The class will be divided into six groups: each group should rotate and familiarise themselves with each of the instruments and devices. Lenses of known parameters should be labelled and assigned to each station. The objective is to measure the lenses and attempt to obtain the same readings as those indicated on the labels.

Station 1: Modified keratometer

Station 2: Thickness gauge

Station 3: Focimeter

Station 4: Profile projector

Station 5: Hand refractometer

Station 6: Dark-field microscope

Spherical SCL Parameter Verification

The students should complete the assigned exercises and record their findings on the record forms provided.

Station 1: Lens inspection (naked eye and dark field microscope)

Station 2: Front and back vertex powers (focimeter)

Station 3: Back optic zone radius (modified keratometer)

Station 4: Total lens diameter (profile projector)

Station 5: Geometrical centre thickness (thickness gauge)

Station 6: Inverted appearance (naked eye)

Station 7: Lens tinting (naked eye)

Station 8: Water content (hand refractometer)

Setting Up the Verification Equipment

Station 1: Modified Keratometer (Zeiss)

1. Place the lens in the wet cell (with the front surface resting on the O-ring).
2. Place the wet cell on the reflecting prism.
3. Locate the mires in the centre of the view through the eyepiece of the keratometer.
4. Turn the white knob beneath the keratometer until the hollow mire is filled with the solid mire (cross lines).
5. Read the radius measurement.
6. Convert this measurement to the true BOZR (multiply the reading by the refractive index of saline) and record the result.
7. Now find the best fit on the soft contact lens base curve template and compare this reading to the reading above.

Station 2: Thickness Gauge

1. Place clear plastic domes over the measuring pins so as not to damage the soft lens.
2. Zero the measuring device.
3. Blot the lens surface water with an absorbent lint-free tissue.
4. Centre the lens on the bottom stop.
5. VERY GENTLY lower the plunger until it rests against the lens.
6. Read and record the thickness. Repeat three times and record the mean of these measurements.

Station 3: Focimeter

1. Correctly focus the eye piece.
2. Place the lens on a lint free tissue. Fold the tissue over to blot both surfaces of the lens. Move the lens with the tweezers to a dry spot on the tissue and blot again. This process should be repeated three or four times.
3. Place the lens with the concave side against the lens stop. Centre the lens.
4. Obtain the clearest mire image.
5. Repeat the readings rapidly, two or three times to verify accuracy within 0.25 D. If the mires are distorted, reblotting or cleaning with a surfactant, rinsing and drying may be necessary.
6. Record the lens power.
7. Alternatively, the lens can be placed in a wet cell filled with saline and centred on the lens stop. Consult the appropriate conversion table to convert the readings.

Station 4: Profile Projector

1. Place the lens in a wet cell (with the front surface resting against the rubber O-ring).
2. Focus the image of the lens profile.
3. Set one side of the lens against the marker and zero the instrument gauge.
4. Move the lens until the opposite side is positioned against the marker.
5. Read and record the lens diameter.

Station 5: Hand-held Refractometer

1. Focus the refractometer by looking into the eyepiece and pointing the instrument towards the daylight or a bright artificial light. Rotate the eyepiece rim until the inner scale is sharply defined.
2. Dab the lens very lightly with a soft lint-free tissue to remove excess surface moisture. The lens surface should be moist prior to measurement. Therefore, do not dry the lens completely. If a lens is measured following lens wear, it need not be dabbed dry.
3. Open the daylight plate and place the lens gently on the centre of the prism with the convex (anterior) surface of the lens pointing downwards.
4. Close the daylight plate and apply light pressure on the top of the plate (on the Atago label) so that the lens is sandwiched between the daylight plate and the prism.
5. View the internal scale through the eyepiece. Point the instrument towards daylight or bright artificial light.
6. The position of the boundary between the upper and lower parts of the fields indicates the water content (%) of the lens, which can be read off the vertical water content scale (separation between the blue and white fields). Record this measurement.

Station 6: Dark-Field Microscope

1. Place the lens in the wet cell of the dark-field microscope.
2. Focus the instrument and adjust the magnification and illumination to examine the lens.
3. Record the appearance of the lens (e.g. manufacturing marks, scratches, tears, deposits).

Spherical SCL Parameter Verification
RECORD FORM

Name:_____ Date:_____

Instruction: Rotate through the following areas in the order shown in the schedule. Follow the procedure outlined for each station and record findings on the form below. For each parameter record the mean of three measurements.

Station 1: Lens Inspection

Examine the general appearance of the lenses with the naked eye and record your observations.

- remove excess fluid from the lens with a tissue
- hold the lens gently with the tweezers
- use your pen torch to illuminate the lens (from the side and from behind).

LENS NUMBER	APPEARANCE

Use the **dark-field microscope** to examine the lenses. Record the appearance of each lens.

LENS NUMBER	APPEARANCE

Station 2: Front and Back Vertex Powers, (F_v, F_v')

Use the focimeter to measure the front and back vertex powers of the lenses provided.

LENS NUMBER	FRONT VERTEX POWER, F_v, (D)	BACK VERTEX POWER, F_v', (D)

Station 3: Back Optic Zone Radius (BOZR), r_0

Use the keratometer to measure the BOZR of the lens

LENS NUMBER	BOZR, r_0, (mm)

Station 4: Total Lens Diameter, $\varnothing_T$

Use the projection magnifier to measure the diameter of the lenses.

LENS NUMBER	TOTAL LENS DIAMETER, $\varnothing_T$, (mm)

Station 5: Geometrical Centre Thickness, t_c

Use the thickness gauge to measure the thickness of the lenses.

LENS	GEOMETRICAL CENTRE THICKNESS (mm), t_c

Station 6: Inverted Appearance

Examine the lens to determine if it is inside out:

- Blot the lens with a lint free tissue.
- Place the lens on a dry finger tip and hold it up to eye level.
- Does it form a smooth bowl shape indicating that the lens is resting on your finger with the back surface facing up?
- Turn it inside out and compare the shape (bowl *versus* Mexican hat).

Station 7: Lens Tinting

Examine the lenses provided and describe the appearance of the various tints. Assess the following: colour, depth of tint, small aperture or clear pupil, opaque versus non-opaque.

LENS NUMBER	TINT APPEARANCE

Station 8: Water Content

Use the hand refractometer to measure the water content.

LENS NUMBER	WATER CONTENT

Toric SCL Parameter Verification
RECORD FORM

Name:_____ Date:_____

Instruction: Rotate through the following areas in the order shown in the schedule. Follow the procedure outlined for each station and record findings on the form below. Allow a maximum of five minutes per station.

Station 1: Lens Inspection

Examine the general appearance of the lenses (lens design) with the naked eye and record your observations.

- Remove excess fluid from the lens with a tissue.
- Hold the lens gently with the tweezers.
- Use your pen torch to illuminate the lens (from the side and from behind).

LENS NUMBER	APPEARANCE

Use the **dark-field microscope** to examine the lenses.

LENS NUMBER	APPEARANCE

Station 2: Front and Back Vertex Powers, (F_v, F_v')

Use the focimeter to measure the front and back vertex powers of the lenses provided.

LENS NUMBER	FRONT VERTEX POWER, F_v ,(D)	BACK VERTEX POWER, F_v', (D)
	_____Sph_____Cyl _____	_____Sph_____Cyl _____
	_____Sph_____Cyl _____	_____Sph_____Cyl _____

Station 3: Laser Marking Inspection

Examine the lenses provided with the 10x loupe and note any type of laser markings that may be on the lens such as:

- /|\
- |
- R
- L
- ●

LENS NUMBER	LENS MARKINGS

Practical 2.6.3

(8 Hours)

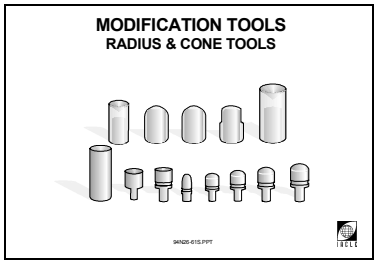
Modification of Rigid Gas Permeable Lenses

Schedule of Practical Session

Modification of RGP Lenses

The preparation and use of tools and equipment during the modification process will be demonstrated by the instructor. The students should familiarize themselves with the following tools and equipment:

- Cones.
- Sponge.
- Suction cup.
- Peripheral radius tools.
- Spinner.
- Polishes.
- Magnification loupe.
- Radiuscope.
- Projection magnifier.
- Polishing bowl.
- Focimeter.
- Thickness gauge.



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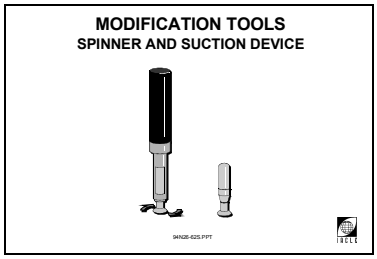

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After each student has performed the modifications at each station, the lenses should be checked by the instructor and the laboratory sheet signed.

Station 1: Surface polishing and changing power

Station 2: Adjusting peripheral curves

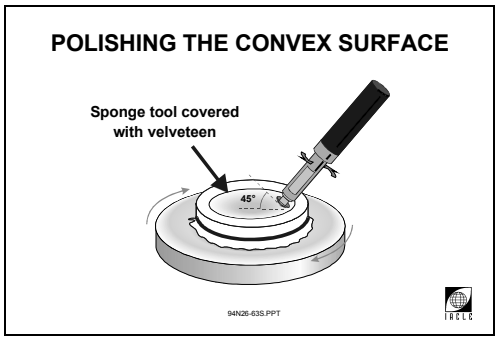
Station 3: Edge modification

Station 4: Reducing the diameter

Station 5: Finishing from semi-finished blank

Station 1: Surface Polishing and Changing Power

1. The preferred polishing compound is XPAL. This is a powder which has to be mixed with water.
2. To polish the **convex surface** centre the lens on the suction cup, convex side out.
3. Thoroughly moisten a *flat sponge tool* and place on the spindle. The sponge in the spindle should be covered with a velveteen material.
4. Once the tool is rotating, continually apply polish and place the lens half way between the centre and the edge of the sponge.
5. Hold the at 45° angle and rotate it in the opposite direction to the rotation of the tool. This rotation of the lens may be accomplished with the manipulation of the fingers or by the use of a spinner tool.



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6. The lens is depressed into the sponge during the procedure for 10 to 15 seconds.
7. Polish the **centre** of the lens by holding the suction cup perpendicular to the sponge and depressing the lens in and out of the sponge 10 to 12 times at a position between the centre and edge of the sponge.

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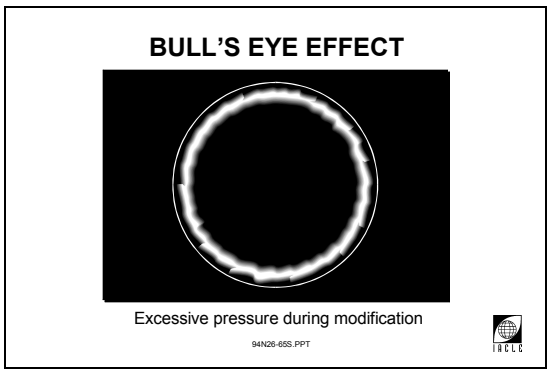
8. Examine the lens every 20 to 30 seconds for remaining scratches with a 10X loupe or a projection magnifier, and verify the power with a lensometer.

9. Low spindle speeds (1000 RPMs or less) require frequent polish application. Minimal pressure will ensure good optical quality. The following diagrams illustrate improper or inadequate polishing. When scratches are deep and excessive, polishing may still leave superficial marks on the lens surface.



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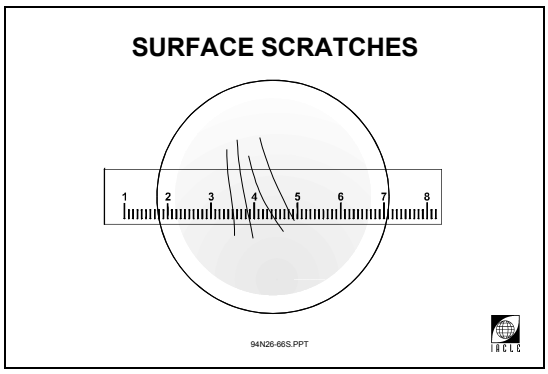

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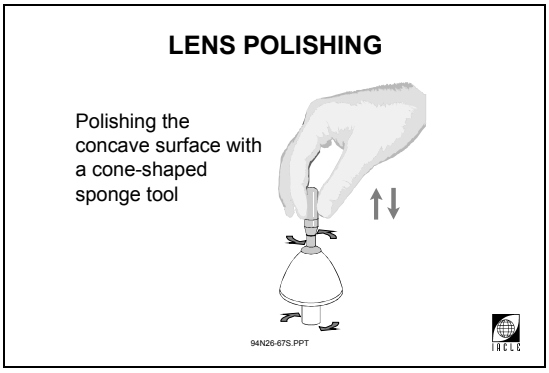
10. To polish the **concave surface**, mount the lens on suction cup concave side out.
11. Use a *cone sponge* and polish the concave surface of the lens by depressing the lens on to the rotating sponge cone while applying the liquid polishing compound. Rotate the suction cup in the opposite direction to the rotation of the cone.



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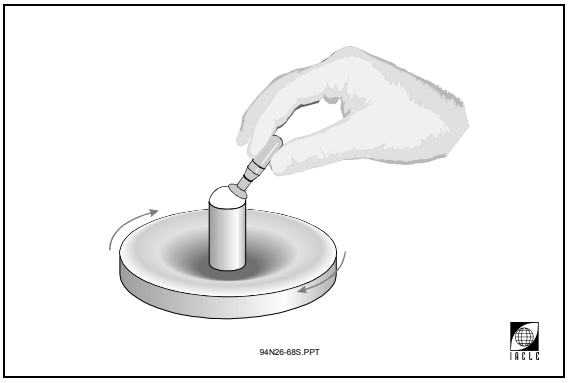
12. Alternatively, if a *circular sponge tool* is used, hold the suction cup at 30°.



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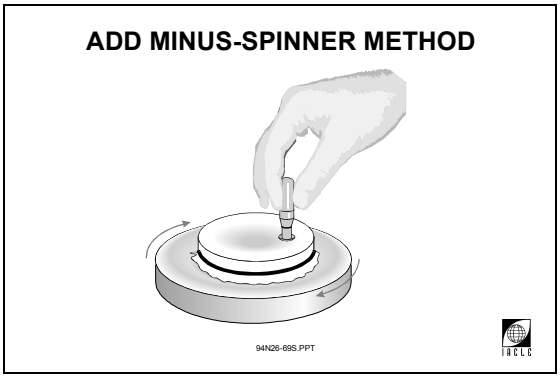
13. To **add minus power** to the lens, carefully centre the lens convex side out on a suction cup.
14. Thoroughly moisten the *large flat sponge* tool.
15. Apply polish throughout the procedure to the centre of the tool.
16. Hold the lens perpendicular to the tool surface at all times, approximately 2.5 cm in from the peripheral edge of the sponge.



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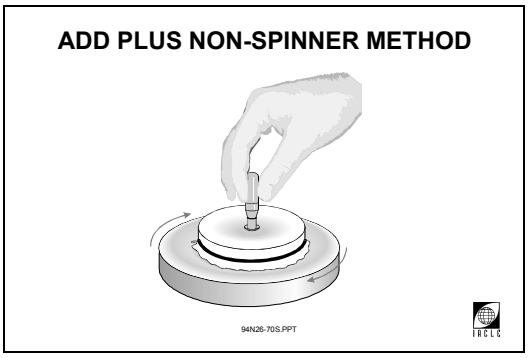
17. Using very slight pressure, revolve the lens around the tool counterclockwise if the spindle turns clockwise. The lens should not be twisted around the axis of the suction cup.
18. Check the power every 10 to 15 seconds.

19. To **add plus power** to the lens, follow the procedure outlined in steps 13-15. Hold the lens in the suction cup vertically and at the centre of the sponge covered with velveteen. This ensures that the paracentral portion of the lens' front surface is polished rather than the centre.



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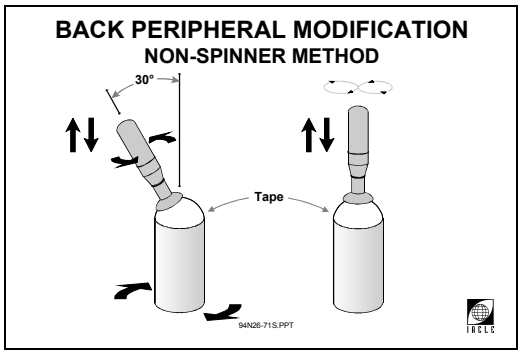
Station 2: Adjusting the Back Peripheral Curve Radii

1. Attach the lens to a suction cup or a spinner tool, concave side out.
2. Attach a square of waterproof adhesive tape (which should be somewhat abrasive) over the surface of a radius tool. The thickness of this tape should be taken into consideration when choosing the appropriate radius tool: deduct 0.2 mm (tape) from the required radius measurement, e.g. if a 9.0 mm back peripheral curve is needed, use a 8.8 mm tool.
3. Place the radius tool on the spindle.
4. Turn the motor on.
5. Apply polish to the tool surface and continue to apply it throughout the procedure.
6. Hold the lens lightly against the tool with the concave side facing the tool.
7. If a *suction cup* is used, the lens should be held at 30° and the entire outer edge should be in contact with the tool at all times. Rotate the cup smoothly and evenly with the fingers in the opposite direction to the spindle rotation. Alternatively, the lens may be held vertically to the radius tool and rotated in a figure-eight design.



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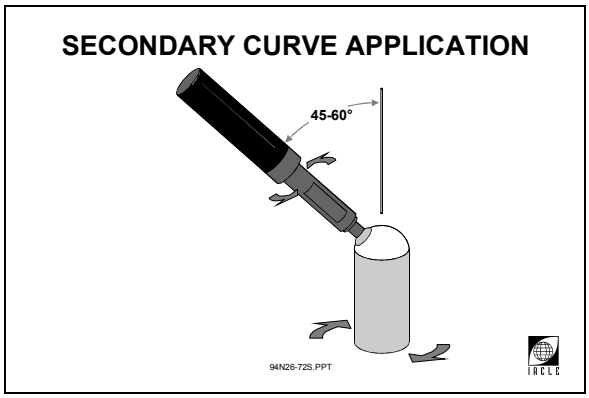
8. Lift the lens from the tool every 5 to 10 seconds and add polish to the surface.
9. If a *spinner tool* is used, centre the lens on the spinner tool and hold at 45° to 60° off the centre of the radius tool. The lens must be spinning at all times during the procedure and polish continually applied.



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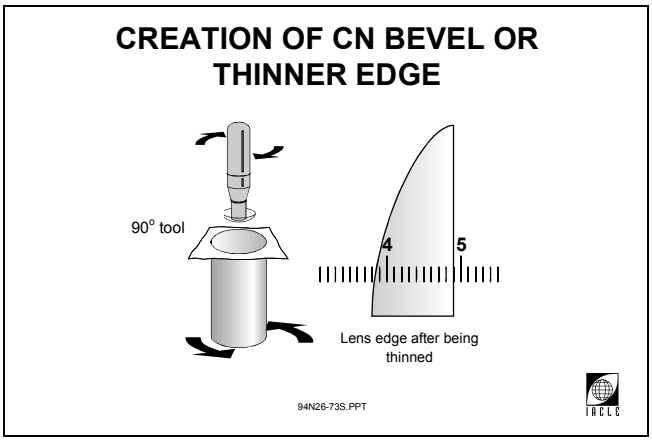
1. The lens should be monitored periodically during the procedure; remove from the lens holder, clean thoroughly and view through a loupe or projection magnifier.
2. Spindle speed, pressure of the lens against the pad, consistency of the polish and the flatness of the radius tool in relation to the back optic zone radius (BOZR) will influence the width of the back peripheral curve being generated.
3. If blending of the back peripheral curves is required, select a tool with a radius approximately halfway between the radii of the adjacent curves. Use a gentle touch for a short time. To ensure a smooth blend, this tool should be covered with a soft flannel cloth.

Station 3: Edge Modification

1. Use a **cone tool** to thin the edge or to create an anterior or CN bevel.
2. Use a 90° cone tool to generate an anterior or CN bevel. A narrower bevel can be created with a 60° tool or a wider bevel with a 120° tool.
3. Mount the lens on a suction cup so that the convex surface faces the cone tool.
4. Adhesive abrasive tape with a one-quarter section cut out is placed within the tool so that it conforms to the cone surface.
5. Apply polish throughout the procedure.
6. Place the lens within the cone and rotate the lens in the opposite direction to the rotation of the cone.



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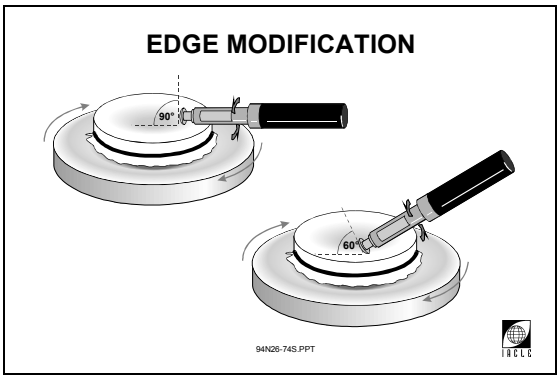
7. Examine the lens every 10 seconds until the desired edge thickness is reached.
8. Polish the edge of the lens after the procedure.
9. Use a **flat sponge tool** covered with velveteen on a spindle for minor shaping and polishing of the edge.
10. Apply polish as the spindle rotates and continue to apply it throughout the procedure.
11. Mount the lens on a spinner tool concave surface out and hold at 30° to the rotating tool with the lens in contact with the surface, approximately halfway between the centre and the edge of the sponge.

12. Alter the angle of the lens edge on the pad, depending on the shape of the edge and thickness of the edge that is required.



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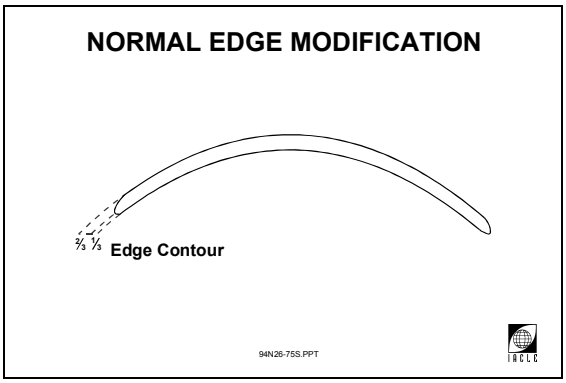
13. Keep checking the edge with a loupe or projection magnifier. Also ensure that the diameter does not decrease unintentionally.



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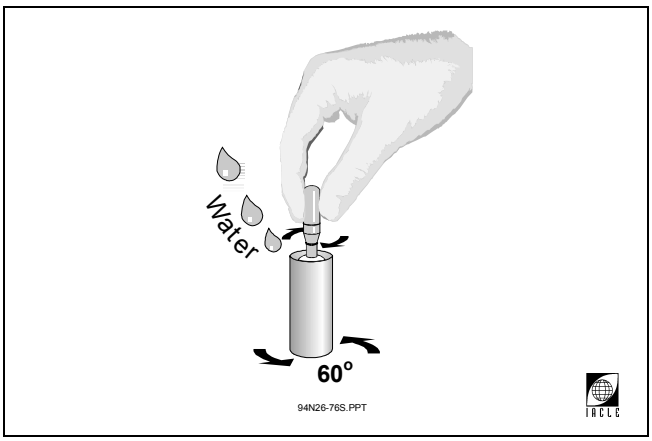
Station 4: Reducing the Total Diameter

1. Decide on the desired overall diameter for the finished lens.
2. Set the goal of the cut down to be 0.2 mm larger than the final specified lens diameter (the extra size will be reduced during the edge finishing techniques).
3. Mount the cut-down stone (a 60°, 90° or 120° cone made of stone, emery or diamond particles on the surface of the tool) on the spindle.
4. Centre the lens on the suction cup, concave side out.
5. Cool the rotating cut-down stone with tap water, not polishing compound.
6. Bring the contact lens down perpendicularly to the stone, concave side down into the cone.
7. Place the lens into the cone of the tool so that the sides of the lens touch the stone evenly.
8. Constantly, and with a light pressure, hold, then slowly rotate the suction cup between the thumb and the index finger. Rotate the suction cup against the tool's spin to reduce the diameter more quickly.
9. Apply some water during this process.



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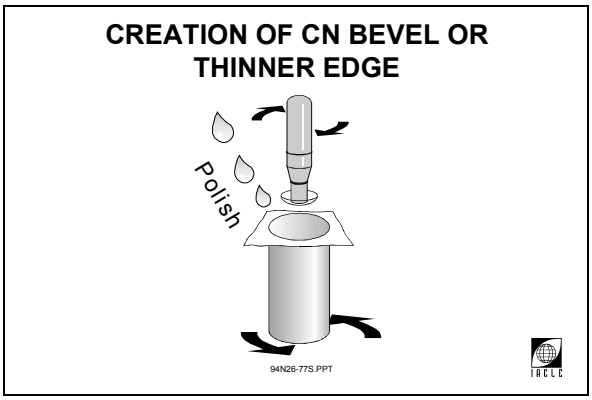
10. Periodically check the lens diameter. Lenses with thick edges take longer to cut down.

11. In order to reduce the edge thickness, the diameter and to start the front surface bevel, turn the lens over and adhere the suction cup to the concave surface so that the diameter reduction will continue by grinding the front surface edge in the 90°cone.



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12. Constantly, with light pressure, rotate the suction cup between the thumb and index finger against the rotation of the tool's spin.
13. Using the V-gauge, periodically check the lens until the desired diameter is achieved, i.e. approximately 0.2 mm larger than the final specified lens diameter.

Station 5: Finish from Semi-finished Blank

Semi-finished PMMA or RGP blanks are usually provided in 10 - 11 mm diameters. The procedure of finishing the lens so that it is wearable is as follows:

1. Decide on the final lens design and parameters, e.g. tricurve lens; total diameter, back optic zone diameter, secondary curve width and radius, and back peripheral curve width and radius.
2. **Reduce total diameter**. Follow the procedures described for Station 4 in this practical.
3. Use an 11 mm radius stone to grind the back peripheral curve. This speeds up the procedure of cutting away excess material to enable the secondary curve to be polished on more quickly.
4. **Polish on the secondary curve** to the desired back optic zone diameter, or slightly larger if a blend has to be applied. Note that the secondary curve width at this stage is larger than the final specification. This will be reduced when the back peripheral curve is polished on, thus reducing the secondary curve width to its final dimensions.
5. **Polish on the peripheral curve**. This curve width should be approximately 0.1 mm larger than its final dimensions, because the overall lens diameter is still 0.2 mm larger than the final specification. The lens diameter and peripheral curve will be reduced to the specified dimensions with the next procedure which is the edge treatment.
6. **Blending**. This should be performed on the junctions between the three curves.
7. **Edge finish/modification**. The same procedures described for Station 3 in this practical, should be followed.

LABORATORY SHEET

Instructions. Each student is to rotate through each of the five stations. Follow the procedure outlined for each station and have the supervisor check each lens after modification.

Station 1: Surface Polishing and Changing Power

Lenses required: (lenses with scratches are preferable)

- To increase minus power.
- To add plus power.

Procedure:

- Measure lens BVP. Signed by:
- Examine lens surfaces.
- Polish surface scratches.
- Modify both lenses by 0.50 D. _____
- Measure modified lens BVP. Supervisor

Station 2: Adjusting Back Peripheral Curve Radii

Lenses required:

- With known back peripheral curve (to be made flatter).

Procedure:

- Inspect the lens.
- Decide on the radius of tools required (radius chosen should be flatter than secondary peripheral curve). Signed by:
- Mount lens on the spinner or suction cup.
- Perform modification using polishing compound. _____
- Inspect the modified lens. Supervisor

Station 3: Edge modification

Lenses required:

- Lens with square edge .
- With sharp pointed edge.

Procedure:

- Inspect edge shape. Signed by:
- Decide on tools required.
- Mount lens on spinner or suction cup.
- Perform modification. _____
- Inspect the modified edge. Supervisor

Station 4: Reducing the Total diameter

Lens required:

- Lens of any diameter.

Procedure: Signed by:

- Measure lens diameter.
- Mount on spinner or suction cup.
- Perform modification. _____
- Measure new diameter. Supervisor

Station 5: Finish from Semi-Finish Blank

Lens required:

- Semi-finished lens blank. Signed by:

Procedure:

- Decide on lens design. _____
- Follow procedures listed. Supervisor

Practical 2.6.4

(2 Hours)

Inspection of Special Lenses

Schedule of Practical Session

Instructions: The students are to divide into groups to observe and familiarise themselves with the following special lenses:

- Aspheric.
- Bifocals.
- High powered lenses.
- Special lens materials.
- Toric lenses.
- Sclerals.
- Prosthetics.
- Toric RGP (with different stabilisers).
- Scleral.
- Prosthetic.

Measure and record your findings on the RECORD FORMS provided.

RECORD FORM

Group:_____ Date:_____

Lens number:_____

LENS PARAMETERS	MEASUREMENTS
Lens Type	
Back Optic Zone Radius (BOZR)	_____ mm
Thickness Central Peripheral	 _____ um _____ um
Back Vertex Power (BVP)	_____ D
Diameter Back Optic Zone Diameter (BOZD) Total Diameter (TD)	 _____ mm _____ mm
Lens Design	
Optical Quality (describe or use Optical Quality Analyser)	
Other Observations (special features)	

Tutorial 2.6

(1 Hour)

Rigid Gas Permeable Lens Modification

Video and Discussion

Instruction: A video program on RGP modification will be viewed. At the end of the program, an open forum and class discussion on altering lens parameters for the following conditions will be held:

- How to add minus power to a lens.
- What modifications can loosen a tight fitting lens and how are these modifications accomplished.
- How to reduce the edge thickness of a lens.

References

Bennett A, Rabbetts R (1984). *Clinical Visual Optics*, 2nd ed., Butterworths.

Bier N, Lowther G (1977). *Contact Lens Correction*, Butterworth & Co. (Publishers) Ltd.

Chaston J (1977). *In-Office measurements of soft contact lenses*. Am J Optom Physl Opt. 54(5): 290.

Chaston J, Irving F (1981). *The influence of temperature on the base curve of high plus soft contact lenses*. ICLC. 8(1): 45.

Chaston J, Irving F (1982). *Optical measurement of front and back radius of soft contact lenses in saline*. ICLC. 9(1): 11 - 18.

Ehrmann K (1995). *A 3D optical profilometer using a compact disc reading head* (unpublished*).*

El Hage S, Bacigalupi M (1992). *A new method of contact lens verification*. CL Spectrum. 7(7): 31 - 35.

Fatt I (1983). *Changes in dimensions of soft contact lenses while on the eye*. CL Monthly. March, 11 - 14.

Forst G (1973). *Kritischer Vergleich der verschiedenen Meßverfahren zur Ermittlung der Krümmungsradien von weichen Kontactlinsen*. Die Kontaktlinse. 7(4): 4 - 11.

Hamano H, Kawabe, H (1978). *Method of measuring radii of a soft lens with an electronic device*. Contact. 22(1): 4 - 8.

Henry VA, Barr JT (1990). *Verification, modification and care*. CL Spectrum. 5(9): 57 - 67.

Holden BA (1976). *Soft lens verification*. New Zealand Contact Lens Society Transactions. July, 20 -27.

La Hood D (1988). *Edge shape and comfort of rigid lenses*. Am J Optom Physl Opt. 65(8): 613 - 618.

Lowther G, Snyder C (1992). *Contact Lenses: Procedures and Techniques*, Butterworth-Heinemann.

Lycho T, La Hood D (1987). *Information on lens coding, measurement and storage system (internal CCLRU Research Report RR 87/47/P & 87/50/P).*

Mishima S (1968). *Corneal thickness*. Surv Ophthalmol. 13: 57 - 96.

Paramore JE (1981). *A technique for center thickness measurement of hydrogel contact lenses.* Am J Optom Physl Opt. 58(8): 635 - 636.

Parelhoff ES, Weissman BA (1986). *Using a radiuscope to measure base curves & soft contact lenses*. Int Eyecare. 2(5): 271 - 273.

Phillips A, Stone J (1989). *Contact Lenses*, 3rd Ed., Butterworth & Co. (Publishers) Ltd.

Port MJA (1976). *New methods of measuring hydrophilic lenses*. Ophthalmic Optician. 16(25): 1079 - 1082.

Port MJA (1980). *The radius measurement of soft lenses in air*. J Brit Cont Lens Assoc. 3: 168 - 174.

Port MJA (1982). *Assessing a new soft lens radiuscope: The AMS Optison*. CL Monthly. 183(4726): 11 - 14.

Rogers JE (1979). *Instrumentation used in contact lens verification - I*. The Optician. 177(4588): 27 - 28.

Rotlex Optics Ltd. (1994). *Brass 2 Instruction Manual*. 12.

Rotlex Optics Ltd. (1995). *The Contest Software Instruction Manual*. Ver. 1.13. 1 - 66.

Sarver MD, Kerr K (1964). *A radius of curvature measuring device for contact lenses*. Am J Optom. 41: 481 - 489.

Saseini LS (1980). *A guide to radiuscopes*. The Optician. 124(79): 14.0

Yumori RW, Mandell RB (1981). *Optical power calculation for contact lens wet cells*. Am J Optom Physl Opt. 58(8): 637 - 639.