The IACLE Contact Lens Course

MODULE 1

Anterior Segment of the Eye

First Edition

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The International Association of Contact Lens Educators

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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.

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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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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 are 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 many copyright illustrations are reproduced with permission of the original publishers and/or copyright owners. The reference section at the end of each unit details the information sources used throughout.

Teaching Resources - Module 1

Module 1 of the IACLE Contact Lens Course has 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.

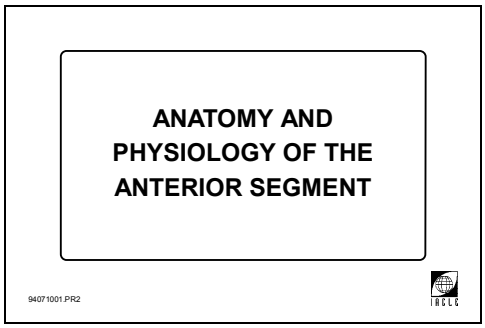
   The suggested lecture, practical and tutorial hours of the module are outlined in the Summary of Module 1 on page *xi*. The manual details recommended activities, references, textbooks and evaluation techniques in the interests of their standardization. Ultimately however the design and methodology of 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 and which should be used in any communication with IACLE regarding the slides.

For example:

To re-order this slide please quote this identification code



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

SYMBOLS			
↑	increase, high	{	collectively produced by
↓	decrease, low	}	collectively produces
→	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

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

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

Summary of Module 1: Anterior Segment of the Eye

Course Program

Lecture			Practical Session			Tutorial (Small Group Teaching)		
Title	***Hrs***	***Level****	***Title***	***Hrs***	***Level****	***Title***	***Hrs***	***Level****
L 1.1 Anatomy and Physiology of the Anterior Segment	2	1				T 1.1 Anatomical Eye Structure Identification	1	1
L 1.2 Corneal Topography: Measurement and Significance	2	1	P 1.2 Keratometry	2	1	T 1. 2 Interpretation of Keratometry Results	1	1
L 1.3 Examination of the Anterior Segment	2	1	P 1.3 Measurement and Assessment of Ocular Parameters	2	1			
L 1.4 Slit-lamp Biomicroscopy Procedures	2	2	P 1.4.1 Slit-lamp Biomicroscopy: Illumination Techniques	2	2	T 1.4 Review of Slit-lamp Illumination Techniques	1	2
			P 1.4.2 Slit-lamp Biomicroscopy: Examining the Eye	4	2			

* Level 1 = Basic: essential knowledge
Level 2 = Intermediate: desirable knowledge

Course Time Allocation

Level	Lecture	Practical (Laboratory)	Tutorial (Small Group Teaching)	Total Hours
Basic	6	5	2	**13**
Intermediate	2	6	1	**9**
TOTAL	**8**	**11**	**3**	**22**

Unit Objectives

UNIT 1.1: Anatomy and Physiology of the Anterior Segment

Objectives:

This lecture and tutorial reviews the basic anatomical structures and physiological processes of the anterior segment of the eye.

Upon completion of the unit the students should:

- have a **knowledge** of, and be able to **identify**, those anatomical structures of the anterior eye which are important in contact lens wear.
- have an **understanding** of the physiological processes of the anterior eye and especially those that may be affected by contact lens wear.

UNIT 1.2: Corneal Topography: Measurement and Significance

Objectives:

This lecture, practical and tutorial review the normal corneal shape, anomalies, and methods of measuring corneal shape.

Upon completion of the unit the student should:

- have a **fundamental understanding** of the shape of the cornea and its importance to choosing and fitting contact lenses.
- **understand** the operating principles of the instrumentation used to measure corneal shape.
- be able to **measure** corneal curvature, then **record, interpret** and **apply** the results to contact lens practice.

UNIT 1.3: Examination of the Anterior Segment

Objectives:

This lecture, practical and tutorial cover an examination of the external eye relevant to contact lens practice.

Upon completion of the unit the student the student should be:

- **familiarised** with the basic methods of, and instrumentation for, examining the anterior eye.
- able to **examine and record** features of the external eye routinely and systematically.
- **skilled** at everting the upper and lower lids.
- able to **differentiate** between normal and abnormal appearances of the external eye.

UNIT 1.4: Slit-Lamp Biomicroscopy Procedures

Objectives:

This lecture, practical and tutorial present the basic principles and applications of the slit-lamp biomicroscope.

Upon completion of the unit the student should be:

- **proficient** at setting up the slit-lamp and positioning the illumination system's slit-image on the object of regard.
- able to **perform** the slit-lamp to examine the external eye and to use the appropriate methods of illumination to best observe particular eye structures.
- able to **demonstrate and explain** the purpose of each feature of the slit-lamp and the underlying principles of each illumination technique.

Request for Feedback

As this is the first edition it is our intention to revise and update it 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 for improvement which you feel will enhance the accuracy or quality of the Course. Such 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 removed or photocopied. Please complete your contact details as the 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: _____
(yy-mm-dd)

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Address: _____

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Module: _____ Unit: _____ Page Number: _____

Slide Code: _____ Section: _____

Comments:

Thank you

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Unit 1.1

(3 Hours)

Lecture 1.1: Anatomy and Physiology of the Anterior Segment

Tutorial 1.1: Anatomical Eye Structure Identification

Course Overview

Lecture 1.1: Anatomy and Physiology of the Anterior Segment

I. Anatomy of the Anterior Segment

II. Physiology of the Anterior Segment

Tutorial 1.1: Anatomical Eye Structure Identification

- Quiz

Suggested Evaluation Techniques

- Written examination.
- Written assignments on any of the following topics:
    1. Metabolic changes in the closed-eye environment;
    2. Corneal changes associated with contact lens wear;
    3. Techniques for measuring lacrimal gland and tear functions.
- Slide quiz.

Lecture 1.1

(2 Hours)

Anatomy and Physiology of the Anterior Segment

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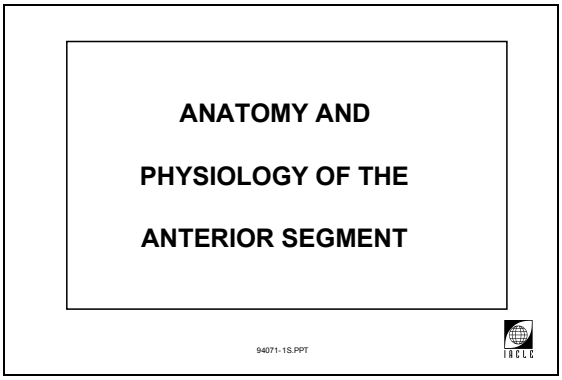
Anatomy and Physiology of the Anterior Segment

I Anatomy of the Anterior Segment

I.A Cornea

1



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Anatomy and Physiology of the Anterior Segment *(title slide)*

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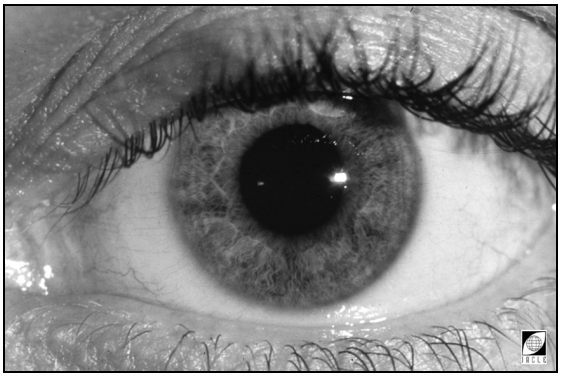

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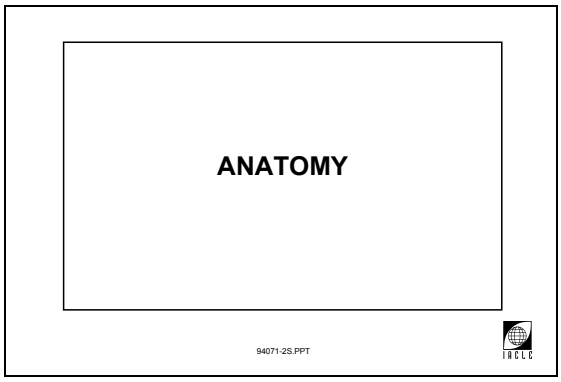
The Eye *(frontal view)*

- The anterior segment is composed of the eyelids (and margins), conjunctiva, sclera, cornea, limbus and iris.

A knowledge of the normal anatomy, histology and physiology of the eye is required to enable detection of changes induced by disease or contact lens wear.

This knowledge is also required to facilitate the diagnosis of the signs and symptoms of any such changes.

3



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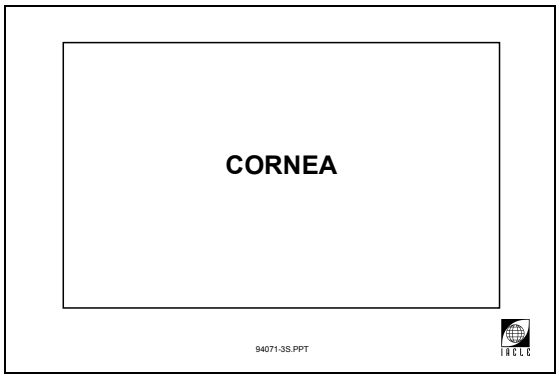
Anatomy of the Anterior Segment *(title slide)*

4 **Cornea** *(title slide)*



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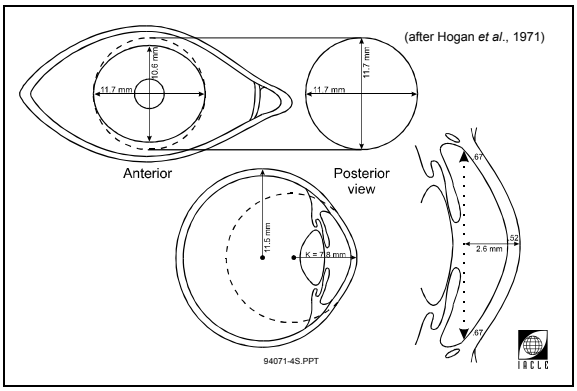
I.A.1 Dimensions

5



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Dimensions of the Cornea

- Corneal shape is elliptical because of the encroachment of the opaque limbus into the cornea's superior and inferior borders.
- Horizontal visible iris diameter (HVID) is 11.7 mm and vertical visible iris diameter (VVID) is 10.6 mm on average. These may be about 0.1 mm less in females.
- Corneal area is 1.3 cm^2 or $^1/_{14}$ of the total area of the globe.
- The globe is bi-spherical with the cornea having the smaller posterior spherical radius of curvature of 6.2 to 6.8 mm (average 6.5 mm).
- According to Maurice (1969), the average corneal thickness is 0.52 mm in the centre and 0.67 mm at the limbus.
- Sagittal depth of the cornea is 2.6 mm with variations largely dependent on the radius of corneal curvature.

6

The cornea
is ***not*** symmetrical
and
corneal curvature flattens
towards the periphery

94071-5S.PPT

1L194071-5

The cornea is *not* symmetrical and is *not* a solid of rotation about the optic, geometric or any other axis.

- Corneal curvature flattens towards the periphery and the degree of increase in the radii of curvature varies from one meridian to the next. This variation in flattening indicates that the curvature is *not* a solid of rotation about any particular axis.
- Greater corneal toricity is mirrored in an increased difference in the radii of curvature of the principal meridians.
- The outline defining the central spherical area of the cornea is an irregular shape.
- The eye is never still. Constant movement of the eye (saccadic movement) does not allow for a fixed centre of rotation.

7

CORNEAL SHAPE

- Meniscus lens
- ***Not*** a solid of rotation about any axis
- Front apical radius 7.8 mm K=43.27 D
- Back apical radius 6.5 mm -6.15 D
- Actual refractive index, cornea = 1.376
  - Not optically homogenous
  - $\boldsymbol{n}_{\text{ground substance}}$ = 1.354, $\boldsymbol{n}_{\text{collagen}}$ = 1.47

94071-6S.PPT

1L194067-6

Corneal Shape

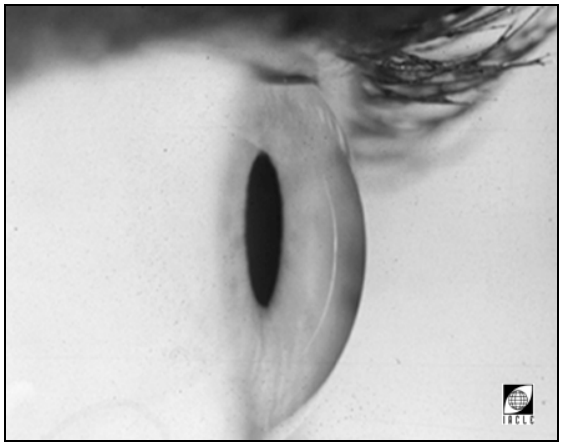
The cornea is a meniscus lens.

- The average front apical radius is 7.8 mm (corneal power = 43.27 D with an instrument calibrated for a refractive index of 1.3375).
- The average back apical radius of 6.5 mm gives the posterior cornea a power of -6.15 D (assumptions: n_{aqueous} = 1.336 and $n_{\text{post. cornea}}$ = 1.376, $r_{\text{post.cornea}}$ = 6.5 mm).
- The actual refractive index of the cornea (n_{cornea}) is 1.376 (ignoring the tear film).
- The cornea is not optically homogeneous. However the actual refractive indices of the individual layers are not known accurately.
- Most values are for homogenized corneal

material.

- Little light is reflected from internal layer interfaces, suggesting minimal refractive index differences. However: $n_{\text{ground substance}}$ =1.354 and n_{collagen} =1.47. Since ground substance constitutes about 1% of the cornea and collagen about 15%, this observation is perhaps a little surprising given the significant refractive index difference.

8



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Corneal Profile

The cornea is:

- Transparent.
- The principal optical surface of the eye, accounting for approximately two-thirds of the eye's refractive power.

9

CORNEA

- 78% water
- 15% collagen
- 5% other parts
- 1% GAGs
- Epithelium ≈ 10% of cornea's wet weight

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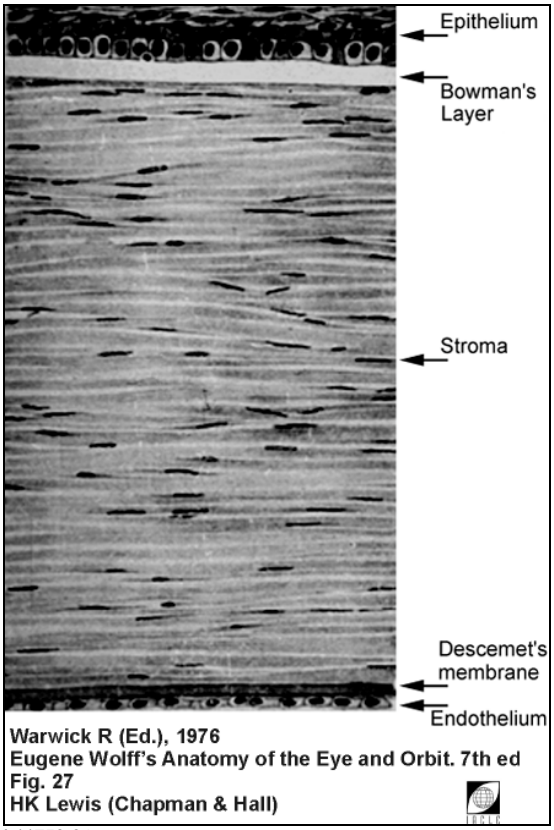
Corneal Composition

The cornea is composed of:

- 78% water.
- 15% collagen.
- 5% other proteins.
- 1% glycosaminoglycans (GAGs).
- 1% salts.

These are wet weight figures.
The epithelium accounts for approximately 10% of cornea's wet weight.

10



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Transverse Section of the Cornea
(Warwick, 1976)

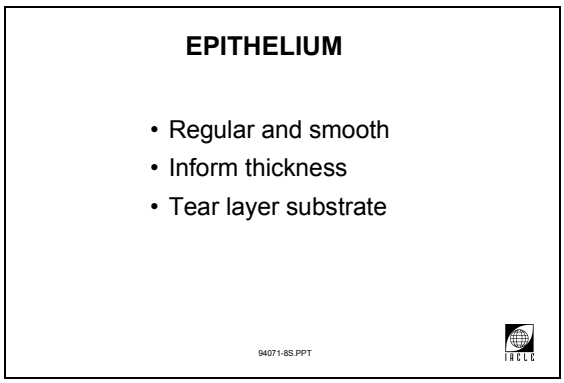
The cornea consists of 5 layers:

- Epithelium.
- Bowman's layer.
- Stroma.
- Descemet's membrane.
- Endothelium.

Examination and assessment of the cornea is best done using the slit-lamp biomicroscope.
Observation of a transverse section of the cornea requires a narrow slit-beam, together with high magnification.

I.A.2 Epithelium

11



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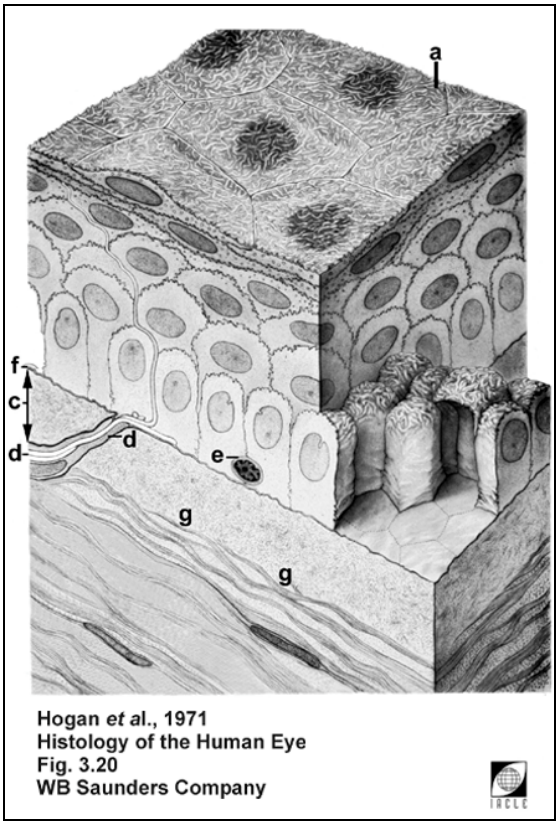
Epithelium

- The outer surface is smooth and regular to provide a tear layer substrate. It is of uniform thickness and benefits from an orderly replacement scheme after desquamation.
- Any slight irregularity is compensated for by the overlying tear film.

12



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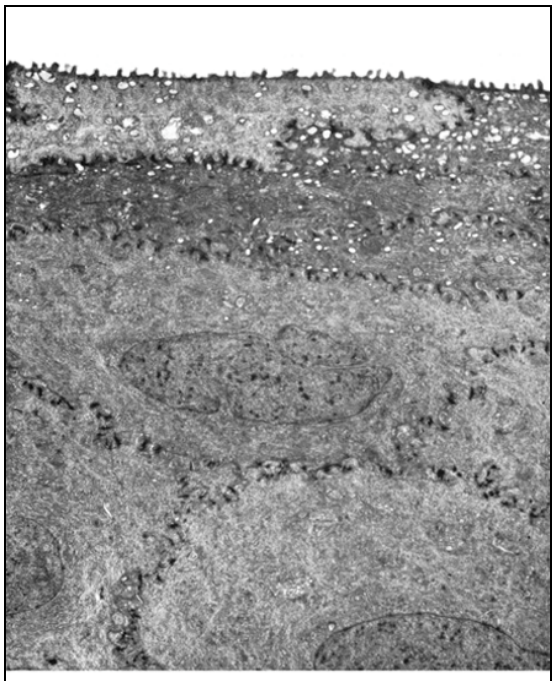
Layers of Epithelium
(Hogan et al., 1971)

- The epithelium is made up of three types of cells:
  - squamous cells (surface).
  - wing cells.
  - columnar (or basal) cells (deepest).
- The outer surface is smooth and regular, allowing it to act as a tear layer substrate. It is of uniform thickness and benefits from an orderly replacement process following desquamation.
- Any slight irregularity is compensated for by the overlying tear film.
- The epithelium is avascular and is usually transparent.

13



Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.12
WB Saunders Company

1L10613-95

Electron Micrograph of the Epithelium
(Hogan et al., 1971)

- Microplicae and microvilli are seen on the surface. They are thought to play a role in tear film stability by anchoring the mucus layer.
- This transverse section shows both the squamous (surface) and wing cells.

14

EPITHELIUM

- 50 microns thick
- 5-layered structure
  - squamous cells (surface)
  - wing cells
  - columnar cells (basal)
- Cell turnover (basal to surface)

≅7 days

94071-9S.PPT

1L194071-9

Epithelium

- The epithelium is 50 microns thick.
- It is a five-layered structure:
  - outer surface cells: two layers of flattened squamous cells
  - middle wing cells: two to three layers of polygonal cells
  - inner basal cells: one layer of columnar cells.
- Cellular turnover, i.e. the time required for basal cells to migrate anteriorly to become surface cells, is approximately seven days.

15

EPITHELIUM CELLS

SURFACE CELLS (2 Layers)

- Thin
- Squamous
- Overlapping polygonal cells

WING CELLS (2 Layers)

- Overlays Basal layer
- 'Wings' protruding into space between domes of basal cells

BASAL CELLS

- Deepest
- Columnar
- Hemispherical anterior surface

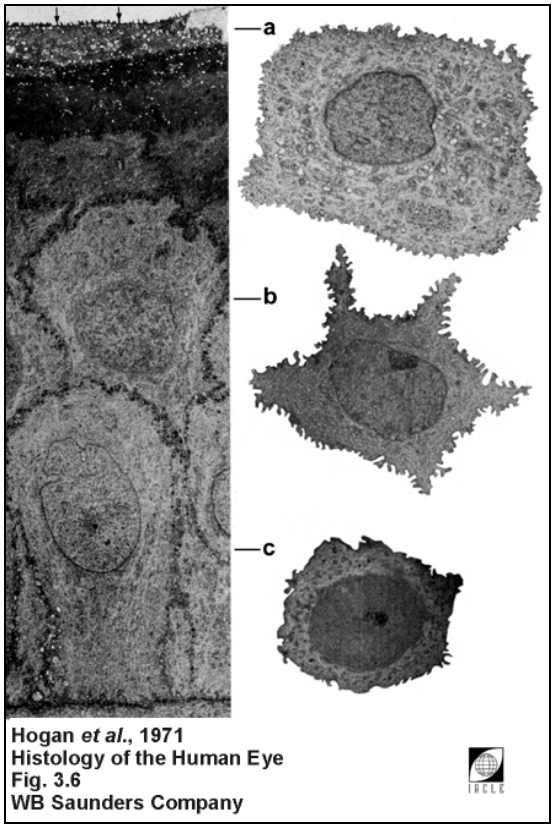
94071-10S.PPT

1L194071-10

Epithelial Cells
(Hogan et al., 1971)

- Surface cells (two layers):
  - thin
  - squamous
  - overlapping polygonal (see *a* in slide 16).
- Wing cells (two layers):
  - overlay the basal layer
  - 'wings' protruding into the space between domes of basal cells (see *b* in slide 16).
- Basal cells (one layer):
  - deepest
  - columnar

16



1L1749-94

– hemispherical anterior surface (see *c* in slide 16).

17

OTHER CELLS
BASAL LAYER

- Pigmented melanocytes (peripheral epithelium)
- Macrophages
- Lymphocytes

94071-11S.PPT

1L194071-11

Other Cells

Basal layer

- Pigmented melanocytes (in the peripheral cornea).
- Macrophages.
- Lymphocytes.

18

MICROPLICAE AND MICROVILLI

- Present on anterior of surface epithelial cells
- Responsible for tear film retention?

94071-12S.PPT

1L194071-12

Microplicae and Microvilli

- Present on the anterior surface of surface epithelial cells.
- May be partially responsible for tear film retention?

I.A.3 Basement Membrane

19

BASEMENT MEMBRANE
(*basal lamina*)

- Interface between basal cell layer of epithelium and Bowman's layer
- Thickness - 10-65 nm

94071-13S.PPT

1L194071-13

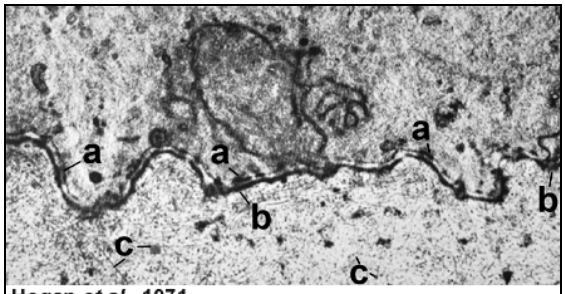
Basement Membrane (basal lamina)

- This is the interface between the basal cell layer of the epithelium and Bowman's layer.
- Thickness: 10-65 nm. Thicknesses quoted in the literature vary greatly, e.g.:

10-30 nm	Baron
20 nm	Binder & Zavala
30-60 nm	Mandell
48 nm	Hogan
65 nm	Hamano

  Its thickness also varies according to location. It is thinner in the centre and thicker in the periphery.
- Its anterior surface is well defined. However, the posterior is indistinct and blends with Bowman's layer.

20



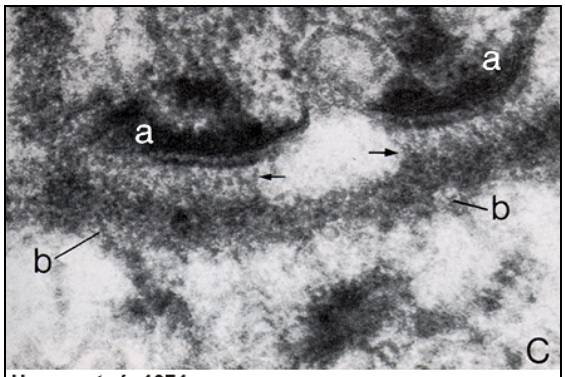
Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.8
WB Saunders Company

1L11346-96

Epithelial Adhesion
(Hogan et al., 1971)

- Keratin filaments extend from the hemidesmosomes (a), which are located on the cytoplasmic face of the posterior basal cell membrane (b), into the basal cell itself.
- On the opposite side, anchoring filaments extend towards the basement membrane.
- These anchoring fibrils connect with the basement membrane as well as pass through it. Structurally, they contain Type VII collagen (c). The fibrils terminate 1-2 microns into Bowman's layer, in cytoplasmic bars termed anchoring plaques.

21

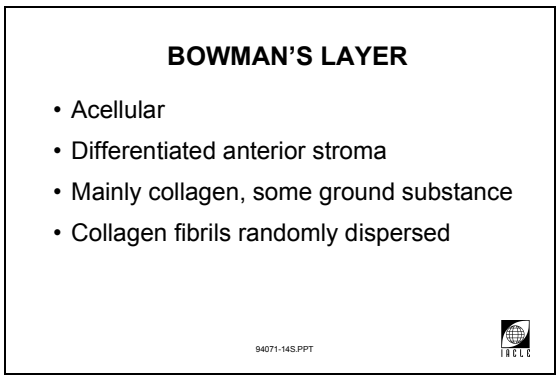


Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.9C
WB Saunders Company

1L101345-96

I.A.4 Bowman's Layer

22

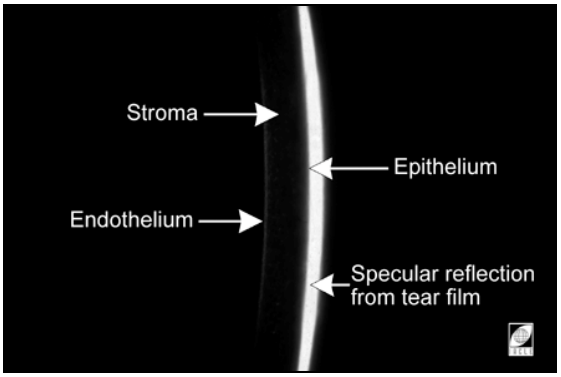


1L194071-14

Bowman's Layer

- It is an acellular tissue with a thickness of 8-14 µm. It is thicker in the peripheral one-third and thins as it rounds off at the limbus.
- It is actually differentiated or modified anterior stroma, and is sometimes called the anterior limiting lamina.
- It is composed mainly of collagen fibrils and some ground substance. The randomly dispersed collagen fibrils are some 24-27 nm thick and are therefore smaller than the stromal fibrils (32-36 nm). They are also less densely packed than the stromal fibrils.

23



1L11511-95L

Thin Optic Section of the Human Cornea.

This image clearly demonstrates the stromal contribution to total corneal thickness (i.e. ≈ 90%).

I.A.5 Stroma

24

STROMA

- 0.50 mm thick
- (90% of corneal thickness, mostly collagenous lamellae)
- Contains 2-3% keratocytes (fibroblasts) and about 1% ground substance

94071-15S.PPT

1L194071-15

Stroma

- The stroma is approximately 0.50 mm thick centrally (90% of corneal thickness).
- It is composed almost entirely of collagenous lamellae whose turnover time is 12 months or more.
- It contains 2 - 3% keratocytes (also known as corneal fibroblasts) and about 1% ground substance (glycosaminoglycans or GAGs).

25

GROUND SUBSTANCE (GAGs)

- Very hydrophilic

Responsible for:

- exact spacing of fibrils
- H_2O imbibition pressure of cornea (due to hydrophilicity)

94071-16S.PPT

1L194071-16

Ground Substance (GAGs)
(glycosaminoglycans)

- Very hydrophilic.
- Responsible for
  - exact spacing of fibrils
  - H_2O imbibition pressure of the cornea. This is due largely to their hydrophilicity.

26

KERATOCYTES

- Interspersed between collagenous lamellae
- Thin, flat cells 10 µm in diameter with long processes
- 5-50 µm of intercellular space
- Joined together by macula occludens or hemidesmosomes

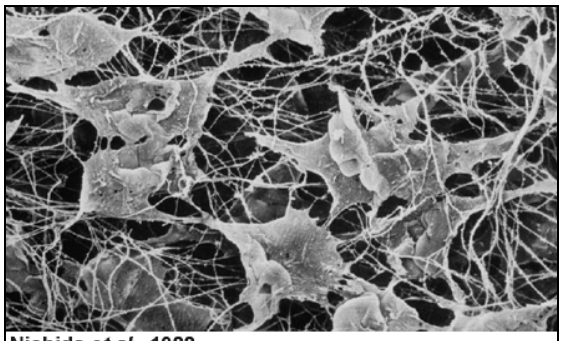
94071-17S.PPT

1L194071-17

Keratocytes (Corneal Fibroblasts)
(Nishida et al., 1988)

- Keratocytes are interspersed between the layers of the stromal collagenous lamellae.
- Keratocytes are thin flat cells some 10 µm in diameter with long cytoplasmic processes. These processes contact those of other keratocytes to form a continuous 2-D network. Evidence of some connections between layers has also been found.
- There is some 5-50 µm of intercellular space between keratocytes whose processes are in contact with each other. The junctional complexes are usually macula occludens or hemidesmosomes. The cells themselves are characterized by having a rough-surfaced (granular) endoplasmic reticulum.

27



Nishida *et al.*, 1988
Investigative Ophthalmology & Visual Science 29 1988
Fig. 1
Libbincott-Raven Publishers

1L11688-91

28

STROMAL LAMELLAE

- Dense and orderly fibrous connective tissue
- Stable protein collagen fibrils
- Regular arrangement is important for corneal transparency

94071-18S.PPT

1L194071-18

Lamellae

- Lamellae are made of dense fibrous connective tissue and are arranged in a very orderly manner.
- They are made up of stable proteinaceous collagen fibrils arranged parallel to one another. The fibrils extend across the entire diameter of the cornea.
- The regular and orderly arrangement of the collagen fibrils is important to the maintenance of corneal transparency. It is believed that transparency is achieved by the elimination of light scatter using destructive interference.

29

STROMAL LAMELLAE

- 200 - 250 lamellae superimposed on one another

Thickness: 2 µm
Width: 9-260 µm
Length: 11.7 mm

94071-19S.PPT

1L194071-19

Lamellar Dimensions

200 - 250 lamellae superimposed on one another.

Dimensions:

- Thickness: 2 µm
- Width: 9-260 µm
- Length: up to 11.7 mm

30

LAMELLAR ARRANGEMENT

Parallel to:

- corneal surface
- one another

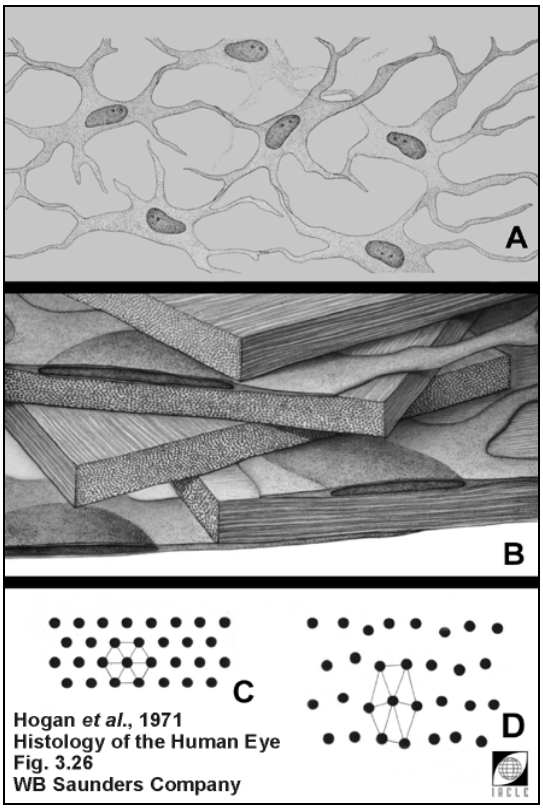
94071-20S.PPT

1L194071-20

Lamellar Arrangement
(Hogan et al., Fig. 3.26)

- Stromal lamellae are parallel to:
  - the corneal surface
  - one another.
- Collagen fibrils of the stroma are also parallel to each other.
- The fibrils are coated and separated from each other by a cementing ground substance.
- Stromal fibrils are thicker than those found in Bowman's layer. See slide 31.

31



1L11744-94

A: Keratocytes or corneal fibroblasts.

B: Stromal lamellae showing the collagen fibrils within.

C: Diagrammatic representation of the orderly arrangement of the collagen fibrils.

D: Diagram of an oedematous cornea showing a disturbance of the orderly arrangement. This disturbance results in light scatter and increased corneal translucency.

I.A.6 Descemet's Membrane

32

DESCEMET'S MEMBRANE

- 10-12 µm
- Structureless
- Slightly elastic
- Secreted by the endotheluim
- Very regularly arranged stratified layer
- Functions as basement layer of endothelium

94071-21S.PPT

1L194071-21

Descemet's Membrane

- Thickness: 10-12 µm (microns).
- It is structureless, slightly elastic and secreted by the endothelium.
- It is a very regularly arranged, stratified basement layer of the endothelium.

33

HASSALL-HENLE WARTS

- Periodic thickenings of Descemet's membrane
- Can protrude into anterior chamber

94071-22S.PPT

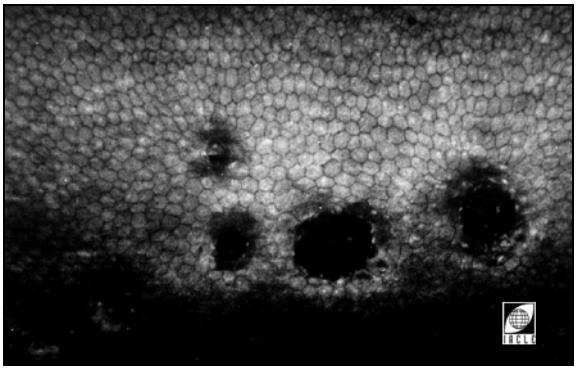
1L194071-22

Hassall-Henle Warts

(Hogan et al., 1971)

- These periodic thickenings of Descemet's membrane can extend into the anterior chamber. However they are covered by altered (thinned) endothelium.
- Commonly seen peripherally during a slit-lamp examination by using specular reflection of the nasal or temporal endothelium.
- The disturbance to the cornea/anterior chamber interface alters its specular reflection properties. Light is lost by scatter and reflection from the irregular surface. If sufficient light is lost, the affected area appears black.

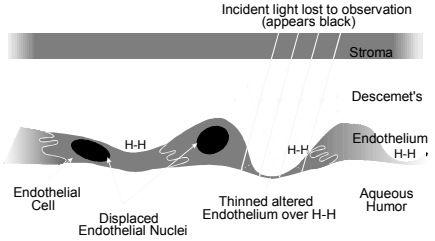
34



1L11886-93

35

POSTERIOR PERIPHERAL CORNEA



H-H = Hassall-Henle Bodies (warts)

94071-23S.PPT

1L194071-23

I.A.7 Endothelium

36

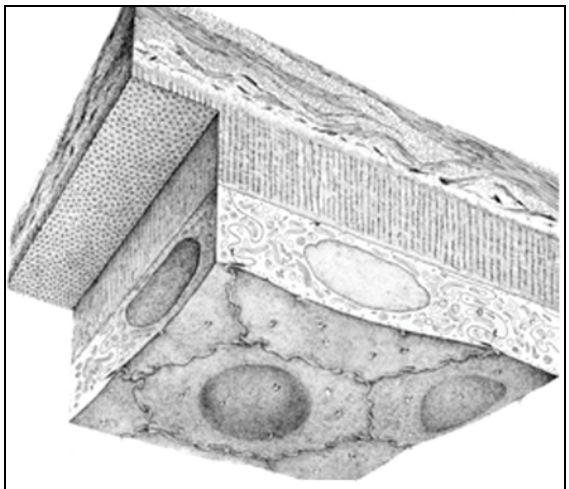
ENDOTHELUIM

- Single layer
- 500,000 mainly hexagonal cells
- 18-20 µm diameter
- 5 µm thick
- Non-replicating

94071-24S.PPT

1L194071-24

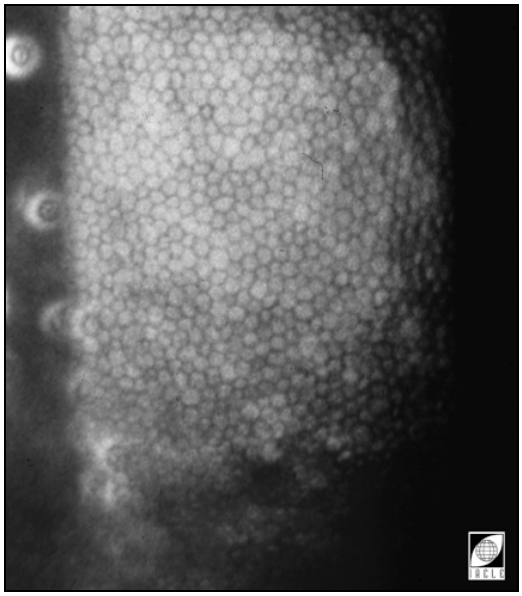
37



Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.34
WB Saunders Company

1L10615-95

38



1L10941-91

Endothelium
(Hogan et al., 1971)

- Composed of a single layer of approximately 500,000 polygonal (mainly hexagonal) cells (see next slide).
  - Cell diameter: 18-20 µm
  - Cell thickness: 5 µm.
- Adult cell loss results in thinning and spreading of remaining cells to maintain the endothelial barrier function necessary for corneal transparency. The cells do not reproduce.
- The endothelium can be viewed by specular reflection using a slit-lamp biomicroscope at high magnification (25X - 40X).
- Higher magnification observation and photography is possible with a contacting specular microscope (magnifications up to the order of 200X are possible).

39

ENDOTHELUIM CELL NUCLEI

- Centrally located
- Uniformly spaced in the young

94071-25S.PPT

1L194071-25

Endothelial Cell Nuclei

- Endothelial cell nuclei are flattened and have a diameter of about 7 µm.
- The nuclei are located centrally and are uniformly spaced in the young.

40

AGE-RELATED CELLULAR CHANGES

- Cell degeneration and non-replacement
  - decreased uniformity
  - decreased thickness with age
- Polymegethism

94071-26S.PPT

1L194071-26

Age-Related Cellular Changes

- Age-induced endothelial cell degeneration/loss combined with an inability to reproduce lost cells, results in a decrease in uniformity, thickness and cell density of the endothelium.
- These age-related changes manifest themselves as an increase in the range of cell sizes. This is termed *polymegethism* which in Greek literally means - *many sizes*.

41

ENDOTHELIAL CELL ULTRASTRUCTRURE

- Rich in organelles engaged in active transport (active pump)
- Protein synthesis for secretory purposes
- Large number of mitochondria
- Mitochondria more numerous around nucleus

94071-27S.PPT

1L194071-27

Endothelial Cell Ultrastructure

- Organelles are engaged in active transport (an active pump) which is necessary for hydration control and protein synthesis for secretory purposes.
- There are large numbers of mitochondria which are more numerous around the nucleus.

I.A.8 Vasculature and Nerve Supply

42

PERIPHERAL CORNEAL VASCULATURE

- Peripheral cornea (and sclera adjacent to Schlemm's canal) supplied by circumcorneal vessels
- Minor role in corneal nutrition
- Remainder of cornea is avascular

94071-28S.PPT

1L194071-28

Peripheral Corneal Vasculature

- The peripheral cornea and sclera adjacent to Schlemm's canal are supplied by conjunctival, episcleral and scleral terminals of the circumcorneal vessels.
- These vessels play a minor role in corneal nutrition.
- The rest of the cornea is normally avascular.

43

CORNEAL INNERVATION

- One of the richest sensory nerve supplies
- Ophthalmic division of trigeminal nerve (N 5)
- Fibres become more visible in oedema

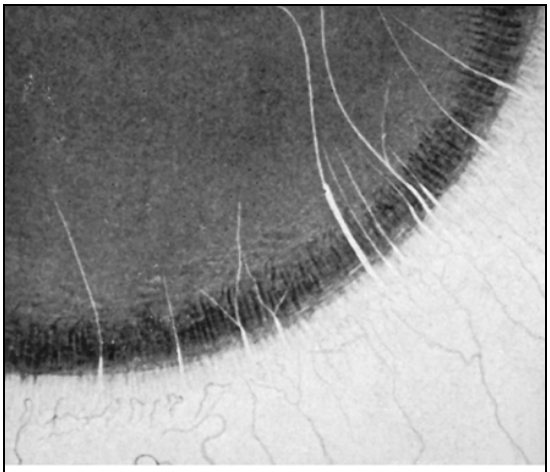
94071-29S.PPT

1L194071-29

Corneal Innervation

- The cornea has one of the richest sensory nerve supplies in the body.
- It is supplied by the ophthalmic division of the maxillary branch of the trigeminal nerve (5th cranial nerve, N5).
- The nerve fibres become more visible when the cornea is oedematous.

44



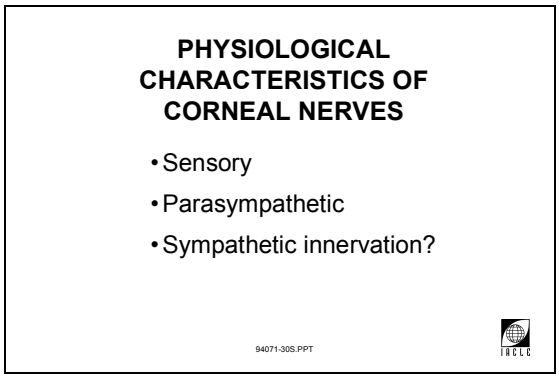
Warwick R (Ed.), 1976
Eugene Wolff's Anatomy of the Eye and Orbit. 7th ed
Fig. 233
HK Lewis (Chapman & Hall)

1L11750-94

Medullar Changes of Corneal Nerves
(Warwick, 1976)

- There are about 30 nerves entering the cornea which appear as axon bundles near the limbus.
- The corneal nerves lose their medullar coat (myelin sheath) before their first division, a division which is usually dichotomous.

45



1L194067-30

Physiological Characteristics of Corneal Nerves

- Sensory.
- Parasympathetic.
- Whether or not the cornea is sympathetically innervated is uncertain, and the evidence for and against is contradictory.

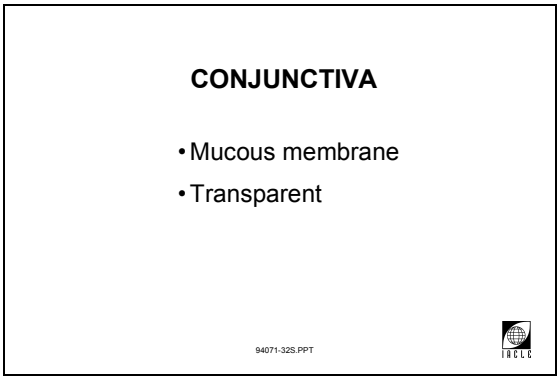
I.B Conjunctiva

46

1L194071-31

Conjunctiva *(title)*

47



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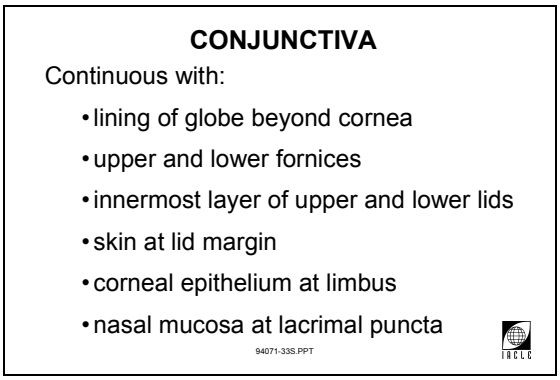
48



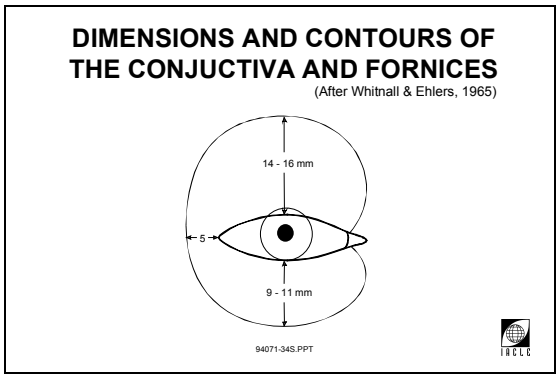
1L194071-33

Conjunctiva

- The conjunctiva is a mucous membrane consisting of loose, vascular connective tissue.
- It is transparent.
- Its transparency is less than that of the cornea when observed with a slit-lamp.
- It is continuous with
  - the lining of the globe beyond the cornea
  - the upper and lower fornices
  - the innermost layer of the upper and lower eyelids
  - the skin at the lid margin
  - the corneal epithelium at the limbus
  - the nasal mucosa at the lacrimal puncta.

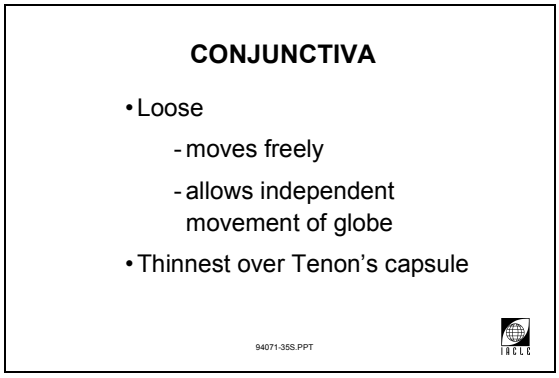
The diagram illustrates the contours of the fornices and the approximate dimensions of the unextended conjunctival sac (in mm) when the eye is open. Based on the data of Baker, Whitnall and Ehlers (diagram after Phillips and Stone, 1989).

49



1L194071-34

50

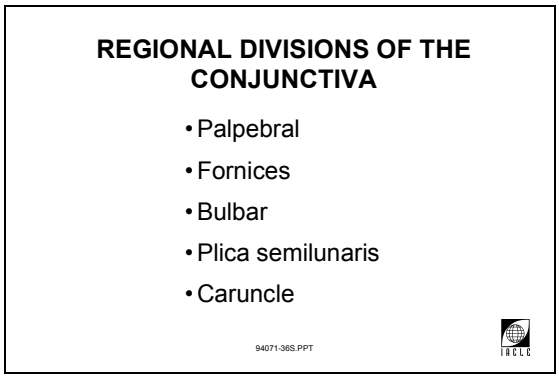


1L194071-35

Conjunctiva

- Is loose, to allow free and independent movement of the globe.
- Is thinnest over the underlying Tenon's capsule.

51



1L194071-36

Regional Divisions of the Conjunctiva

Palpebral:

- Conjunctiva lining the inner eyelids and extending to the lid margins.

Fornices:

- Loose conjunctival tissue that is continuous with the palpebral and bulbar conjunctivae.

Bulbar:

- Conjunctival tissue overlying the sclera and limbus.

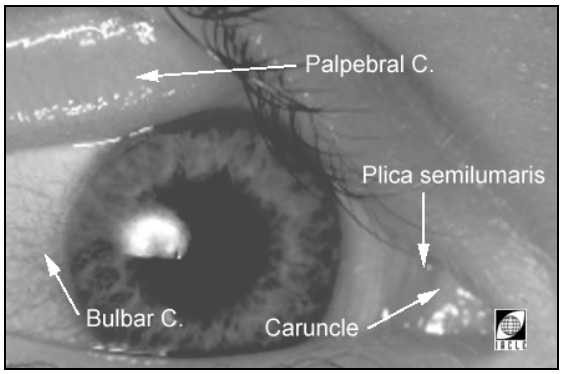
Plica semilunaris:

- Fold of conjunctiva at the inner canthus, appearing as a bi-concave crescent partly covered by the caruncle.

Caruncle:

- Conjunctival tissue nasal to the plica semilunaris and defining the medial canthus.

52



1L10573-95

53

Conjunctiva is composed of 2 layers:
- Epithelium
- Stroma

94071-37S.PPT

1L194071-37

The conjunctiva is composed of two layers:

- Epithelium.
- Stroma.

54

CONJUNCTIVAL EPITHELIUM
- 5 layers of the corneal epithelium cells becomes 10-15 layers of the conjunctival epithelium at limbus due to increasing wing cell numbers
- Surface not as smooth as cornea
- Basement membrane present
- Surface cells have microplica and microvilli

94071-38S.PPT

1L194071-38

Conjunctival Epithelium

- The five layers of the corneal epithelium become 10-15 layers of the conjunctival epithelium at the limbus. This is due to an increase in the number of wing cells.
- The surface cells have microplicae and microvilli, and the surface is not as smooth as the cornea.
- A basement membrane is present, with melanin pigment often seen in basal and wing cells.

55

CONJUNCTIVAL STROMA
- Loosely arranged bundles of coarse collagen
- Bundles are approximately parallel to surface
- Numerous fibroblasts (main cell type)
- Some immunological cells present

94071-39S.PPT

1L194071-39

Conjunctival Stroma

- The conjunctival stroma is made up of loosely arranged bundles of coarse collagen tissue.
- The collagen bundles are approximately parallel to the surface. They mix randomly with other cells and structures.
- There are numerous fibroblasts (the main cell type).
- Some immunological cells are also present, i.e. mast cells, macrophages, polymorphonuclear leucocytes, eosinophils and lymphocytes.

56

CONJUNCTIVAL GLANDS
- Goblet Cells
- Glands of Wolfring
- Glands of Krause
- Crypts of Henle

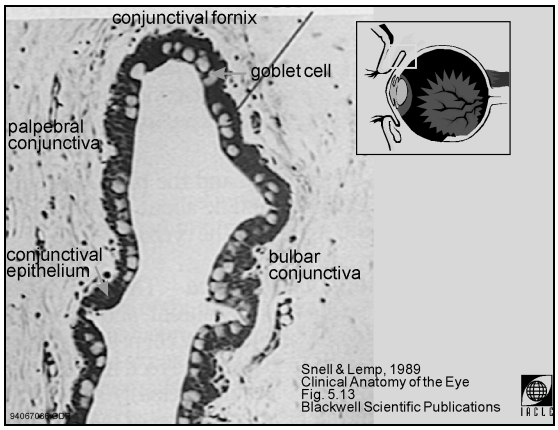
94071-40S.PPT

1L194071-40

Conjunctival Glands

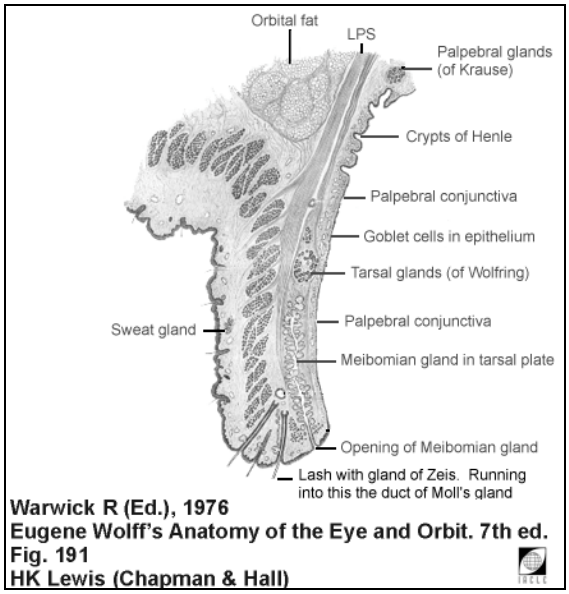
- Goblet cells are (Snell and Lemp, 1989):
  - unicellular and sero-mucous secreting
  - found in the epithelial layer
  - absent near the limbus and lid margins
  - more numerous in the bulbar region.
- Glands of Wolfring are:
  - contributors to the aqueous layer of the tears(along with the lacrimal gland)
  - similar in structure to the lacrimal gland, although on a smaller scale
  - located at the upper limit of the tarsal plate found in the conjunctival stroma.
- Glands of Krause are (Steuhl,

57



1L194067-86

58



1L11213-96

1989):

- contributors to the aqueous layer of the tears
- similar in structure to the lacrimal gland
- located near the fornices in the conjunctival stroma
- approximately 20 in the upper and 8 in the lower conjunctiva
- more numerous laterally.

- Crypts of Henle are:
  - mucous crypts or invaginations found in the superior peripheral palpebral conjunctiva.

59

CONJUNCTIVAL ARTERIES

- Palpebral branches of nasal and lacrimal arteries of lids
  - larger branches form peripheral and marginal arterial arcades
  - lower lid peripheral arcade not always present
- Anterior ciliary arteries

94071-41S.PPT

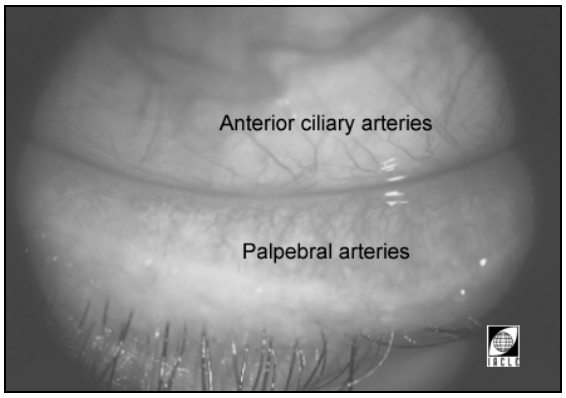
1L194071-41

Conjunctival Arteries

The conjunctiva is supplied by:

- Palpebral branches of the nasal and lacrimal arteries of the lids
  - larger branches form peripheral and marginal arterial arcades
  - the lower lid peripheral arcade is not always present.
- Anterior ciliary arteries.

60



1L12551-93L

I.C Limbus

61

LIMBUS

- Transition zone between cornea and conjunctiva/sclera
- Anatomical reference

94071-42S.PPT

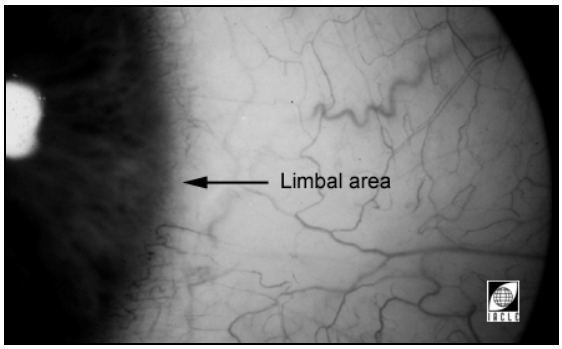
1L194071-42

Limbus

The limbus is:

- A transition zone of the epithelia and connective tissues of the cornea, and the conjunctiva and sclera combined.
- An anatomical reference for surgical procedures, biomicroscopy and contact lens fitting.

62



1L10384-93

63

CORNEA TO CONJUCTIVA SCLERA TRANSITION

CORNEA		CONJUNCTIVA
5 layer epithelium	→	10-15 layer epithelium
Bowman's layer	→	stroma and Tenon's capsule
Stroma	→	sclera proper

94071-43S.PPT

1L194071-43

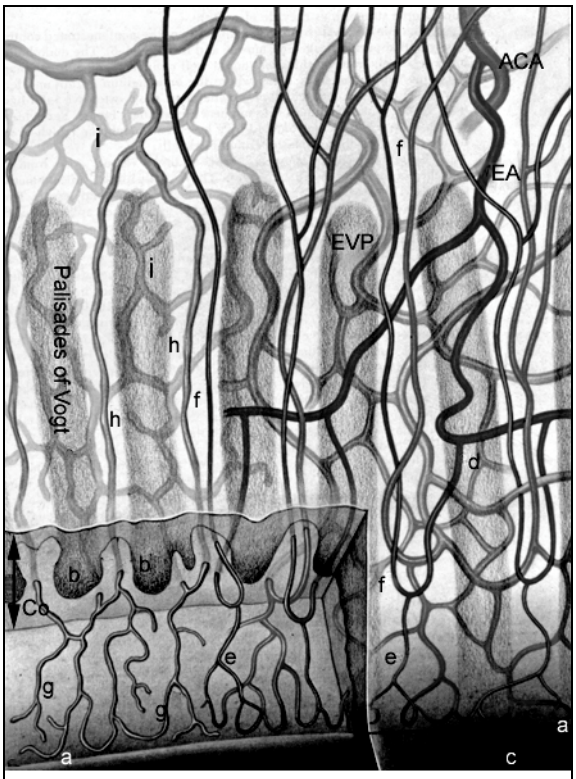
Cornea to Conjunctiva/Sclera Transition

(Hogan et al., 1971)

Cornea		Conjunctiva
5 layer epithelium	→	10 to 15 layer epithelium
Bowman's layer	→	stroma and Tenon's capsule
stroma	→	sclera proper

Epithelial radial 'pegs' produce the Palisades of Vogt, which are seen more in the inferior and superior quadrant and may be pigmented in darker races. The Palisades arise from the stroma of the conjunctiva.

64



Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 4.3
WB Saunders Company

1L10616-95

Legend for slide 64:

a = termination of Bowman's Layer

b = epithelial rete pegs

Co = conjunctival cross-section

d = superficial marginal arterial plexus

e = terminal vessels

f = recurrent vessels

g = peripheral lymphatic system

h = superficial radial lymphatic group

i = deep radial lymphatic

ACA = anterior ciliary artery

EA = episcleral arteries

EVP = episcleral venus plexus

65

LIMBAL EPITHELIUM

	Corneal	Limbal	Bulbar Conjunctival
Goblet cells	✗	✗	✓
Melanocytes	✗	✓	✓
Underlying blood vessels	✗	✓	✓

94071-44S.PPT

1L194071-44

The limbal epithelium is anatomically different from that of the bulbar conjunctiva because:

- It does not have goblet cells.

The limbal epithelium is different from the corneal epithelium because:

- It does contain melanocytes.
- It does have blood vessels underlying it.

66

DIMENSIONS OF THE LIMBAL REGION

Depth: 1.0 mm

Width: 1.5 mm (horizontally)
2.0 mm (vertically)

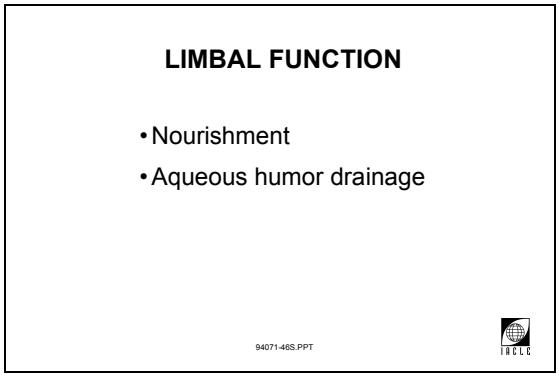
94071-45S.PPT

1L194071-45

Limbal Region

- Extends 1.5 - 2.0 mm from the corneo-limbal junction to the sclero-limbal junction. The corneo-limbal junction begins at the termination of Bowman's layer.
- It can be seen as a circumferential strip of tissue around the corneo-scleral zone:
  - depth: 1.0 mm
  - width: 1.5 mm (horizontally)
    2.0 mm (vertically).

67

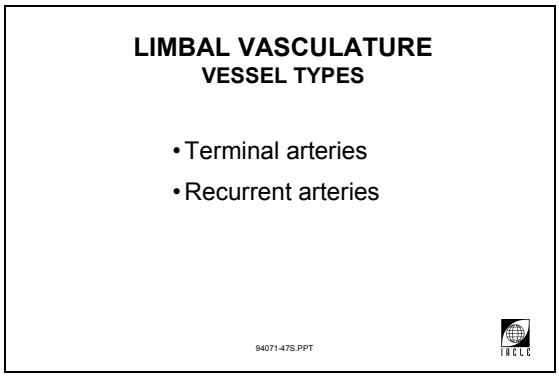


1L194071-46

Limbal Function

- Provides limited nourishment to the peripheral cornea via the limbal vasculature.
- Site of the aqueous humor drainage system including Schlemm's canal. This system is important for the maintenance of the intra-ocular pressure.

68



1L194071-47

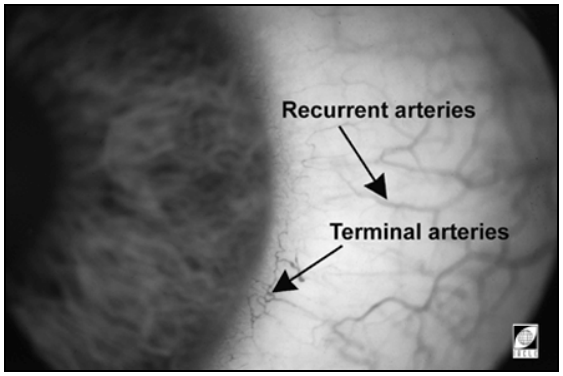
Limbal Vasculature

Begins with arteries from the superficial marginal arterial plexus which originates from the anterior ciliary arteries. There are two types of limbal vessels:

- Terminal arteries which form the peripheral cornea arcades.
- Recurrent arteries which form the peripheral arcades which pass through the Palisades of Vogt to supply the perilimbal conjunctiva.

The blood then returns via the venous system which mirrors the arterial system closely. The episcleral venous plexus lies (deeper) underneath the Palisades. The lymphatic vessels also follow a similar path and are divided into superficial (arranged radially) and deep (arranged as a network) groups.

69



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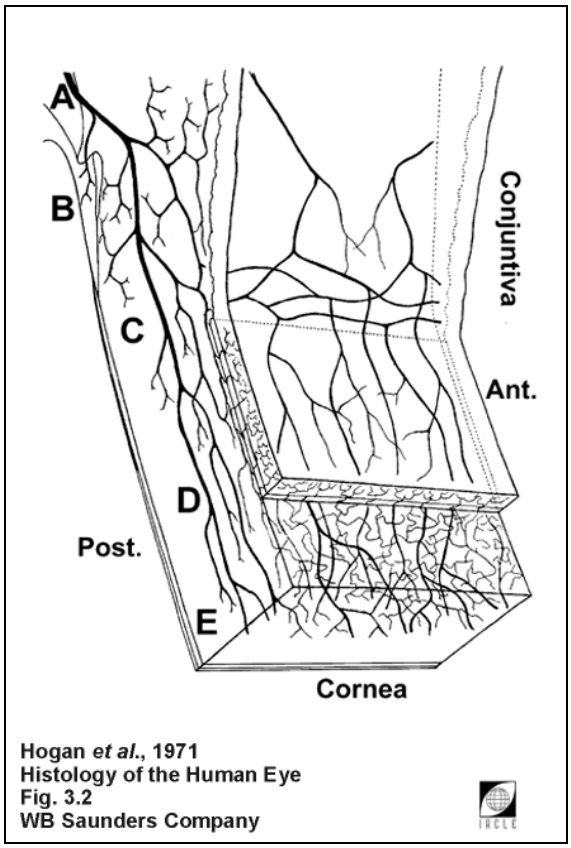
70



1L10618-95

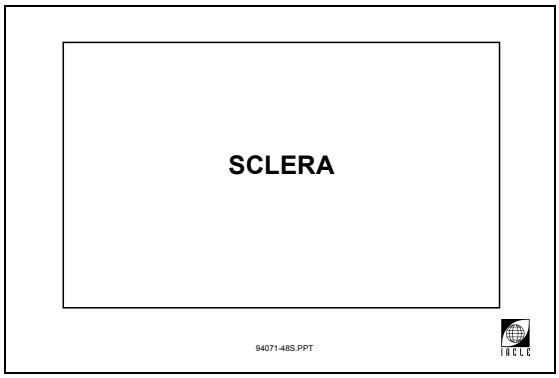
Limbal Innervation

(Hogan et al., 1971)

- Limbal nerves arise from the intrascleral and conjunctival nerves. These originate from the long ciliary nerves (A).
- Innervation extends into the trabecular meshwork (B) and the cornea (C).
- Note that:
- The deep cornea (D) has few nerves.
- The cornea adjacent to Descemet's membrane (E) has no nerves.

I.D Sclera

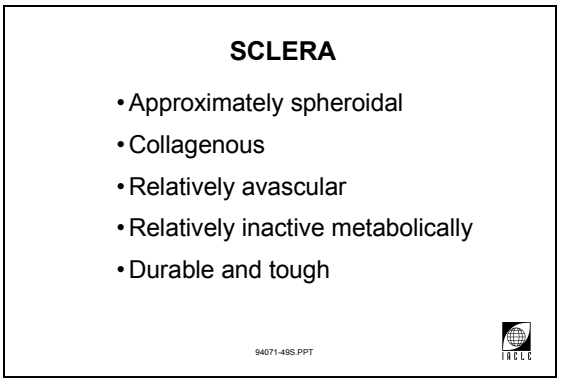
71



1L194071-48

The Sclera *(title slide)*

72



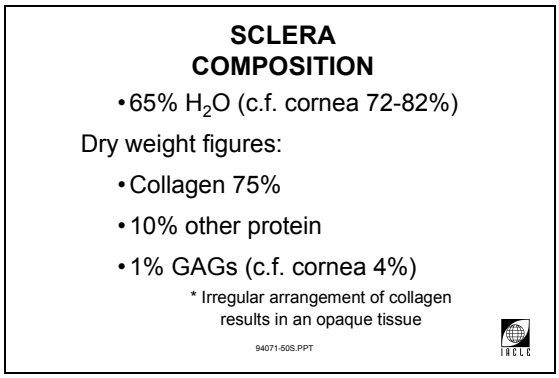
1L194071-49

The Sclera

The Sclera is:

- Approximately spheroidal.
- Collagenous.
- Relatively avascular.
- Relatively inactive metabolically.
- Durable and tough, exhibiting visco-elastic properties although not particularly extensible.

73



1L194071-50

Scleral Composition

- Water content: 65% H_2O (cf. cornea 72-82%).
- It has a low glycosaminoglycan (GAG) content.
- Collagen comprises 75% of the dry weight of the cornea, GAGs comprise 1% (compared to the cornea's 4% of the dry weight) and 10% is made up of other proteins. These are dry weight figures and should not be confused with the wet weight corneal data presented in slide 9.
- The irregular arrangement of collagen results in an opaque tissue. Interestingly, when the H_2O content is outside the range 40-80%, the sclera becomes quite transparent.
- In older eyes, fatty deposits may produce a yellowing of the sclera.

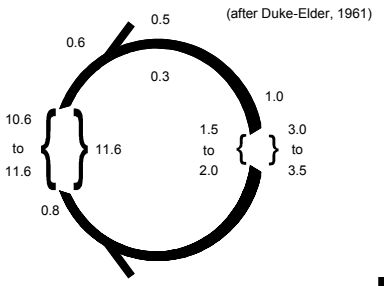
74

SCLERA
DIMENSIONS
- Approximately spheroid
- 22 mm diameter
- >80% of eye external surface
- Thickness
  - 0.8 mm at limbus
  - 0.6 mm at front of rectus muscle tendon
  - 0.3 mm behind rectus muscle insertions
  - 0.4-0.6 mm at equator of globe
  - 1.0 mm at optic nerve head

94071-51S.PPT

1L194071-51

75



94071-52S.PPT

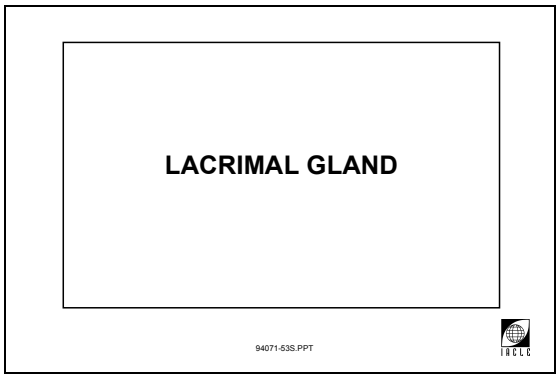
1L194071-52

Scleral Dimensions

- Diameter: 22 mm.
- It makes up more than 80% of the eye's external surface.
- Thickness: (*Duke-Elder, 1961)*
  - 0.8 mm at the limbus
  - 0.6 mm in front of the rectus muscle tendon
  - 0.3 mm behind the rectus muscle insertions
  - 0.4 - 0.6 mm at the equator of the globe
  - 1.0 mm near the optic nerve head.

I.E Lacrimal Glands

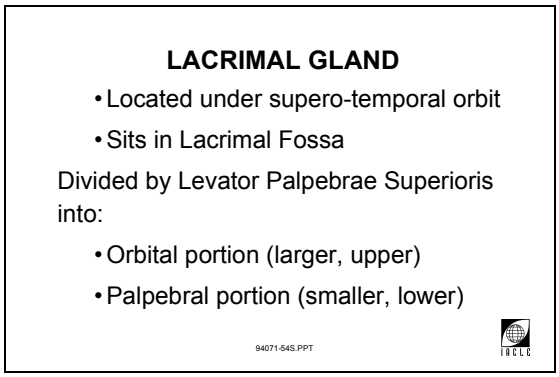
76



1L194071-53

Lacrimal Gland *(title slide)*

77

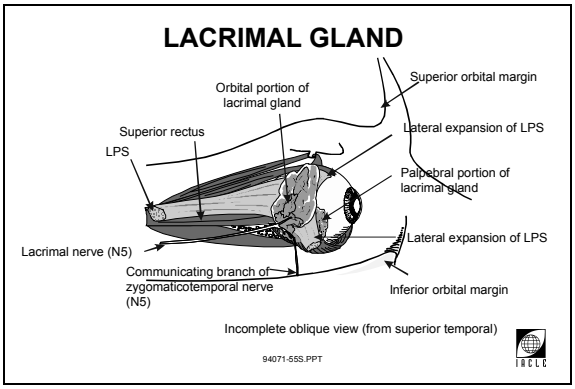


1L194071-54

Lacrimal Gland

- Each lacrimal gland is located in a depression called the lacrimal fossa (*fossa glandulae lacrimalis*) in the supero-temporal orbit just behind the orbital margin This lacrimal fossa is one of two in each orbit, the other is a more obvious but smaller oval depression on the anterior nasal orbit wall in which the lacrimal sac is located.
- The lacrimal gland is divided by the levator palpebrae superioris muscle (LPS) into
  - larger upper orbital portion
  - smaller lower palpebral portion.

78

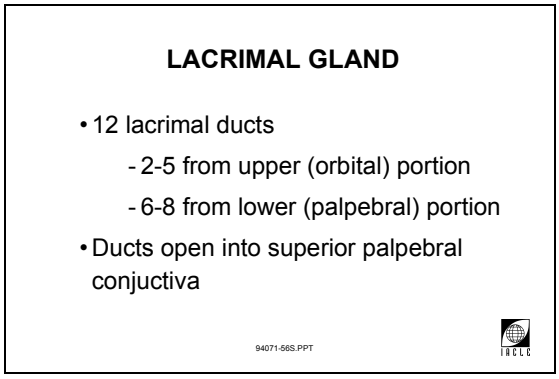


1L149071-55

Lacrimal Gland: Innervation

- Lacrimal Gland innervation comes from the lacrimal branch of the ophthalmic division of the trigeminal (N5) nerve (afferent), the facial (N7) nerve (efferent) and the superior cervical ganglion and carotid plexus (sympathetic). It is believed that the sphenopalatine ganglion provides parasympathetic innervation to the lacrimal gland via very fine fibres (the *rami lacrimales*) passing directly to the lacrimal gland.

79



1L194071-56

Lacrimal Gland

- The lacrimal gland has up to 12 ducts
  - two to five from the upper (orbital) portion
  - six to eight from the lower (palpebral) portion.
- The ducts open onto the superior palpebral conjunctiva.

80

ACCESSORY LACRIMAL GLANDS
GLANDS OF KRAUSE

- Similar structure to lacrimal gland
- In conjuctival mucosa near fornices
- 20 in upper lid, 8 in lower lid
- More numerous laterally
- Supply aqueous phase of basal tear film

94071-57S.PPT

1L194071-57

Accessory Lacrimal Glands

Glands of Krause:

- Similar in structure to the lacrimal gland.
- Situated in the conjunctival mucosa near the fornices.
- Approximately 20 in upper lid and eight in the lower lid.
- More numerous laterally.
- Supply aqueous phase of basal tears.

81

ACCESSORY LACRIMAL GLANDS
GLANDS OF WOLFRING

- Similar structure to lacrimal gland
- Near upper border of tarsal plate
- Supply aqueous phase of basal tear film

94071-58S.PPT

1L194071-58

Accessory Lacrimal Glands

Glands of Wolfring:

- Similar in structure to the lacrimal gland.
- Situated near the upper border of the tarsal plate in the upper lid.
- Supplying the aqueous phase of basal tears.

82

ACCESSORY LACRIMAL GLANDS
GLANDS OF ZEIS

- Sebaceous glands
- Associated with lash follicles
- Partially supply lipid layer of tears

94071-59S.PPT

1L194071-59

Accessory Lacrimal Glands

Glands of Zeis:

- Sebaceous glands.
- Associated with lash follicles.
- Partially supply the lipid layer of the tears.

83

ACCESSORY LACRIMAL GLANDS
MEIBOMIAN GLANDS

- Sebaceous glands
- Main supply of lipid layer of tears
- 25 in upper lid, 20 in lower lid (shorter)
- Prevent tear spillage

94071-60S.PPT

1L194071-60

Accessory Lacrimal Glands

Meibomian Glands:

- Sebaceous glands.
- Main supply of the lipid layer of the tears.
- 25 in the upper lid and 20 in the lower lid. The glands in the lower lids are shorter.
- Oil on the lid margins prevents tear overflow.

84

ACCESSORY LACRIMAL GLANDS
CRYPTS OF HENLE

- Invaginations of superior peripheral palpebral conjuctiva
- Mucous crypts

94071-61S.PPT

1L194071-61

Accessory Lacrimal Glands

Crypts of Henle:

- Invaginations of the superior peripheral palpebral conjunctiva near the superior fornix.
- Mucous crypts.

85

ACCESSORY LACRIMAL GLANDS
GOBLET CELLS

- Unicellular sero-mucous glands
- In epithelium of conjunctiva
- Provides mucoid layer of tears
- Have a single-discharge life-cycle

94071-62S.PPT

1L194071-62

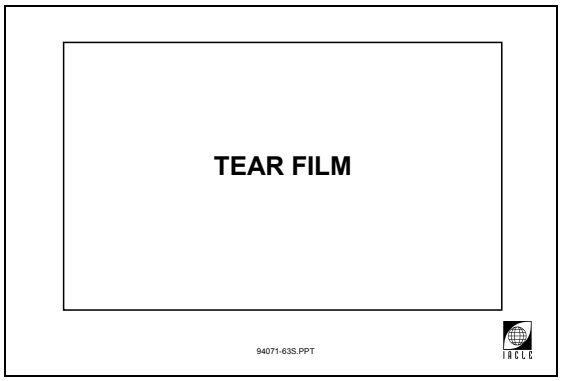
Accessory Lacrimal Glands

Goblet Cells:

- Unicellular sero-mucous glands.
- Situated in the epithelium of the conjunctiva.
- Provide the mucoid layer of tears.
- Single-discharge life-cycle.

I.F Tear Film

86



1L194071-63

Tear Film *(title slide)*

87

1L194071-64

Tear Distribution

- The tears are distributed by the following mechanisms
  - normal and voluntary eyelid action, with each blink 'resurfacing' the pre-corneal tear film
  - normal and voluntary movement of the globe.
- The tears form a lacrimal 'river' on the lid margins and a lacrimal 'lake' at the inner canthi.

88

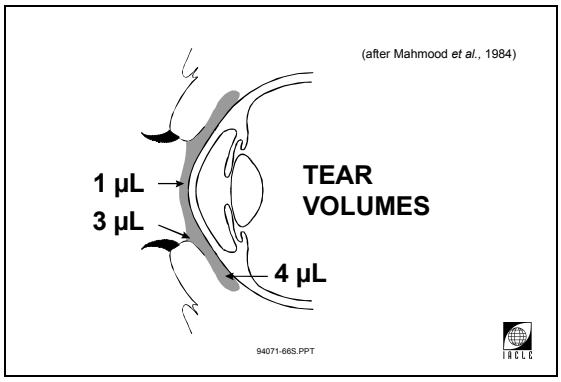
1L194071-65

Tear Flow

Tear flow is aided by:

- Capillary action.
- Gravity.
- Blinking.

89



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Distribution of Tear Volumes

- Pre-corneal: 1 µL
- Tear meniscus: 3 µL
- Cul-de-sac: 4 µL

90

TEAR FILM STABILITY

- Mucin layer spread by lid action enhances wettability of epithelium
- Evaporation leaves an oil and mucin admixture
- Admixture does not 'wet' epithelium causing a break-up of tear film

94071-67S.PPT

1L194071-67

Tear Film Stability

- The mucin layer is spread by the action of the lids. The wettability of the epithelium is enhanced by the renewed mucin layer.
- Tear thinning leaves an oil and mucin admixture which does not 'wet' the epithelium leading to a break-up of the tear film.

91

MECHANICS OF TEAR FILM SPREADING

- Upward lid movement draws aqueous component over the surface
- Lipid layer spreading over surface increases film thickness and stability

94071-68S.PPT

1L194071-68

Mechanics of Tear Film Spreading

- Upward lid movement draws the aqueous component over the cornea and conjunctiva.
- This is followed by the lipid layer spreading over the surface. This increases tear film thickness and stability.

92

TEAR FLOW: LID CLOSURE
MOVEMENT TOWARDS THE MEDIAL CANTHUS

- Lid closure is scissor-like towards the nose
- Tears move towards the medial canthus

94071-69S.PPT

1L194071-69

Tear Flow: Lid Closure

Movement towards the Medial Canthus

- Contraction of the orbicularis oculi muscle causes lid closure with a scissor-like action towards the nose.
- Lid closure propels the tears towards the medial canthus.

93

TEAR FLOW: LACRIMAL PUMP

- Upper part of lacrimal sac distends when orbicularis oculi contracts
- Distention induces negative pressure which draws tears into lacrimal sac
- Capillary action and gravity play a part
- Turnover rate of tears ≈ 16% per minute

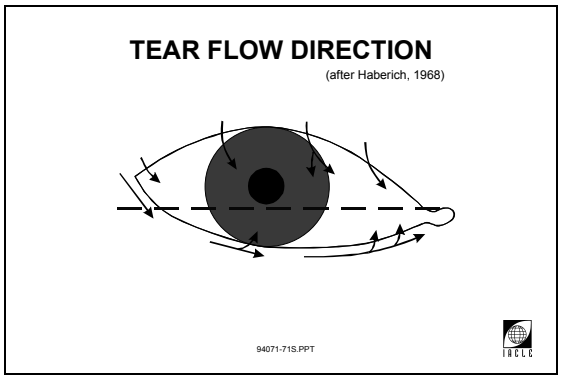
94071-70S.PPT

1L194071-70

Lacrimal Pump

- The upper part of the lacrimal sac is distended by contraction of the orbicularis oculi. This distension induces a negative pressure which draws tears into the drainage system. On eye opening this action is reversed.
- Capillary action and gravity play a part in tear drainage.
- The turnover rate of tears is approximately 16% per minute.

94



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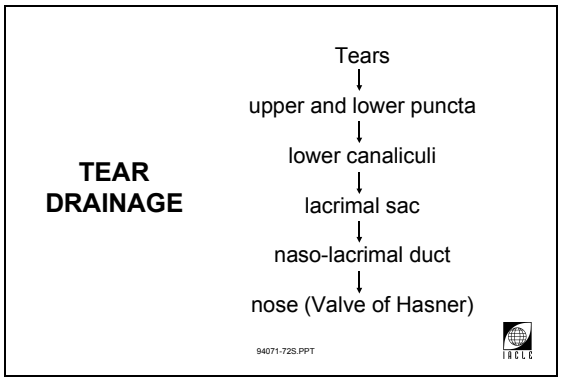
Tear Flow Directions

The compressive force of blinking on the tears combined with the scissor-like action of lid closure, gives a directional flow towards the medial canthus.

95



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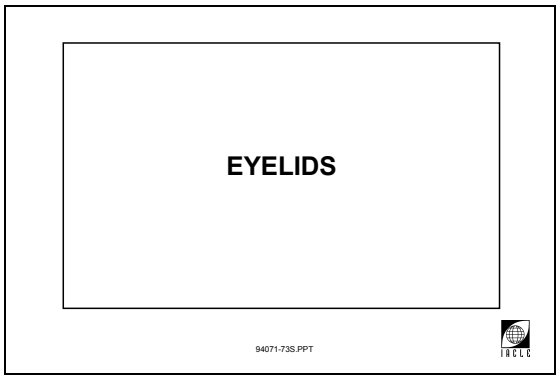
Tear Drainage

- Tears are drawn into the upper and lower canaliculi via the upper and lower lacrimal puncta located on the lacrimal papillae.
- The upper and lower canaliculi join and then almost immediately enter the lacrimal sac.
- The tears pass through the naso-lacrimal duct and finally into the nose.
- Exit to the naso-lacrimal duct is guarded by the valve of Hasner.
- The valve of Hasner prevents the reflux of nasal contents into the naso-lacrimal duct or lacrimal sac.
- The normal action of the lids can also activate the valve of Hasner. Lid closure closes the va
- lve of Hasner.

I.G The Eyelids

96



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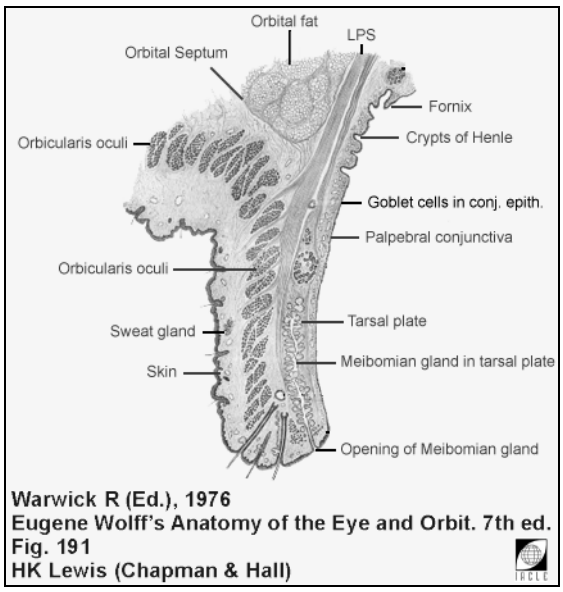
The Eyelids *(title slide)*

97



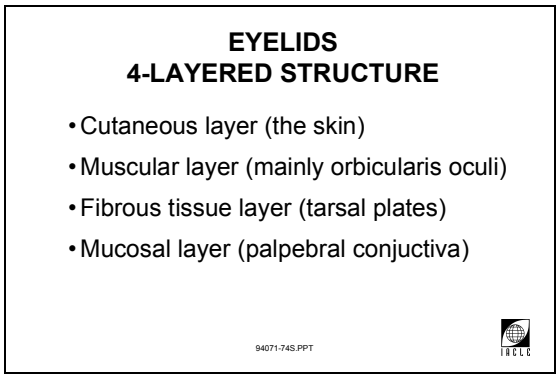
1L11212-96

Cross-section View of the Eyelids
(*Warwick,1976*)

The eyelid has four structural planes:

- Cutaneous (the skin).
- Muscular (mainly the orbicularis oculi).
- Fibrous (the tarsal plates).
- Mucosal (the palpebral conjunctiva).

98



1L194071-74

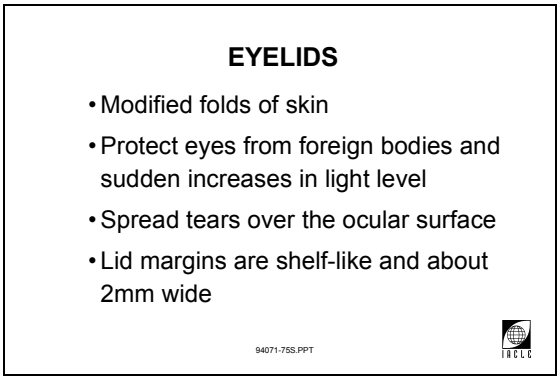
The Eyelids are a Four-layered Structure

- Cutaneous layer:
  - The skin of the eyelids is atypical, being loose and elastic, having very few hairs, and containing no sub-cutaneous fat. It has three layers and is rich in blood vessels, lymphatics and nerves.
- Muscular layer:
  - This layer consists mainly of the oval, concentric orbicularis oculi muscle involving the lids and orbital margins.
  - It also contains the smooth Muller's muscle which helps the levator palpebrae superioris keep the eye open when awake.
- Fibrous tissue layer:
  - This layer is made up of tarsal plate, orbital septum and Meibomian glands.
  - The semi-rigid tarsal plates are made of fibrous and elastic tissue arising from the medial and lateral palpebral ligaments.

- The orbital septum is a thin layer of elastic connective tissue. It is fused with the sheath of the levator palpebrae superioris.
- The Meibomian glands are longer in the upper lids and are embedded in the tarsal plate. Each gland opens onto the lid margin.

- Mucosal layer:
  - This innermost layer is largely the palpebral conjunctiva.

99



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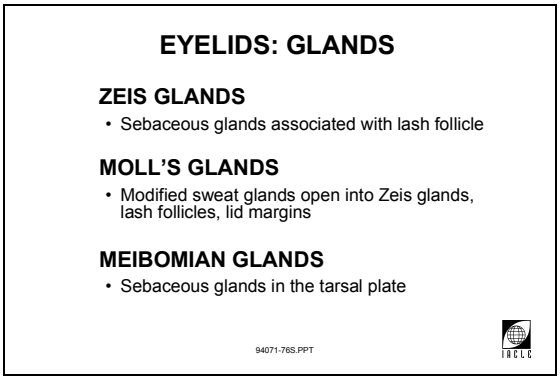
The Eyelids

- The eyelids are modified folds of skin.
- The eyelids protect the eyes from foreign bodies and sudden increases in the level of incident light.
- They also spread tears over the ocular surface.
- The lid margins are shelf-like and are about 2 mm wide.

100



1L194071-76

Glands of the Eyelid

Zeis Glands:

- These are the sebaceous glands associated with lash follicles. They contribute to the lipid layer of the tears.

Moll's Glands:

- These modified sweat glands open into:

  the Zeis Glands

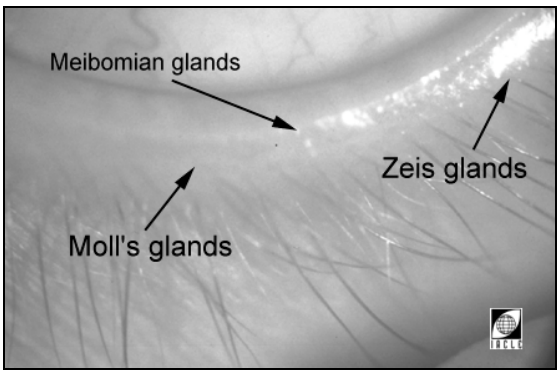
  the lash follicles close to the surface; or

  the lid margins between lashes.

Meibomian Glands:

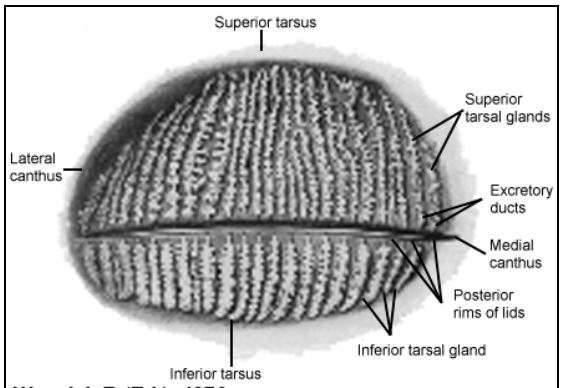
- These are the sebaceous glands in the tarsal plate. They are the main source of the tear lipid layer.

101



1L11687-93L

102



Warwick R (Ed.), 1976
Eugene Wolff's Anatomy of the Eye and Orbit. 7th ed
Fig. 194
HK Lewis (Chapman & Hall)

1L11746-94

Meibomian Gland Array
(Warwick, 1976)

- 20 (lower lid) and 25 (upper lid) vertical glands situated parallel to each other.
- These glands are located in the tarsal plates. The orifice of each gland is located along the inner side of the lid margins.
- Meibomian glands are well developed sebaceous glands.

103

EYELIDS: BLOOD VESSELS

Supply oxygen to the cornea via palpebral conjuctival vessels

94071-77S.PPT

1L194071-77

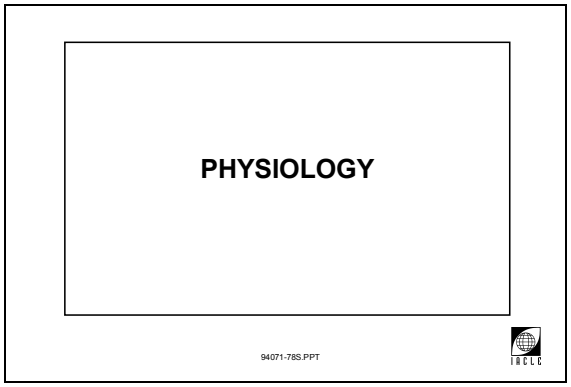
Blood Vessels of the Eyelids

- There are two sources of arterial blood supply to the eyelids:
  - facial system
  - orbital system.
- The palpebral vascular structure provides oxygen to the cornea via palpebral conjunctival vessels when the lids are closed.

II. Physiology of the Anterior Segment

II.A Cornea

104



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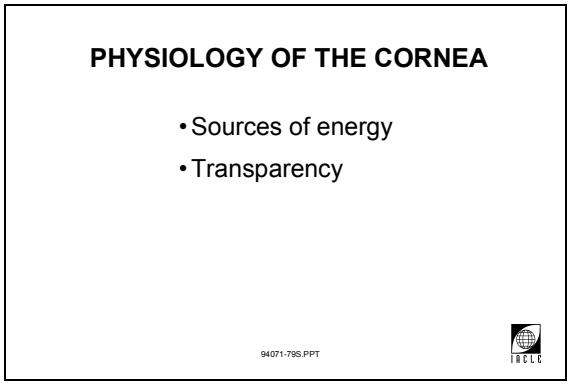
Physiology *(title slide)*

105



1L194071-79

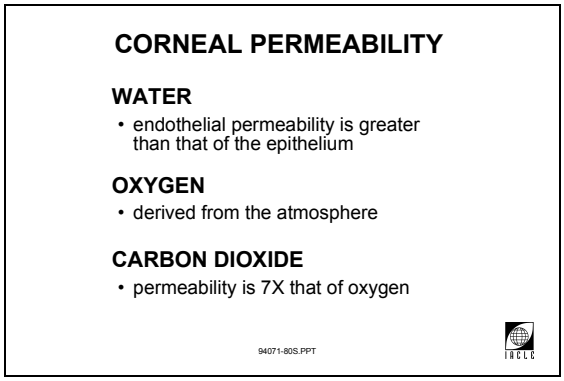
Physiology of the Cornea

Corneal physiology is primarily concerned with:

- The sources of energy which fuel the cornea's metabolic activity.
- Corneal transparency and its maintenance.

II.A.1 Corneal Permeability

106



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Corneal Permeability

Water:

- The endothelium has greater water permeability than the epithelium.
- The epithelium has low permeability to lactic acid which moves through the stroma to the aqueous humor. This lactate-induced osmotic gradient towards the posterior interface produces an influx of water.

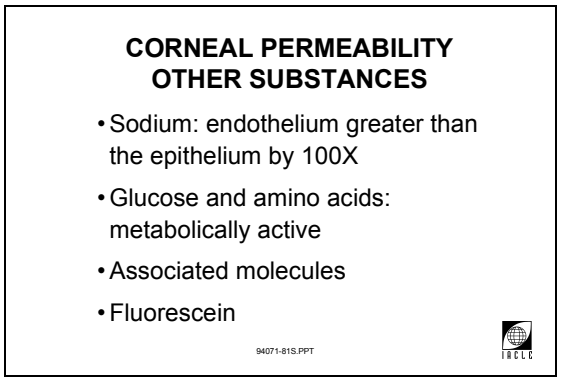
Oxygen:

- Oxygen is needed to maintain corneal integrity and is derived mostly from the atmosphere. Some is derived from the palpebral conjunctiva and the limbal vasculature (especially in closed-eye circumstances).

Carbon dioxide:

- The cornea is highly permeable to carbon dioxide. The Dk_{CO2} is about 7X Dk_{O2}. This is necessary to resist pH and metabolic changes in the cornea.

107



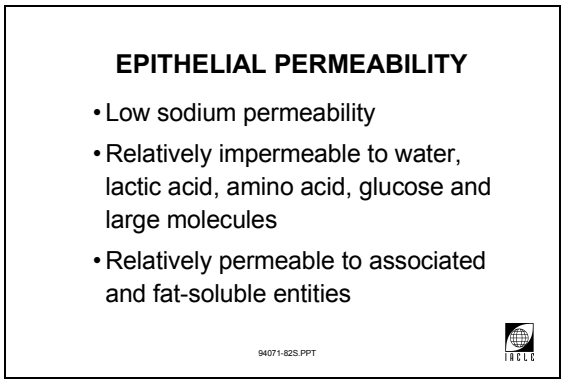
1L194071-81

Corneal Permeability

The cornea is permeable to other substances:

- Na^+ ion permeability of the endothelium is 100X that of the epithelium.
- Glucose and amino acids permeate the endothelium much more than their molecular weight or molecular radius would suggest. This is because they are metabolically active.
- Often associated molecules penetrate faster. Corneal pH can affect the level of dissociation. Therefore, their state of dissociation can affect the cornea's permeability to particular molecules.
- The corneal permeability to fluorescein is higher than was previously thought.

108



1L194071-82

Epithelial Permeability

- The permeability of the epithelium is believed to depend largely on the properties of the surface cells.
- Relatively permeable to associated and fat-soluble entities.
  - generally therefore, associated and fat-soluble entities penetrate the epithelium more readily.

109

ROLE OF CELL JUNCTIONS

- Communication
- Electrical coupling
- Barrier to: - electrolytes
  - fluids
  - macromolecules

94071-83S.PPT

1L194071-83

Role of Cell Junctions

- Act as communication links between cells.
- Electrically couple adjacent cells.
- Serve as barriers to:
  - electrolytes
  - fluids
  - macromolecules.

110

GENERAL CLASSIFICATIONS OF JUNCTIONS

- Occluding or tight
- Adhering
- Each futher subdivided according to shape and size of cell contact
  - zonulae (belts)
  - fasciae (bands)
  - maculae (focal)

94071-84S.PPT

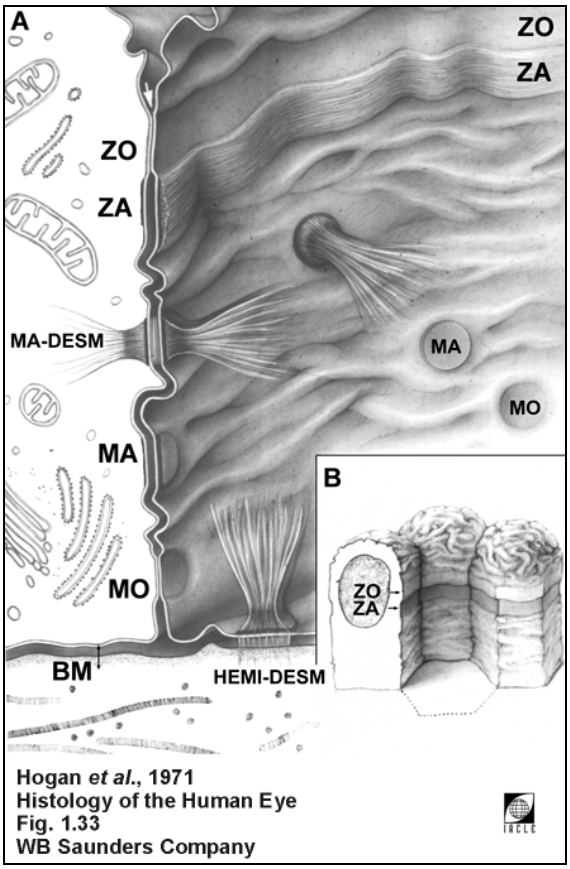
1L194071-84

General Classification of Junctions

- There are two main types:
  - Occluding or Tight Junctions
  - membranes of adjacent cells are fused to eliminate space between cells, e.g. zonula occludens, macular occludens.
- Adhering Junctions
  - attachments to each others' membranes via an intercellular substance, e.g. zonular adherens, macula adherens.
- Each main type can be further subdivided according to its shape and size:
  - Maculae (focal junctions) or fasciae (band junctions).
  - Zonulae (belt junctions) - these surround the entire cell.
  - A variation of the adhering type has tonofilaments joined to the areas of cell attachment, e.g. desmosomal-type macula adherens.

    A hemidesmosome is a special type of desmosome found in the basal cell layer of the corneal epithelium. Hemidesmosomes anchor the epithelium to its basement membrane and may reach or even penetrate Bowman's layer.

111



1L11748-94

Schematic Composite View of All Junction Types
(*Hogan et al., 1971*)

Legend:

A = Intercellular junctions seen from within cell

ZO = zonula occludens

ZA = zonula adherens

MA-DESM = macula adherens (desmosomal-type)

MA = macula adherens

MO = macula occludens

HEMI-DESM = hemidesmosome

BM = basement membrane

B = ZO and ZA shown as continuous structure around cells

112

FIBRONECTIN

- Cell surface glycoprotein
- Involved with cell adhesion to surfaces
- Released beneath regenerating epithelium
- Synthesized by cornea
- Found in basal and apical surfaces of cultured endothelial cells

94071-85S.PPT

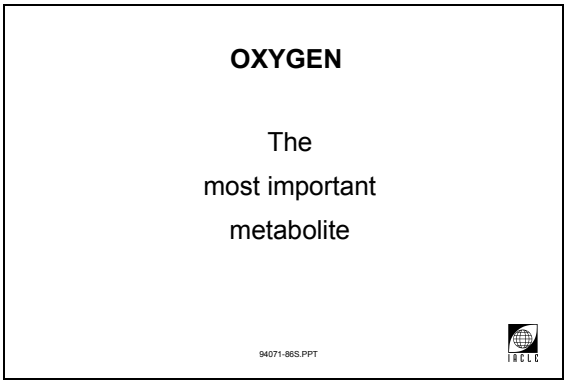
1L19407-85

Fibronectin

- This is a cell-surface glycoprotein involved in cell adhesion (to other cells or to the corneal matrix). Fibronectin molecules may be connected to the intracellular anchoring microfilaments as they are parallel to, and aligned with, the microfilaments associated with the hemidesmosomes of the epithelial basal cells.
- Fibronectin is released beneath the regenerating epithelium and is synthesized by the cornea.
- Also found in basal and apical surfaces of cultured endothelial cells.

II.A.2 Metabolic Changes

113



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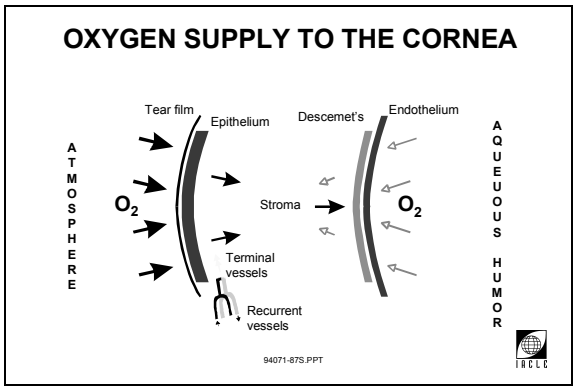
Oxygen

Oxygen is the most important metabolite.

114



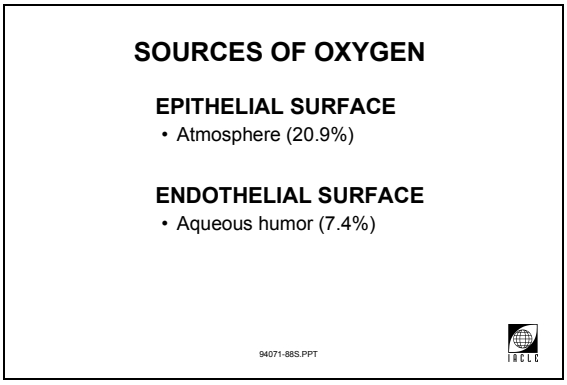
1L194071-87

Oxygen Paths into the Cornea

The cornea derives its oxygen supply from several sources:

- Atmosphere (main supply) via the tear film.
- Capillaries of the limbal region.
- Aqueous humor via the corneal endothelium.
- Capillaries of the palpebral conjunctiva.

115



1L194071-88

Sources of Oxygen

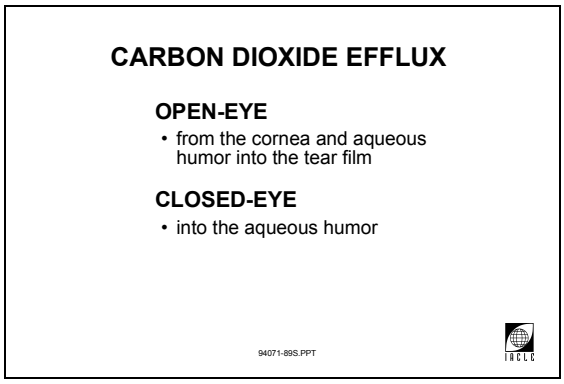
Epithelial surface:

- Derives its oxygen from the atmosphere (20.9% oxygen or 155 mm Hg partial pressure) with little dependence on the aqueous humor.

Endothelial surface:

- Derives its oxygen from the aqueous humor (7.4% oxygen or 55 mm Hg partial pressure) with some dependence on atmospheric oxygen as shown by Zantos' blebs (transient endothelial changes).
- Studies have revealed that pure oxygen decreases lactic acid concentration and pure nitrogen increases lactic acid concentration in the rabbit cornea. Human corneas are believed to behave similarly.

116



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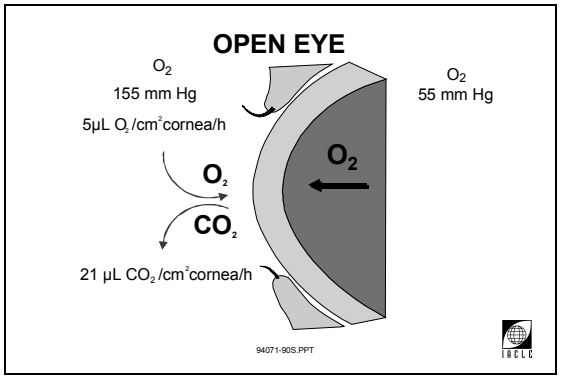
117



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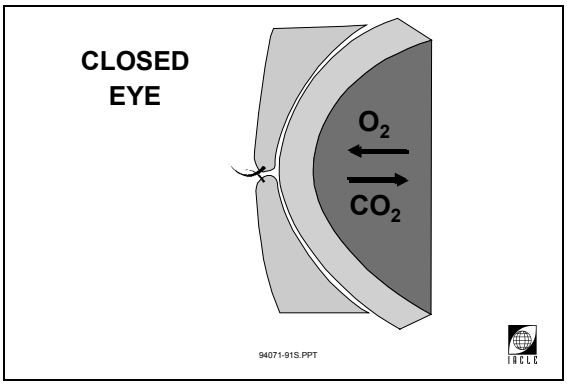
118

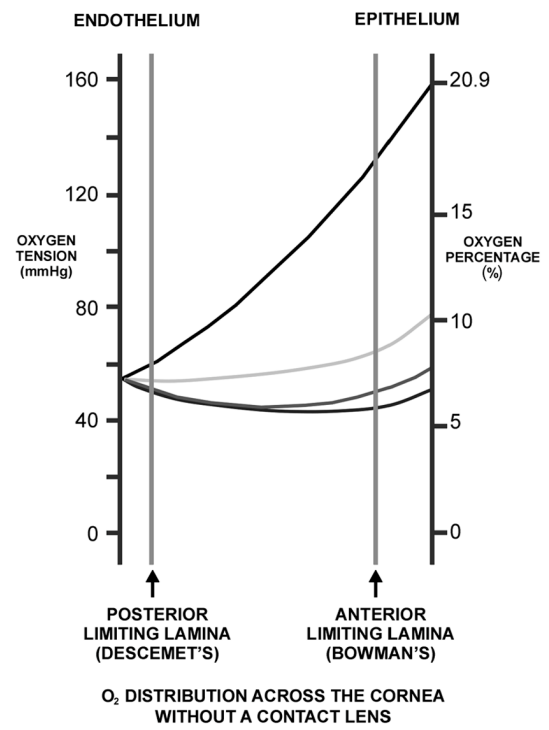


1L194071-91

Carbon Dioxide Efflux

- Carbon dioxide from the cornea and aqueous humor pass out through the tears during open-eye conditions.
- During closed-eye conditions, carbon dioxide exits through the aqueous humor.
- The amount of carbon dioxide that diffuses freely from the cornea for every 5 μL O_2/cm^2 cornea/hour consumed is 21 μL CO_2/cm^2 cornea/hour.

119



Ruben & Guillon, 1994
Contact Lens Practice
Fig. 3.1
Chapman & Hall

1L10604-95

Contact Lenses are a Barrier to Oxygen and Carbon Dioxide Transmission

(Ruben & Guillon, 1994)

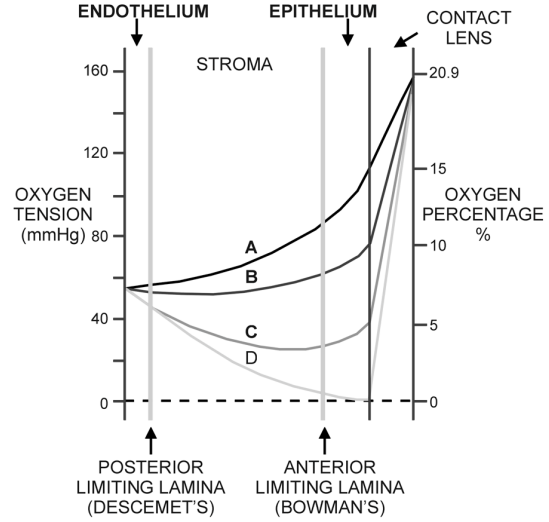
- Contact lenses act as a barrier to oxygen influx and carbon dioxide efflux.

A comparative study of the effects of contact lens wear and no-contact lens wear on the oxygen tension in open-eye and closed-eye conditions revealed the results presented graphically in slides 119 and 120 (Fatt, 1968; Fatt and Bieber, 1968; Fatt et al., 1969; Ruben and Guillon, 1994).

Slide 119 shows the oxygen tensions at various levels of the cornea in open and closed eye circumstances, for central and superior corneal locations, without a contact lens present. Some typical results follow.

- Open-eye, central cornea: 20.9%.
- Open-eye, superior cornea: 10.4%.
- Closed-eye, central cornea: 7.7%.
- Closed-eye, superior cornea: 6.6%.

120



Ruben & Guillon, 1994
Contact Lens Practice
Fig. 3.2
Chapman & Hall

1L10605-95

With Contact Lenses

Slide 120 shows the oxygen tensions at various levels of the cornea, when wearing contact lenses which allow 15%, 10%, 5% and 0% oxygen at the *anterior corneal surface* respectively. These lenses are identified as A to D which correspond to the range 15% to 0% respectively.

121

METABOLISM
CORNEAL ENERGY BY CARBOHYDRATE METABOLISM

- Glucose enters cornea from the aqueous humor
- Energy: ATP (Adenosine Triphosphate)
- 2 main pathways:
  - Anaerobic: ATP from breakdown of glucose into lactic acid
  - Aerobic: ATP from breakdown of glucose by TCA into carbon dioxide and water

94071-92S.PPT

1L194071-92

Corneal Energy by Carbohydrate Metabolism

- Energy expended by the cornea is provided by adenosine triphosphate (ATP).
- Glucose from the aqueous humor is the main substrate for carbohydrate metabolism. It reaches the cornea by a process of diffusion.
- There are two main metabolic pathways:
  - Anaerobic - ATP from the breakdown of glucose into pyruvic acid, and ultimately, lactic acid.
  - Aerobic - ATP from the breakdown of glucose into carbon dioxide and water. This breakdown is performed via the glycolytic pathway, the TCA (tricarboxylic acid) cycles and the activity of the mitochondria of epithelial cells, especially of the basal cells.

122

SOURCES OF GLUCOSE
CORNEAL EPITHELIUM

- Aqueous humor (90%)
- Limbal blood vessels and tears (less than 10%)

94071-93S.PPT

1L194071-93

Sources of Glucose: Corneal Epithelium

- The aqueous humor contains 3.0 μmol/mL of glucose (Thoft *et al*., 1971). Epithelial glucose is derived mainly (about 90%) from the aqueous humor of the anterior chamber.
- The limbal vasculature and tears supply less than 10% of the needs of the epithelium.

123

GLUCOSE CONSUMPTION

- 38-90 μg/hour
- 40-66% of total consumption is by the epithelium

94071-94S.PPT

1L194071-94

Glucose Consumption

- 38 - 90 micrograms/hour of glucose is consumed.
- 40% to 66% of this is used by the epithelium.

124

GLUCOSE METABOLIC PATHWAYS

EMBDEN-MEYERHOF PATHWAY
- produces lactate (anaerobic) + 2 ATP

TRICARBOXYLIC ACID CYCLE
- aerobic (along with epithelial cell mitochondria produces CO_2, H_2O and 36 ATP)

HEXOSE MONOPHOSPHATE SHUNT
- aerobic: produces NADPH, CO_2, H_2O and 6 ATP

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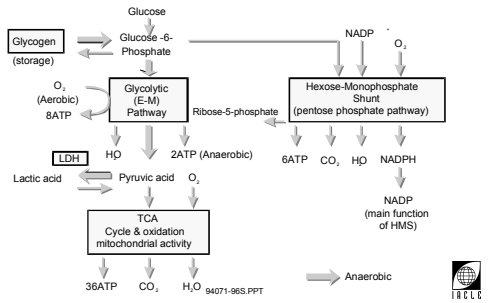
125

CORNEAL GLUCOSE METABOLISM



1L194071-96

Glucose Metabolic Pathways

Anaerobic:

- Embden-Meyerhof pathway (also called the glycolytic pathway):
  - glycolysis produces lactic acid and 2ATP with pyruvic acid as an intermediate product.

Aerobic:

Tricarboxylic acid cycle (also known as citric acid cycle or Kreb's cycle):

- Lower utilization of glucose and uses pyruvic acid and oxygen to produce 36ATP, carbon dioxide and water.

Hexose monophosphate shunt (also known as the pentose shunt or the pentose phosphate pathway):

- Glucose is metabolized to ribose-5-phosphate and reduced nicotinamide adenine dinucleotide phosphate (NADPH) as well as CO_2, H_2O and 6ATP.

126

GLUCOSE PATHWAYS

TCA Cycle, also known as TriCarboxylic Acid Cycle, KREB's Cycle or Citric Acid Cycle is an important pathway for energy production.

94071-97S.PPT

1L194071-97

Glucose Pathways

TCA cycle, also known as the tricarboxylic acid cycle, Kreb's cycle or citric acid cycle is an important pathway for energy production.

- Pyruvic acid (produced from the breakdown of glucose) from the E-M pathway is used in the TCA cycle. With the help of epithelial (largely) mitochondria, pyruvic acid is oxidized to acetyl coenzyme A (CoA) which then enters the TCA cycle.
- Complete oxidation in the TCA cycle produces 36 moles of ATP for every mole of glucose converted.
- Despite the numbers, i.e. 36 (aerobic) *versus* 2 (anaerobic) moles of ATP/mole of glucose consumed, the aerobic net energy contribution is only 3X more efficient than anaerobic glycolysis. This is because the glucose consumed in the TCA/epithelial mitochondria pathway is only 15% of all glucose utilized by the cornea. (By way of comparison, the hexose monophosphate shunt uses 60-70% of the total.)

127

AEROBIC GLYCOLYSIS: TCA CYCLE (& Mitochondria)

- Efficient
- 15% of glucose utilized
- Energy contribution: 3x that of anaerobic glycolysis

94071-98S.PPT

1L194071-98

Aerobic Glycolysis: TCA cycle (& mitochondria)

- Efficient.
- 15% of glucose utilized.
- Energy contribution: 3x that of anaerobic glycolysis.

pyruvic acid from E-M pathway
↓
complete oxidation
↓
36 moles ATP : 1 mole of glucose
(for each mole of glucose consumed, 36 moles of ATP result)

128

AEROBIC GLYCOLYSIS: TCA CYCLE (& Mitochondria)

Pyruvic acid from E-M pathway
↓
Complete oxidation
↓
36 moles ATP: 1 mole of glucose

94071-99S.PPT

1L194071-99

129

ATP

- 'Charged' form of energy
- When ATP imparts energy it is converted to ADP (adenosine diphosphate)
- ADP recharged by mitochondria
- Recycling of ADP into ATP every 50 seconds

94071-100S.PPT

1L194071-100

ATP

- ATP is a 'charged' form of chemical energy.
- When ATP imparts energy, it looses a terminal phosphate group and is converted to ADP (adenosine diphosphate).
- ADP can be recharged by mitochondria (largely in epithelial cells, some in endothelium, little in stroma) to be recycled into ATP approximately every 50 seconds.

130

ANAEROBIC GLYCOLYSIS: EMBDEN-MEYERHOF PATHWAY

- 35% of glucose used

G-6-P
(by phosphorylation)
↓
pyruvic acid
↓
lactic acid & ATP
↓
2 moles ATP: 1 mole glucose

94071-101S.PPT

1L194071-101

Anaerobic Glycolysis: Embden-Meyerhof Pathway

- 35% of glucose is used in the process of glycolysis which is catabolized to pyruvic acid. This is converted to lactic acid and 2 moles of ATP.

Glucose
↓
G-6-P
(by phosphorylation)
↓
pyruvic acid
↓
lactic acid & ATP
↓
2moles ATP: 1 mole glucose, i.e. 2 moles of ATP result from each mole of glucose catabolized.
3

131

HEXOSE MONOPHOSPHATE SHUNT (Pentose Phosphate Pathway)

- H-M Shunt NOT efficient as energy source
- NO net gain in ATP
- 60-70% of glucose used
- Limited recycling of glucose: 85% catabolized lactate

94071-102S.PPT

1L194071-102

132

HEXOSE MONOPHOSPHATE SHUNT (Pentose Phosphate Pathway)

G-6-P
↓
Ribose-5-phosphate & NADPH (reduced Nicotinamide Adenine Dinucleotide Phosphate)
↓

Ribose - 5 - phosphate
↓
Glycolytic pathway

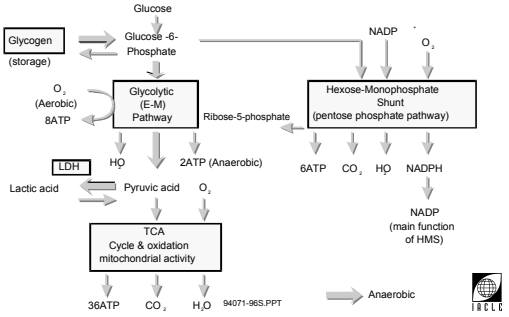
NADPH
↓
NADP
↓
Substrate for RNA & DNA

94071-103S.PPT

1L194071-103

133

CORNEAL GLUCOSE METABOLISM



1L194071-104

Hexose Monophosphate Shunt (Pentose Phosphate Pathway)

- H-M Shunt is not efficient as an energy source because there is no net gain in ATP when the HMS is synthesizing NADPH, its main function. If glucose is oxidized to form water and carbon dioxide then 35 moles of ATP are liberated but this is not the HMS's primary route or function.
- 60-70% of glucose is metabolized to form ribose-5-phosphate and NADPH (reduced nicotinamide adenine dinucleotide phosphate which is also a carrier of chemical energy by virtue of its 'reducing' power, i.e. it is an electron DONOR).
- Synthesis of fatty acids and proteins requires NADPH.
- Ribose-5-phosphate is used in the synthesis of DNA and RNA.
- There is limited recycling of glucose: 85% is catabolized into lactate.

G-6-P
↓
ribose-5-phosphate and NADPH (reduced nicotinamide adenine dinucleotide phosphate).
↓
NADPH is used to form NADP, a substrate for RNA and DNA synthesis.

134

NORMOXIC CONDITIONS

- Glycogen storage: outermost cell layers of the epithelium
- Glycogen reserves are in preparation for a lack of oxygen and/or mechanical trauma
- ATP production/consumption is normal

94071-105S.PPT

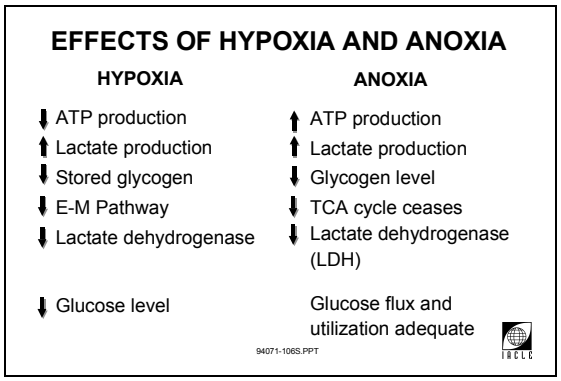
1L194071-105

Normoxic Conditions

When oxygen levels are normal:

- Glycogen is stored in the two surface layers of epithelial cells.
- Glycogen reserves are a preparation for a lack of oxygen and/or mechanical trauma.
- ATP production and consumption is normal under normoxic conditions.

135



1L194071-106

Effects of Hypoxia and Anoxia

H: ATP production falls but consumption continues as before.

A: ATP production by E-M (glycolytic) pathway increases.

H: Lactate production rises.

A: Lactate production increases considerably (40%-140% reported, 100% after 1 hr).

H: Stored glycogen decreases and glycogen is cleaved to produce G-6-P resulting in increased anaerobic glycolysis.

A: Glycogen level falls and the TCA cycle ceases operation.

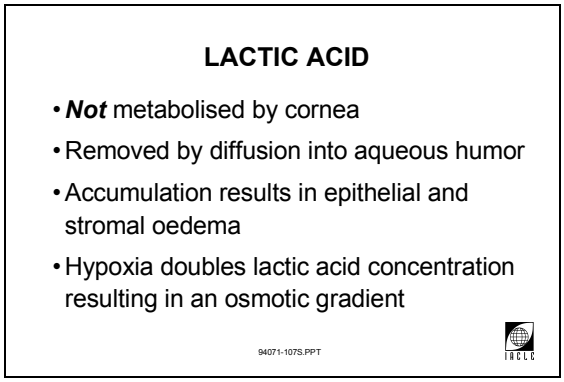
H: Energy efficiency level falls (2 *versus* 36 moles of ATP) and therefore more glucose is expended over time to produce the same amount of energy.

A: Glucose flux and utilization are maintained and produce an adequate supply even when anoxic. Therefore, no glycogen should be required. However, epithelial enzymes are unable to utilize enough glucose to meet the demand for ATP.

H: LDH (lactic or lactate dehydrogenase), hexokinase and protein synthesis activities decrease.

A: LDH, hexokinase, protein and DNA synthesis activities decrease and/or stop.

136



1L194071-107

Lactic Acid

- *Not* metabolized by the cornea.
- Lactic acid is removed by diffusion across the endothelium into the aqueous humor.
- Accumulation of lactic acid produces epithelial and stromal oedema.
- Hypoxia doubles the lactic acid concentration in the cornea to produce increased osmotic pressure resulting in osmotically driven swelling.
- While the epithelium does not swell, it is affected by hypoxia. Changes in optical properties can be detected (e.g. Sattler's veil), that imply that light scattering sites develop, producing haloes.

•

II.A.3 Corneal Transparency

137

CORNEAL TRANSPARENCY STROMA

- Transmits 90% of incident light
- Potentially a non-transparent layer
- Fibrils: *n*=1.47
- Ground substance: n=1.354
- Regular fibril spacing of 60nm

94071-108S.PPT

1L194071-108

Corneal Transparency

Stroma:

- Transmits approximately 90% of incident light.
- Potentially the stroma is a non-transparent layer.
- Fibrils: $n = 1.47$
- Ground substance: $n = 1.354$
- Regular fibril spacing: 60 nm.

138

CORNEAL TRANSPARENCY DIFFRACTION THEORY OF MAURICE

- Depends on ordered arrangement of collagen fibrils
- Transparency is maintained if the disruption is less than a few wavelengths
- Scattering effect increases as swelling increases (fibrils become larger optically)

94071-109S.PPT

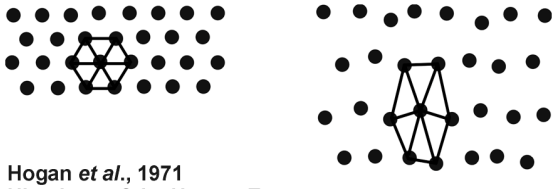
1L194071-109

Corneal Transparency

Diffraction theory of Maurice:

- Transparency depends on ordered arrangement of collagen fibrils.
- Transparency is maintained provided the irregularity does not exceed a few wavelengths.
- Scattering effect increases as swelling increases since the fibrils become larger optically.

139



Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.26
WB Saunders Company

1L11738-94

Disruption of Collagen Fibrils

(Hogan et al., 1971)

This diagram shows the loss of uniformity of fibrillar spacing which results from stromal oedema.

140

CORNEAL SWELLING

- Lactate and metabolite accumulation - osmotic gradient causes water imbibition
- Hydrophilicity of GAGs causes a natural water imbibition
- Swelling during sleep is due to:
  - hypoxia (50%)
  - lower tear osmolarity
  - increased temperature and humidity

94071-110S.PPT

1L194071-110

Corneal Swelling

- The epithelium has a high rate of aerobic metabolism.
- Lactate and metabolite accumulation causes an increased osmotic gradient in the stroma resulting in water imbibition.
- Hydrophilicity of GAGs induces the natural tendency for water imbibition into the stroma. This is normally countered by the barrier functions of the epithelium and the endothelium as well as the endothelial pump.
- Swelling during sleep is caused by hypoxia (50%) in the closed eye, with equal contributions from lower tear osmolarity, increased temperature and increased humidity.

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CORNEAL SWELLING: EFFECTS

- Change in refractive index of intra and extracellular spaces
- Sattler's veil
- Haloes

94071-111S.PPT

1L194701-111

- Optical alterations of the epithelium are caused by changes in the refractive index of intra and extracellular spaces (Sattler's veil, haloes).
- Haloes are caused by an oedematous basal layer of the epithelium.
- Short-term contact lens-induced swelling does not cause decreased endothelial or epithelial ion transport.

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ENDOTHELIAL PUMP

- Each cell pumps its own volume every 5 minutes
- Active transport mechanism
- Na^+ + K^+ + ATPase-dependent pump
- Glucose fueled

94071-112S.PPT

1L194701-112

Endothelial Pump

- The endothelial pump probably plays a minor role in recovering from corneal oedema (about 20%).
- The endothelial pump is glucose fuelled.
- Each endothelial cell pumps its own volume every five minutes.
- The endothelial pump is an active transport mechanism that has several active processes.
- Most active pumps move salts to produce an osmotic gradient that water follows passively. Sodium ions in the stroma are bi-directional i.e. TO and FROM the aqueous humor.
- Sodium + potassium + ATPase (Na^+ + K^+ + ATPase)-dependent pump.
- The sodium pump driving sodium ions (Na^+) FROM the stroma INTO the aqueous humor is electronically balanced by the bicarbonate ion (HCO_3^-) being pumped in the same direction. Thus bicarbonate transport from the stroma to the aqueous humor is electroneutral.
- Only the sodium pump driving sodium ions INTO the cornea from the aqueous humor produces a potential difference (aqueous humor is negative).
- Since isotonicity is maintained, the bicarbonate flow must be in proportion to the sodium and chloride movement.
- Endothelial sodium and chloride permeability is low but water permeability is relatively high. Water transport is highly efficient via the intercellular pathway.
- Na^+ + K^+ + activated ATPase is located in the endothelial and epithelial cell membranes but on the lateral walls only.
- Carbonic anhydrase (a bicarbonate and chloride exchanger as well as bicarbonate synthesizer utilizing carbon dioxide and water) and Na^+ + K^+ + ATPase are both located on the aqueous humor side of the endothelium.
- A sodium-hydrogen ion exchanger is

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ENDOTHELIAL PUMP

- Sodium ions move between the stroma and aqueous humor, water follows passively
- Bicarbonate from stroma ***into*** the aqueous humor is about equal to sodium ion outflow
- Bicarbonate transport is electroneutral
- Only the sodium ions pumped ***into*** the cornea produce a potential difference

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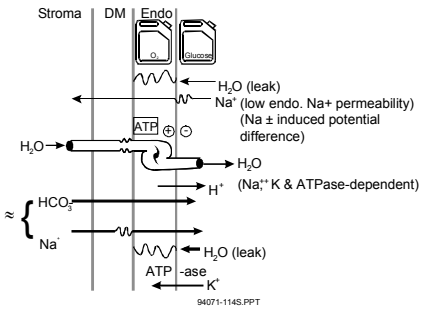
ENDOTHELIAL PUMP



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hypothesized because hydrogen is drawn OUT of the endothelium into the aqueous humor. It may be indirectly coupled with Na^+ + K^+ + ATPase activity.

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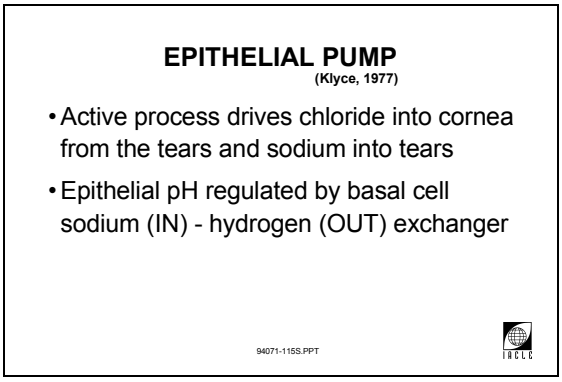

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Epithelial Pump

- This active process drives chloride ions INTO the cornea FROM tears and sodium ions are drawn INTO the tears. Klyce (1977) has also reported that an active transport process for chloride ions exists which draws chloride INTO the tears, creating an osmotic gradient.
- The epithelial pH is regulated by a basal cell sodium (IN) - hydrogen (OUT) ion exchanger.
- Chloride ions are pumped from the stroma to the tears by a process modulated by cyclic AMP (adenosine 3', 5' - cyclic phosphate).
- The osmotic gradient (towards the tears) created by the transport of both Na^+ and Cl^- ions INTO the tears draws water from the cornea passively. However, this outward flow is less than the water leakage in. As a result the epithelium/anterior stroma alone cannot control corneal hydration.
- Lactate generated by the epithelium passes posteriorly to the aqueous humor.

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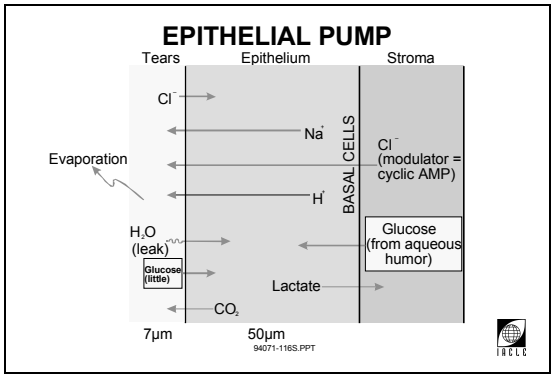

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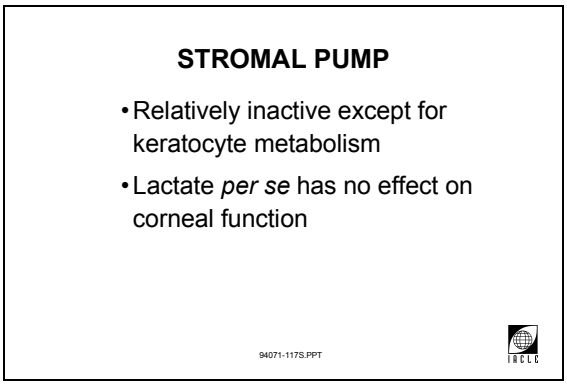

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Stromal Pump

- This pump is relatively inactive except for keratocyte (corneal fibroblast) metabolism.
- Lactate *per se* has no effect on corneal function.

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FACTORS INFLUENCING CORNEAL THICKNESS

- Individual variations
- Tear evaporation and osmotic response (hypertonic) - thinning
- Reflex tearing in CL (hypotonic) - thickening
- CL induce hypoxia - thickening

94071-118S.PPT

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Factors Influencing Corneal Thickness

- Subject to individual variation.
- Closed-eye swelling is 3 to 4%. On eye opening, the cornea thins due to tear evaporation and an osmotic response to the resulting tear hypertonicity.
- Corneal thickness increases can be caused by reflex tearing in contact lens wear. This is because the reflex tears are hypotonic.

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TEAR FILM OSMOLALITY
NORMAL OSMOLALITY

294-334 mOsm/litre (0.91-1.04%)

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TEAR FILM OSMOLALITY: CONTACT LENS EFFECTS

- Initial HCL wear: decreased tear osmolality
- Cornea swells (stromal) 2-4%
- Initial SCL wear: increased tear osmolality (blink rate affects evaporation??)
- Return to pre-lens value: 1 week (HCL), 2-3 days (SCL)

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1L194071-120

Tear Film Osmolality

Normal osmolality:

294-334 mOsm/litre (0.91-1.04%).

Contact lens effects:

- Initial hard lens wear produces decreased tear osmolality brought about by reflex tearing. The cornea swells (mainly stromal) some 2-4%.
- Initial soft contact lens wear increases tear osmolality. This may be caused by changes in the blink rate causing an increase in evaporation.
- Return to pre-lens value is not immediate: 1 week (HCL), 2-3 days (SCL).

Osmolality *versus* Osmolarity:

Osmolality: Osmolality is the number of osmoles of a solute in unit mass of a solvent (usually water). For example: 1 gram molecular weight of NaCl is 58.5 g *but* it dissociates virtually completely when in solution resulting in 2 osmoles of solute not 1. Therefore 58.5 g of NaCl dissolved in 1 kg of water produces a solution with an osmolality of 2 osmoles per kg.

The normal osmolality of body fluids is about 300 milliosmoles per kg.

Osmolarity: Osmolarity is the number of osmoles of a solute in unit volume of total solution. This is a more difficult measure to deal with since the addition of a solute *alters* the volume of the solution and the actual mass of water present is difficult to determine when one is presented with a ready-made solution.

Therefore, 58.5 g of NaCl dissolved in water so that the resultant solution has a volume of 1 litre, will have an osmolarity of 2 osmoles per litre.

Strictly speaking it is the osmolality (osmoles per kg of water) which determines osmotic pressure. At low concentrations (as occur in physiology) the differences between osmolality and osmolarity are less than 1% and can be ignored for qualitative purposes.

II.A.4 Epithelial Barrier Function

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CORNEAL EPITHELIAL REPAIR

- Complete stripping ➡ rapid regeneration:
  - 6 wks for complete cell regeneration
  - conjunctival and corneal cells provide coverage
- Smaller wounds:
  - wing cells and squamous cells slide
  - basal (columnar) cells flatten

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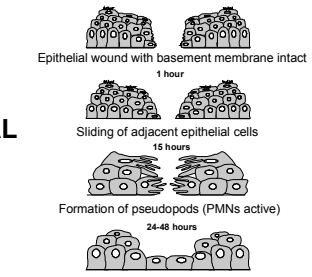
EPITHELIAL REPAIR



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CORNEAL EPITHELIAL REPAIR

- Limited area, basal cells in place:
  - ↑ desquamation of surface cells
  - basal cells become less columnar
  - wounding stops mitosis in adjacent cells
  - mitosis is resumed once full epithelial thickness is achieved

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Corneal Epithelial Repair

- A complete epithelial stripping causes rapid regeneration:
  - at 24 hours there is complete coverage by cells originating from the peri-limbal conjunctiva and limbus as well as from the cornea
  - It takes six weeks for complete cell regeneration and for most of the non-corneal cell's conjunctival or limbal characteristics to be lost. The transformation of cell types into cells with corneal cell characteristics is a 'complication' for the repair process.
- Smaller wounds heal by the sliding of adjacent epithelial cells
  - sliding begins about one hour after trauma and is substantially complete in about three hours
  - wing cells and squamous cells slide
  - basal (columnar) cells flatten
  - Interdigitations between cells loosen. However, cells remain bound by the desmosomes of their extended cytoplasm.
- Wounds of limited area with basal (columnar) cells still in place
  - there is a delay of about 5.5 hours
  - increased desquamation of surface cells
  - basal cells become less columnar
  - wounding stops mitosis which resumes once full epithelial thickness is reached.
- Polymorphonuclear leucocytes or PMNs (mostly polymorphonuclear neutrophils) are usually active during the repair processes described above. PMNs are one of the body's defences which, along with monocytes, attack and destroy invading micro-organisms and other injurious agents.

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CORNEAL EPITHELIAL REPAIR

- Basement membrane layer loss:
  - initially re-epithelialization by sliding or migration
  - by 6 weeks regeneration almost complete
- Epithelium will alter cell thickness and arrangement to maintain corneal curvature
- Protein synthesis ↑ 3X during epithelial sheet movement
- Cell migration necessitates shape change

94071-124S.PPT

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Corneal Epithelial Repair

Wounds with basement membrane layer loss:

- Initially, re-epithelialization occurs by sliding or migration. This process takes about seven days.
- At seven days, laying down of basement membrane starts with hemidesmosomal attachment to Bowman's layer. Attachment is weak and easily broken.
- By six weeks, regeneration is almost complete.
- Epithelium will alter cell thickness and arrangement to maintain corneal integrity and curvature if possible.
- Proteinza synthesis is increased three fold

during epithelial sheet movement.

- Migration is accompanied by cell shape changes as dictated by location within the epithelium (i.e. which layer is involved).

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EFFECT OF REMOVING CORNEAL LAYERS

EPITHELIUM

- Temperature reversal effect still present
- With plastic substitute normal corneal thickness is maintained
- Barrier to passive influx of salts and water Loss results in rapid corneal swelling

94071-125S.PPT

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EFFECT OF REMOVING CORNEAL LAYERS

STROMA with impermeable membrane implant

- Epithelial oedema

ENDOTHELIUM

- Rapid swelling and increased thickness

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1L194701-126

Effect of Removing Corneal Layers

Removal of the following layers causes changes that provide evidence of the layers' roles as barrier or functional layers.

Epithelium:

- Temperature reversal effect is still present, i.e. cornea swells if refrigerated and thins if warmed subsequently, suggesting an active process is being slowed or accelerated respectively.
- When replaced by a plastic substitute, normal stromal thickness is maintained. This suggests a barrier function.
- Barrier to the passive influx of salts and water. Loss results in rapid corneal swelling.

Stroma with impermeable membrane implant:

- Causes anterior oedema only. The posterior stroma maintains its normal thickness. This suggests the control of corneal thickness is in the posterior cornea (i.e. the endothelium).
- Endothelium:
- Causes rapid swelling and increased thickness. This is because the main active control of corneal thickness is the endothelium. The loss of the endothelial pump and, to a lesser extent, its barrier function leads to an uncontrolled corneal swelling driven by the hydrophilicity of the corneal GAGs.

II.A.5 Maintaining Normal Corneal Function

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CORNEAL INTEGRITY
requires:

OXYGEN
- 15% - 20.9% for regular function
- 13.1% to prevent suppression of epithelial mitosis
- 8% to prevent sensitivity loss
- 5% to prevent glycogen depletion

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CORNEAL INTEGRITY
requires:

CO_2 ELIMINATION
- Essential to avoid pH and metabolic changes

GLUCOSE
- Main source: anterior chamber

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CARBON DIOXIDE PERMEABILITY

HYDROGELS
- 21x more than oxygen

RGPs
- 7x more than oxygen

CORNEA
- 7x more than oxygen

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1L194701-129

Corneal Integrity Requires

Oxygen:
- 15 - 20.9% for regular function.
- 7.5 - 21.4% to prevent corneal oedema depending on the criterion applied.
- 13.1%to prevent suppression of epithelial mitosis.
- 8% to prevent corneal sensitivity loss.
- 5% to prevent depletion of stored glycogen.

CO_2 elimination:
- Essential to resist pH and metabolic changes in the cornea.
- CO_2 permeability of

  hydrogels is 21X their O_2 permeability

  RGPs is 7X their O_2 permeability

  cornea is 7X its O_2 permeability.

Glucose supply:
- Main source: anterior chamber.
- Limited source: limbal vessels and tears.

pH tolerance:
- Tears are bicarbonate-ion buffered.
- pH of tear in the open eye: 7.34-7.43.
- pH tolerance of the endothelium: pH 6.8-8.2.
- Eyedrops outside the pH range 6.6-7.8 cause stinging.

Temperature:
- The data is presented in the form: *temperature (standard deviation)*°C.

Corneal:
- open-eye:

  34.2 (0.4)°C Fujishima *et al.*, 1996.

  34.3 (0.7)°C Efron *et al.*, 1989.

  34.5 (1.0)°C Martin & Fatt, 1986.
- closed-eye:

  37.7 (1.2)°C Schwartz, 1964.

  36.2 (0.1)°C Martin & Fatt, 1986.
- other:

  dry eye, 34.0(0.5)°C Fujishima *et al.*

  under 0.07 mm SCL, 34.6°C Martin & Fatt.

  under 0.30 mm, SCL 34.9°C, Martin & Fatt.
- the increase in temperature under a soft contact lens is believed to be due to the insulating effects of the lens.

- Conjunctiva:

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pH

- More comfortable than Schirmer's test
- pH of tears in open eye: 7.34 - 7.43
- pH tolerance of the endothelium: 6.8 - 8.2
- Eyedrops outside pH range 6.6 - 7.8 sting

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TEMPERATURES

Cornea

- Open eye
  - 34.2 (0.4)°C (Fujishima et al., 1996)
  - 34.3 (0.7)°C (Efron et al., 1989)
  - 34.5 (1.0)°C (Martin & Fatt, 1986)
- Closed eye
  - 36.2 (0.1) °C (Martin & Fatt, 1986)
- Other
  - dry eye 34.0 (0.5) °C (Fujishima et al., 1996)
  - under 0.07 mm SCL 34.6°C (Martin & Fatt, 1986)
  - under 0.30 mm SCL 34.9°C (Martin & Fatt, 1986)
- Conjunctiva
  - 34.9 (0.6) °C (Isenberg & Green, 1985)
  - 35.4°C in 20 - 30 year old
  - 34.2°C >60years of age

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- 34.9 (0.6)°C Isenberg & Green, 1985.
- 35.4°C in 20 to 30 year olds.
- 34.2°C >60 years of age.
- this data shows that conjunctival temperature decreases with age.

II.A.6 Age-Related Changes

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AGE-RELATED CORNEAL CHANGES ANATOMICAL

- Arcus sensilis
- White limbal girdle of Vogt
- Decreased nerve elements in cornea and eyelid
- Dystrophies/degenerations
- Pinguecula and pterygium
- ATR astigmatism
- Decreased transparency
- Peripheral thinning
- Endothelial cell loss
- Polymegehism

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Age-Related Corneal Changes

Anatomical:

- Arcus senilis, which occurs in 60% of the population between 40 and 60 years, is caused by deposition of lipid droplets. These droplets are deposited in the entire cornea, but are more concentrated in regions adjacent to Bowman's layer and Descemet's membrane.
- White limbal girdle of Vogt appearing as a narrow, crescent-shaped, chalky line at the nasal and temporal limbus. This is common among 55% of the population between 40 and 60 years of age. This elastic degeneration of sub-epithelial collagen is probably induced by exposure to sunlight.
- Reduced nerve elements in the cornea and eyelids decreases corneal sensitivity.
- Dystrophies/degenerations.
- Pinguecula and pterygium, especially common among fair-skinned races living in countries with hot, sunny climates and high levels of UV exposure.
- Increasing ATR astigmatism as the vertical cornea flattens with increasing age.
- Decreased transparency and a loss of lustre.
- Peripheral thinning.
- Endothelial cell loss and decreased cell density may increase hydration. Changes may be caused by UV light and overnight (closed-eye) hypoxia each and every night of life.

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AGE-RELATED CORNEAL CHANGES FUNCTIONAL CHANGES

- Increase in permeability of limbal vasculature
- Decrease in endothelial pump activity
- Decrease in metabolic activity
- Increase in refractive index
- Increase in visibility of nerves

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Age-Related Corneal Changes

Functional Changes:

- Increased permeability of limbal vasculature allows leakage of low-density lipoproteins into the cornea.
- Decreased endothelial pump activity due to endothelial cell loss and resultant density changes (decrease).
- Decrease in metabolic activity.
- Increase in refractive index possibly due to altered corneal H_2O content.
- Increased visibility of corneal nerves.

II.B Tears

II.B.1 Tear Film Functions and Composition

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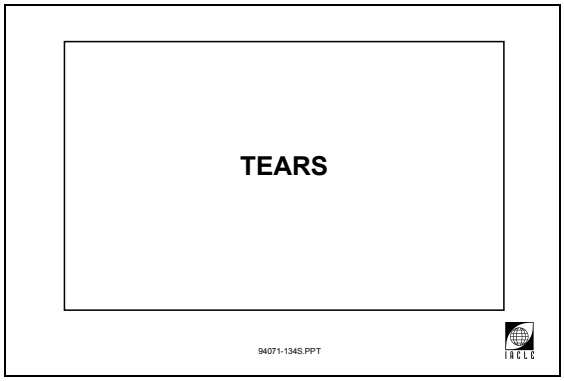

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Tears *(title slide)*

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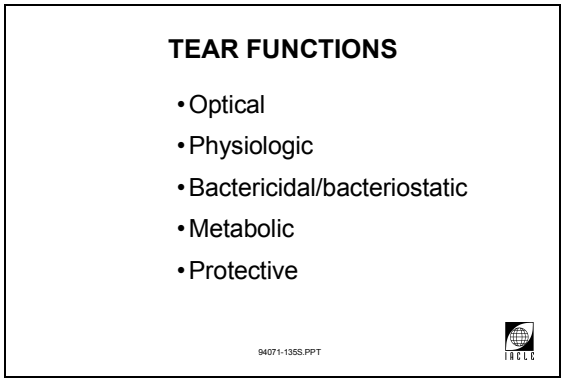

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Tear Functions

- Optical: Form and maintain a smooth optical surface over the cornea.
- Physiologic: Maintain a moist environment for the epithelium of the cornea, conjunctiva and lids.
- Bactericidal/bacteriostatic: Anti-bacterial properties are imparted by the presence of tear lysozyme, lactoferrin, ß-lysin and immunological cells. The leucocyte pathway is invoked in the case of injury.
- Metabolic: Transport of nutrients and metabolic products to and from the cornea via the tears.
- Protective: Elutes and dilutes noxious stimuli, foreign bodies, etc. from the eye's anterior surface.

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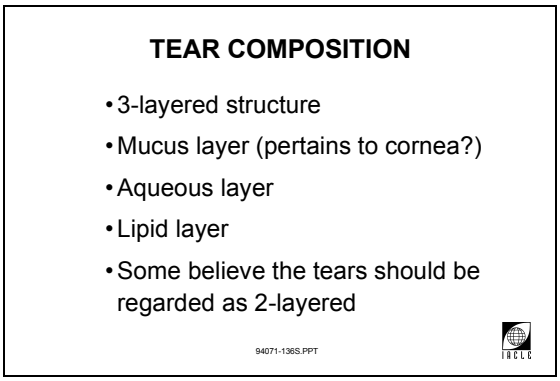

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Tear Composition

- Three-layered structure:
  - mucus layer (sometimes called the mucin layer)
  - aqueous layer
  - lipid layer.
- Some believe the mucus layer should be considered part of the cornea, in which case the tears constitute a two-layered structure.

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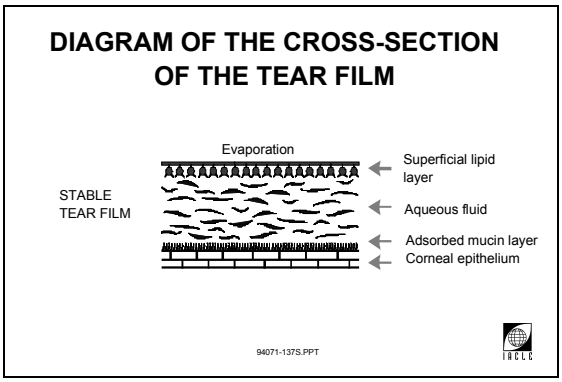

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Diagram of the Cross-section of the Tear Film
(after Smolin & Thoft, 1987)

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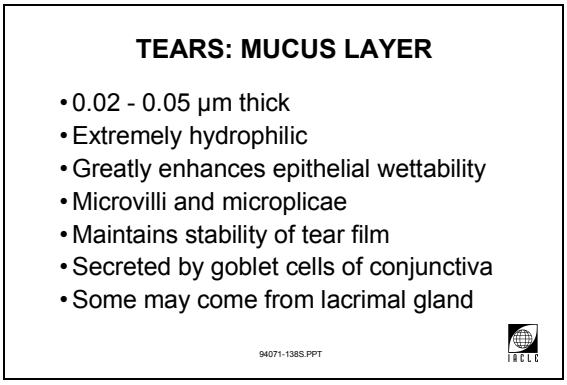

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Tears: Mucus Layer

- This layer is 0.02 - 0.05 µm thick.
- The mucus layer is extremely hydrophilic and greatly enhances epithelial wettability.
- Mucus adhesion to the corneal surface is made possible by the presence of microvilli and microplicae on the surface of the superficial epithelial cells.
- This mucus layer is responsible for maintaining the stability of the tear film, as each blink resurfaces the epithelium with a renewed mucus layer.
- It is secreted mainly by goblet cells of conjunctiva although some may come from the lacrimal gland.

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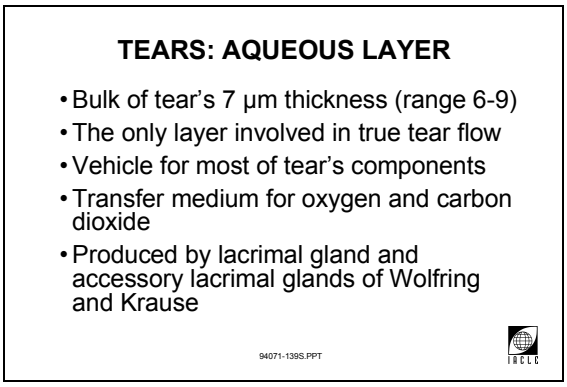

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Tears: Aqueous Layer

- This layer makes up the bulk of the tear's 7 µm thickness (range 6-9 µm).
- It is the only layer involved in true tear flow. The greatest flow is adjacent to the lid margins (upper and lower) and produces the lacrimal 'river' or at the medial canthus the lacrimal 'lake'.
- The aqueous layer is the vehicle for most of the tear film components and is the transfer medium for oxygen (to the cornea) and carbon dioxide (from the cornea).
- The aqueous is produced by the lacrimal gland and accessory lacrimal glands of Wolfring and Krause.

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1L194071-140

Tears: Lipid Layer

- The most superficial layer of the tears. It is a thin lipid film of 0.1 µm thickness.
- It is mainly secreted by Meibomian glands with some contribution from the Zeis glands.
- Its functions are anti-evaporative, especially in low humidity and turbulent air, and to prevent tear fluid overflow.
- It is anchored to the lid margins at the orifices of the Meibomian glands of the upper and lower lids.
- It is not involved in the tear flow towards the puncta.
- Blinking causes it initially to be compressed and thickened. On eye opening, the lipid layer is stretched between lid margins and it drags the aqueous layer along with it, thereby producing an increase in film thickness.
- Observation is made by specular reflection and noting the thin-film interference patterns on the corneal surface.
- Instruments useful for observing the lipid layer of the tear film are:
  - slit-lamp biomicroscope
  - tearscope (of Guillon).

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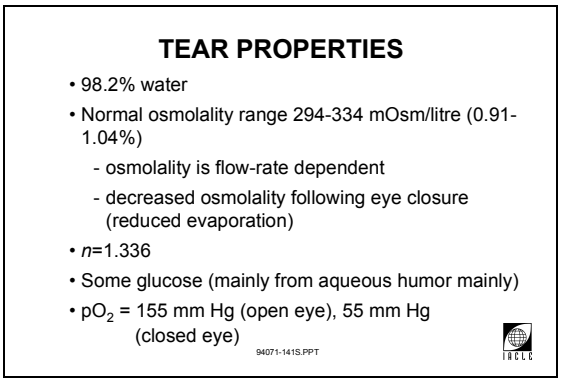

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Tear Properties

- Tears contain 98.2% water.
- The normal osmolality range is 294-334 mOsm/litre (0.91-1.04%) with an average of 310 (0.96%)
  - osmolality is tear flow-rate dependent
  - osmolality decreases to 0.89% following eye closure (due to reduced evaporation).
- Refractive index is: n =1.336.
- Tears contain some glucose.
- Partial oxygen pressure (pO_2)
  - 55 mm Hg or 20.9% (open-eye)
  - 55 mm Hg or 7% (closed-eye).

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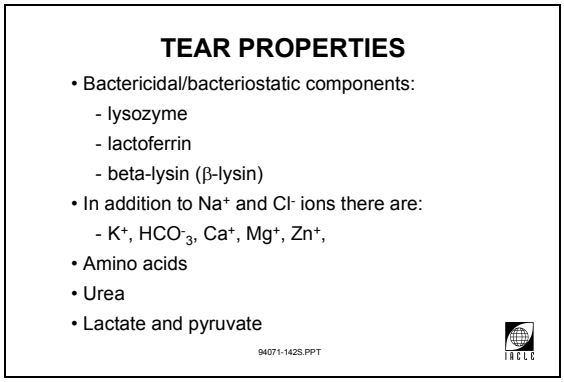

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- Bactericidal/bacteriostatic components
  - lysozyme
  - lactoferrin
  - beta-lysin (β-lysin). The role of β-lysin in affecting bacteria is not well understood.
- In addition to sodium and chloride ions there are
  - potassium, bicarbonate, calcium, magnesium and zinc ions
  - amino acids
  - urea
  - lactate and pyruvate.

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TEAR DIMENSIONS

Volume	6.5-8 µL
Flow rate	0.6 µL/min
Turnover rate	16%/min
Daily production	controversial (range 1-15 g)

94071-143S.PPT

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Tear Dimensions

Volume:	6.5 - 8µL
Flow rate:	0.6 µL/min
Turnover rate:	16%/minute
Daily production:	controversial (range 1-15 g)

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TEAR SECRETION RATE

- Stimuli
  - psychogenic
  - sensory
- Previous divisions
  - basal (immeasurable, <0.3 ml/min)
  - reflex (lacrimation)

94071-144S.PPT

1L194071-144

Tear Secretion Rate

Stimuli

- psychogenic

  caused by mindset, thoughts and emotions

- sensory

  via the sensory root of the trigeminal nerve (N5)

  subliminal stimuli produce little or no response.

- Previous divisions of the levels of lacrimation were:
  - Basal: immeasurably small and certainly less than 0.3 ml/min. This is the normal level of tear secretion;
  - Reflex: the tears resulting from stimulation by insult or psychological/emotional factors.

II.B.2 Tear Film Testing

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TEAR FILM STABILITY

Time taken for the tear film to break up following blink cessation

94071-145S.PPT

1L194071-145

Tear Film Stability

The time taken for the tear film to break up following blink cessation.

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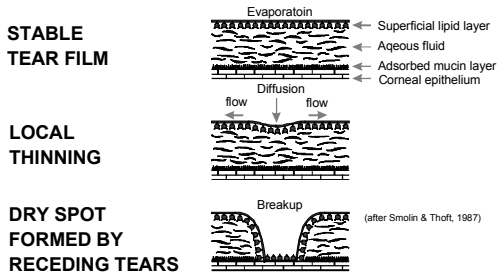
BUT (Break-Up Time) OR TBUT (Tear BUT)

- Na fluorescein instilled onto eye
- Tear film monitored under 'blue' light
- record occurrence of first 'dry spot'
- Repeat measurements required due to:
  - defects in anterior segment
  - surfactants in paper strip
  - abnormal eyes may not form a complete film
- <10 seconds is abnormal
- 15 - 45 seconds is considered normal

94071-146S.PPT

1L194071-146

177



94071-147S.PPT

1L194071-147

BUT (Break-up time) or TBUT (Tear BUT)

- Following evaporation, there is a localized thinning of the tear film. Eventually, dry spots are formed when the film breaks up and the tears recede. (*Smolin & Thoft, 1987)*.
- Sodium fluorescein is instilled onto the eye and the tear film is monitored under 'blue light'. A record is taken of the first occurrence of a 'dry spot' which appears as a black area in the tear film. Care should be taken not to touch or disturb the lids, and to maintain the normal position of the lids.
- Repeated measurements are required because of
  - defects in the surface of the anterior eye
  - surfactants in the paper applicator strip
  - the possibility that abnormal eyes may not form a complete film on blinking.
- BUTs of <10 seconds are considered abnormal.
- BUTs of 15 - 45 seconds are considered normal.

178

NIBUT (Non-Invasive BUT)

- BUT test which does not require staining
- More consistent and reliable

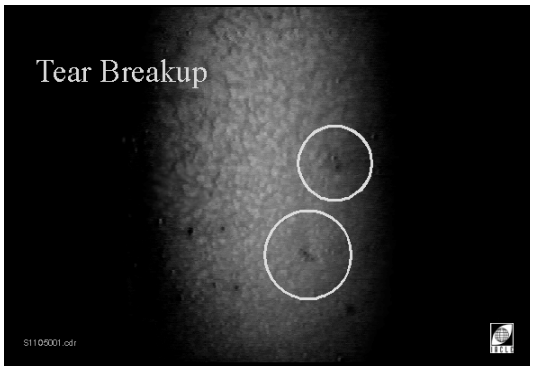
94071-148S.PPT

1L194071-148

NIBUT (Non-Invasive BUT)

- NIBUT is a BUT test which does not require staining.
- Results are more consistent and reliable than those using introduced fluids. However, NIBUT may be more difficult to measure since specular reflection is used and this is possible only over a relatively narrow field. Narrow, wide, dark and bright field instruments have been made to address this limitation.

179



1L1S1105-1

Dry spots formed in the tear film during BUT assessment.

180

WETTING THE CORNEA

- Glycocalyx binds mucus layer
  - glycocalyx: an 'irregularity filler'
- Surface will WET if:
  - surface tensions (ST) of tear film - epith./tear interface< bare epith.
  - ST of epithelium/tear interface is kept low by mucus
  - ST of tear film depends on, and is reduced by, the lipid layer and palpebral fissure width

94071-149S.PPT

1L194071-149

Wetting the Cornea

- The glycocalyx is a loose carbohydrate coating of the entire epithelial cell surface which binds the mucus layer to the epithelium. It acts as an 'irregularity filler'.
- The surface will wet if
  - [(ST of the tear film) – (ST of epithelium/tear interface)] is < (the bare epithelium itself)
  - ST of epithelium/tear interface is kept low by mucus
  - ST of tear film depends on, and is reduced by, the lipid layer and palpebral fissure width. A narrower fissure produces a lower ST. ST = surface tension.

181

TEAR FUNCTION TESTS

- BUT (TBUT)
- NIBUT
- Schirmer test
- Fluorophotometry
- Phenol-red thread test
- Rose bengal staining
- Tear film osmolality test

94071-150S.PPT

1L194071-150

Tear Function Tests

- BUT (TBUT).
- NIBUT.
- Schirmer test.
- Fluorophotometry.
- Phenol-red thread test.
- Rose bengal staining.
- Tear film osmolality test.

182

SCHIRMER TEST

- Thin strip of filter paper is bent into an L shape and inserted into lower fornix
- Wet length after a fixed time period (5 minutes) is measured
- Short wet length means a possible dry eye
- Test is subject to many artefacts
- Cheap and readily available

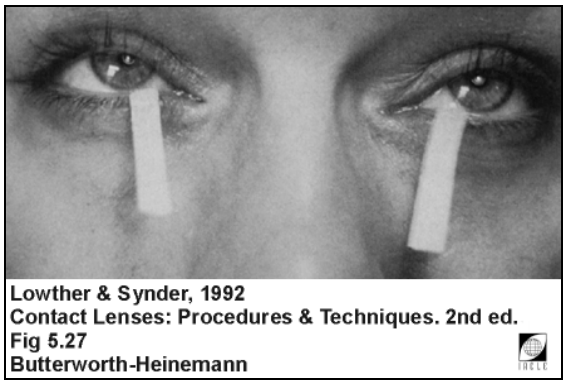
94071-151S.PPT

1L194071-151

Schirmer Test

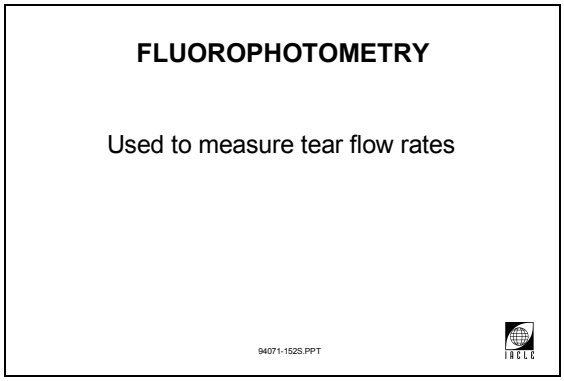
- Thin strip of filter paper is bent into an 'L' shape and inserted into the lower fornix.
- 'Wet length' after a fixed time period (5 min) is measured.
- Short 'wet length' means a possible dry eye.
- This test is subject to many artefacts.
- It is cheap and readily available.

183



1L10587-95

184

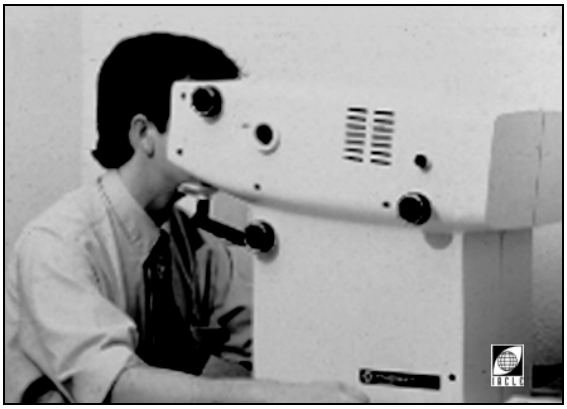


1L194071-152

Fluorophotometry

Used to measure tear flow rates.

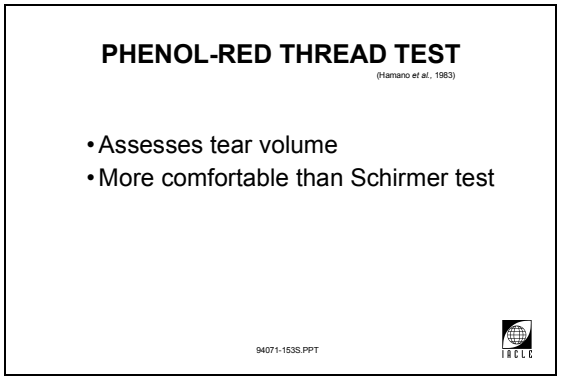
185



1L12249-94

This slide illustrates the Fluorotron™ Master ocular fluorophotometer from Ocumetrics Inc., Mountain View, California.

186



1L194071-153

Phenol-Red Thread Test

The PRT test was introduced by Hamano *et al.* in 1983. It is:

- Used to assess the basal tear volume.
- More comfortable than Schirmer test.

187

1L10398-92

A patient undergoing the PRT test.

188

ROSE BENGAL STAINING

Decreased lacrimation produces cell degeneration.

Rose Bengal stains the resulting necrotic cells

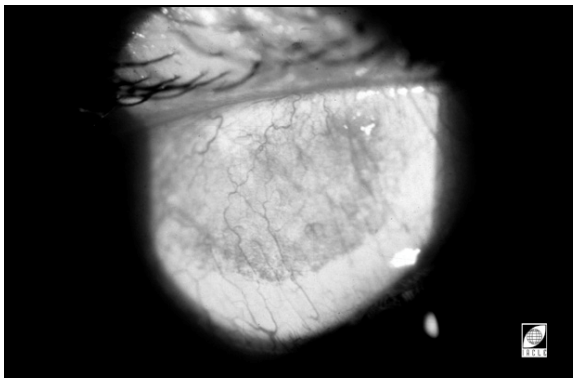
94071-154S.PPT

1L194071-154

Rose Bengal Staining

- Potentially, decreased lacrimation produces cell degeneration.
- Rose Bengal stains the resulting necrotic cells.

189



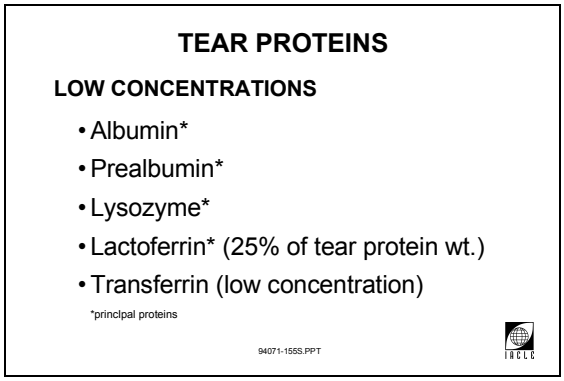
1L10827-91

Rose Bengal Staining

This slide shows Rose Bengal staining of necrotic cells in the superior bulbar conjunctiva.

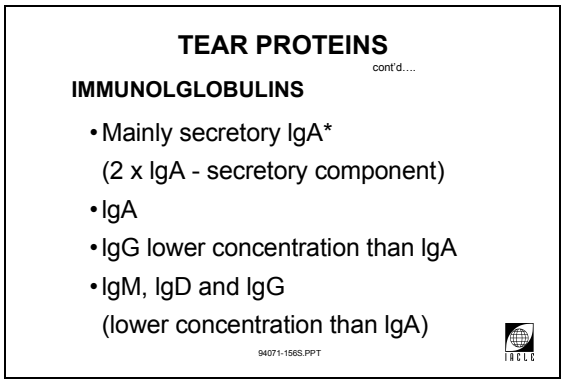
II.B.3 Tear Proteins

190



1L194071-155

191



1L194071-156

Tear Proteins

Low concentrations of:

- Albumin*.
- Prealbumin*.
- Lysozyme*.
- Lactoferrin* (25% of tear protein).
- Transferrin.

Immunoglobulins are:

- Secretory IgA* (composed of 2X IgA + a secretory component).
- IgA.
- IgM, IgD and IgG (in lower concentration than IgA).

*principal proteins

II.B.4 Eyelids

192

CLOSURE OF EYELIDS

- Contraction of orbicularis oculi muscle (OO)
- No reciprocal innervation between OO and levator palpebrae superioris muscle (LPS)
- Innervation by N7 facial nerve
- 'Zipper-like' from temporal to nasal

94071-157S.PPT

1L194071-157

193

CLOSURE OF EYELIDS cont'd….

- Rate: 15 blinks/min
- Duration: 0.3-0.4 s
- Globe moves up and in towards nose and backwards
- Forced closure involves OO and Müller's muscle
- Sleep: tonic stimulation of OO and inhibition of LPS

94071-158S.PPT

1L194071-158

Closure of Eyelids

- Brought about by the contraction of the orbicularis oculi muscle (OO), whose innervational control comes from the frontal lobe of the cortex in the region closely associated with eye movement.
- There is no reciprocal innervation between the orbicularis oculi and the levator palpebrae superioris muscles (LPS).
- Innervation is by the facial nerve (N7).
- The lid action is 'zipper-like' or 'scissor-like' from the temporal to the nasal canthus. The lower lid moves relatively little during a normal blink.
- Blink rate: approx. 15 blinks/min.
- Duration: 0.3 - 0.4 seconds.
- The globe moves up and in towards the nose as well as backwards, and then returns on eye opening.
- Forced closure involves the whole of the orbicularis oculi (especially the orbital portion) and Müller's muscle.
- Eye closure in sleep involves tonic stimulation of the orbicularis oculi and concurrent inhibition of the levator palpebrae superioris muscles.

194

OPENING OF EYLIDS

- Contractions of levator palpebrae superioris muscle
- Some assistance from Müller's muscle (smooth, sympathetic)
- Main innervation from N3 (oculomotor)

94071-159S.PPT

1L194071-159

Opening of Eyelids

- Brought about by contractions of the levator palpebrae superioris (LPS) muscle.
- Some assistance comes from Müller's muscle which is smooth and sympathetically innervated.
- Main innervation comes from the oculomotor nerve (N3). As it has no reciprocal innervation, the orbicularis oculi does not relax even when the levator palpebrae superioris elevates the upper lid.

195

BLINKING

- Lower lid hardly moves during normal blink
- Spontaneous blinking usually a response to:
  - corneal dryness and irritants
  - anxiety
  - sustained sound level
  - air pollution
- Relative humidity is ***not*** a blink stimulus

94071-160S.PPT

1L194071-160

Blinking

- The lower lid hardly moves during a normal blink.
- Spontaneous blinking is usually in response to
  - corneal dryness and irritants
  - anxiety
  - sustained sound level
  - air pollution.
- Relative humidity is *not* a blink stimulus.

196

BLINK REFLEXES

- Facial nerve nucleus connects with:
  - superior colliculus (optic impulses)
  - trigeminal nucleus (sensory impulses)
  - superior olive (acoustic impulses)
- Optic reflex
- Sensory reflex
- Auro-palpebral and cochleo-palpebral reflexes
- Stretching or striking reflex
- Psychogenic reation (non-reflex)

94071-161S.PPT

1L194071-161

Blink Reflexes

- Facial nerve (N7) nucleus connects with
  - superior colliculus (optic impulses)
  - trigeminal nucleus (sensory impulses)
  - superior olive (acoustic impulses).
- Optic reflex
  - eye closure when threatened
  - eye closure when exposed to bright light/dazzle.
- Sensory reflex
  - eye closure when lid or cornea is touched.
- Auro-palpebral and cochleo-palpebral reflexes
  - eye closure caused by a loud sound stimulus.
- Stretching or striking reflex
  - eye closure resulting from stretching or striking anatomical features close to the lids (protective).
- Psychogenic reaction (non-reflex)
  - eye closure caused by emotional stimulus (this reflex is involuntary).

197

EYELIDS AND TEARS

- Lids spread tears
- Resurfacing with mucus later increases tear film stability
- Blinking pumps tears into nose via puncta
- Lid closure compresses lipid tear layer
- Eye opening drags aqeous phase of tears, thickening tear film
- Lids act on lacrimal gland and gravity moves tear over cornea
- Lid muscle action has a role in accessory lacrimal gland output

94071-162S.PPT

1L194071-162

Eyelids and Tears

- The lids spread tears and resurface the epithelium with a mucus layer necessary for enhancing tear film stability. Gravity also moves tears over (down) the cornea.
- Blinking pumps tears into the nose via puncta and also compresses the lipid tear layer between the lid margins.
- On eye opening the receding lids stretch the lipid layer between their margins. The lipid layer in turn drags the aqueous phase of tears along with it, thereby thickening the tear film.
- Lid muscle action has a role in accessory lacrimal gland output.

198

EYELID FUNCTION

Protein from:

- threat
- bright light
- foreign bodies
- desiccation (eye closure)
- visual stimulation during sleep

94071-163S.PPT

1L194071-163

Eyelid Function

Protection from:

- Threat.
- Bright light.
- Foreign bodies.
- Desiccation (by eye closure).
- Visual stimulation during sleep.

Tutorial 1.1

(1 Hour)

Anatomical Eye Structure Identification

Quiz

Name: _____ Date: _____

Instructions: Identify the structure referred to in the slides on the opposite and following pages. Write your answers in the corresponding numbered spaces below.

1. _____

2. _____

3. _____

4. _____

layers:

a. _____

b. _____

c. _____

5. _____

6. _____

7. _____

8. _____

layers:

a. _____

b. _____

c. _____

d. _____

e. _____

9. _____

a. _____

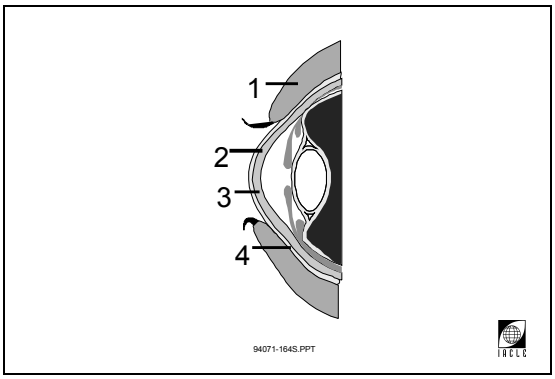
b. _____

c. _____

10. _____

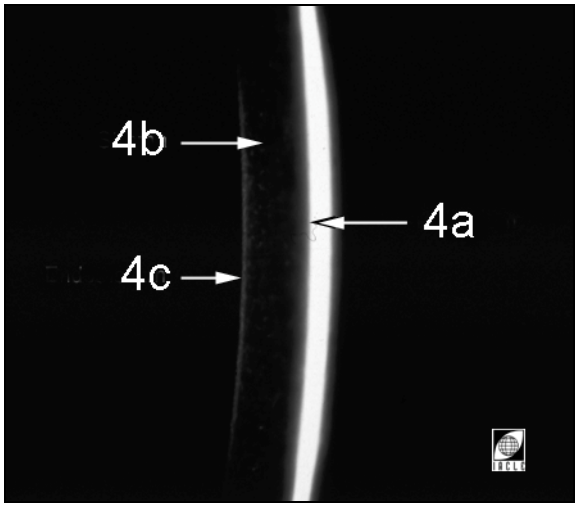
Quiz Slides

199 **Identification of 1, 2, 3 and 4**



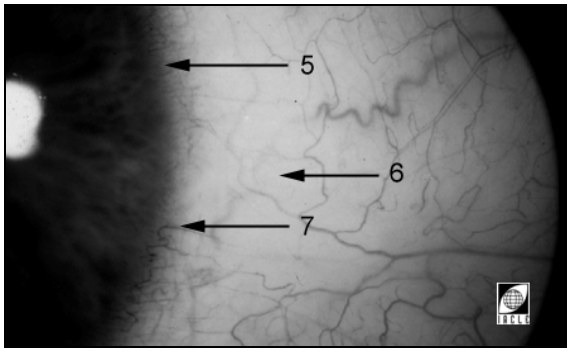
1L19407-164

200 **Identification of 4a, 4b, 4c**



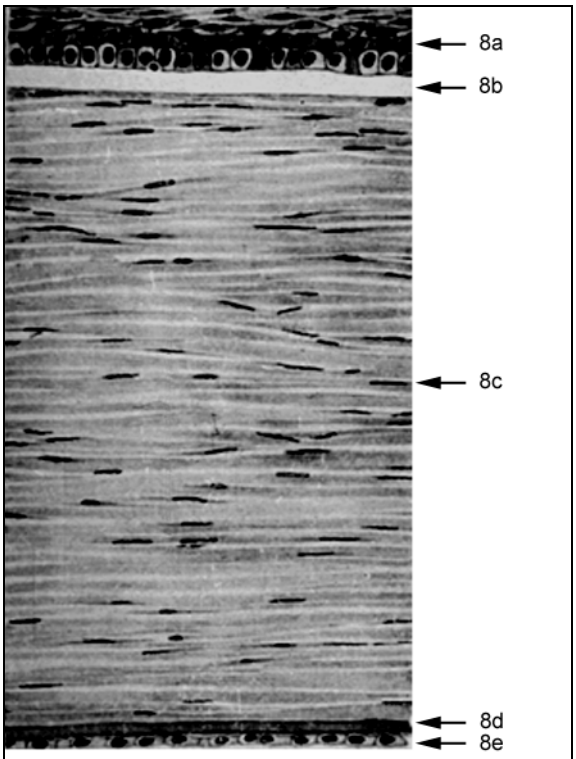
11T11511-95B

201 **Identification of 5, 6 and 7**



11T10384-93L

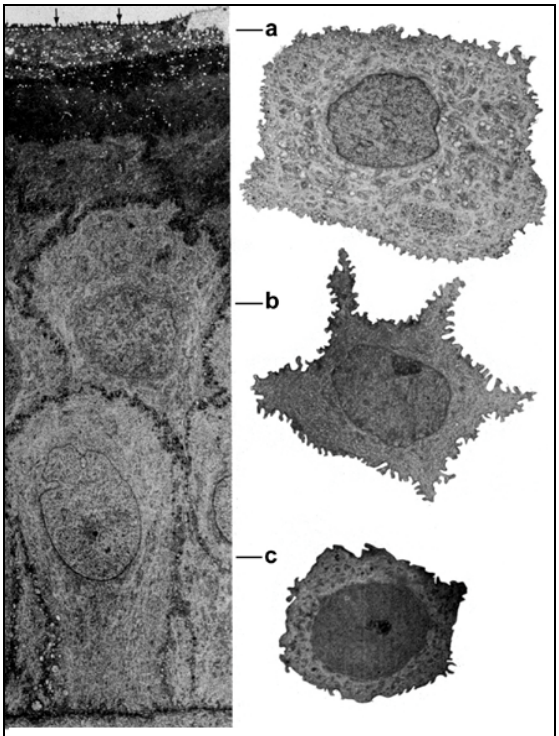
202 **Identification of 8a, 8b, 8c, 8d, 8e**



Warwick R (Ed.), 1976
Eugene Wolff's Anatomy of the Eye and Orbit. 7th ed.
Fig. 27
HK Lewis (Chapman & Hall)

11T11753-94L

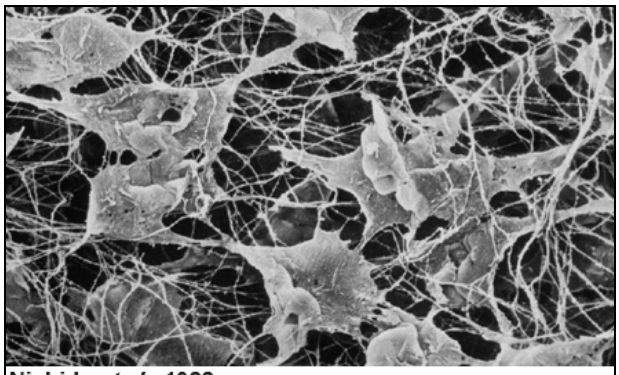
203 **Identification of 9a, 9b, 9c**



Hogan *et al.*, 1971
Histology of the Human Eye
Fig. 3.6
WB Saunders Company

11T11749-94A

204 **Identification of 10**



Nishida *et al.*, 1988
Investigative Ophthalmology & Visual Science 29 1988
Fig. 1
Libbincott-Raven Publishers

11T11688-91

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Unit 1.2

(6 Hours)

Lecture 1.2: Corneal Topography: Measurement and Significance

Practical 1.2: Keratometry

Tutorial 1.2: Interpretation of Keratometry Results

Course Overview

Lecture 1.2: Corneal Topography: Measurement and Significance

I. Normal Corneal Dimensions and Topography
II. Measurement
III. Instrumentation
IV. Clinical Applications

Practical 1.2: Keratometry

- Topographic Instrumentation
- Keratometry of Practice 'Patients'

Tutorial 1.2: Interpretation of Keratometry Results

- Case Analysis.
- Keratometry and Contact Lenses

Suggested Evaluation Techniques

- Role playing by Performing Keratometry on a 'Patient'.
- Analysis of Case Reports.

Lecture 1.2

(2 Hours)

Corneal Topography: Measurement and Significance

Table of Contents

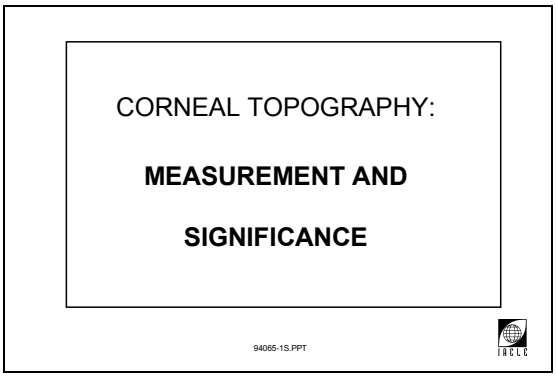
I Corneal Topography: Measurement and Significance **85**
I.A Normal Corneal Dimensions 85
I.B Corneal Topography 89
I.C Measurement and Errors 96
I.D Instrumentation 98
I.D.1 Keratoscopy 100
I.D.2 Keratometers 103
I.E Topography Analysers 111
I.F Clinical Applications 115
I.G Contact Lens Applications 118
I.H Keratometry and Contact Lenses 121

Corneal Topography Measurement and Significance

I Corneal Topography: Measurement and Significance

I.A Normal Corneal Dimensions

1



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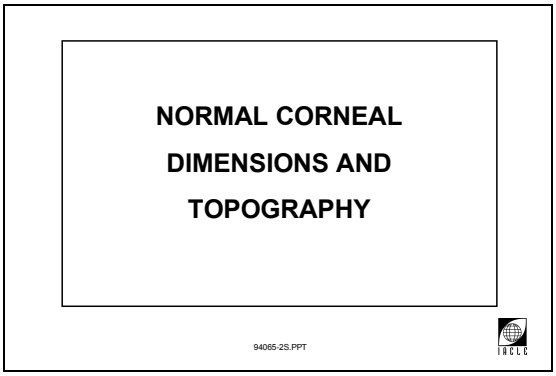
Corneal Topography: Measurement and Significance *(title slide)*

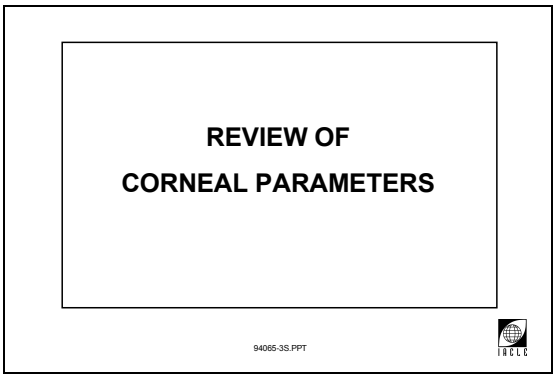
2



1L294065-2

Normal Corneal Dimensions and Topography *(title slide)*

3



1L294065-3

Review of Corneal Parameters *(title slide)*

4

CORNEAL DIAMETER

HVID: 10 - 14 mm
average: 11.7 mm

VVID: average: 10.6 mm
<HVID by 0.5 - 1.0 mm

94065-4S.PPT

1L294065-4

Corneal Diameter

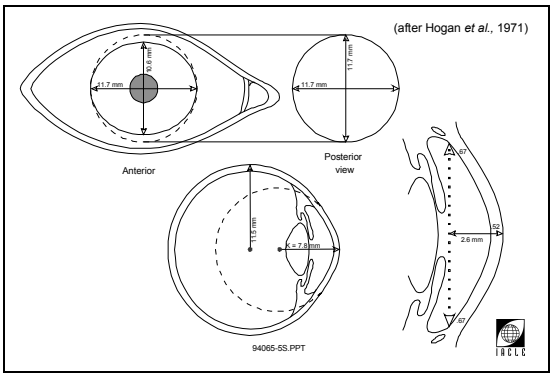
- What we measure is not the true diameter.
- HVID (horizontal visible iris diameter) is the apparent diameter as measured from the front. Investigations on the horizontal corneal diameter give different values:

– average: 11.7 mm
– range: 10 - 14 mm
– longer than the VVID

(Vertical Visible Iris Diameter by 0.5 - 1.0 mm)

- VVID is 10.6 mm.

5



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6

CORNEAL THICKNESS

Clinical Studies:

0.50 - 0.65 mm

Gullstrand's Eye No. 1:

0.50mm

94065-6S.PPT

1L294065-6

Corneal Thickness

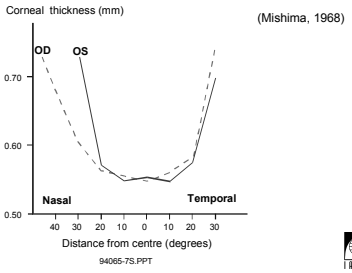
- Clinical studies: 0.50 - 0.65 mm.
- Gullstrand's Eye No.1: 0.50 mm.
- Mishima (1968) showed peripheral corneal thickness increased from the central region

– centre (up to 20°, 3 mm): 0.55 - 0.57 mm
– periphery: 0.66 - 0.76.

- Most investigators agree that age causes a thinning of the cornea.

7

CENTRAL AND PERIPHERAL THICKNESS VARIATION



1L294065-7

8

CORNEAL THICKNESS MEASUREMENT TECHNIQUES PACHOMETERS

- Ultrasonic
  - A-scan or time-amplitude at 20 MHz
- Optical
  - beam-splitting device on slitlamp
  - uses Vernier acuity

94065-8S.PPT

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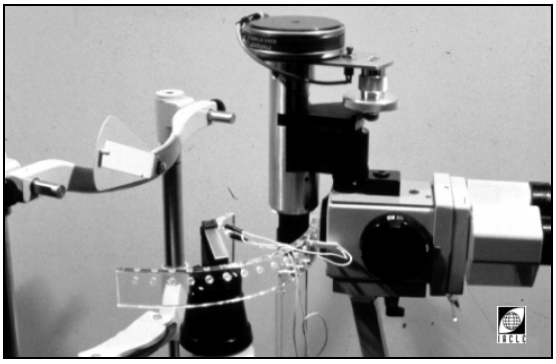

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Corneal Thickness Measurement Techniques

There are three techniques to measure corneal thickness.

- *Ultrasonic pachometer* (using A-scan or time-amplitude) at 20 MHz. Higher frequency is ideal for differentiating corneal boundaries from other ocular structures because of better resolution
  - principle:

    The operating principle is based on timing the reflection of sound from the structures of interest. For corneal pachometry the time taken for sound to travel from the measuring probe in contact with the cornea to the anterior chamber interface and back is of interest. The direction of the ultrasonic beam is aligned with the visual axis.
  - unit of measurement:

    The thickness is measured by the time interval between the anterior and posterior corneal surfaces in microseconds which is calibrated based on the speed of sound in the cornea and converted into millimetres.
  - margin of error:

    ± 0.1 - 0.2 mm
    ± 0.25 - 0.50 D
- Optical pachometer uses a beam-splitting device connected to a slit-lamp. It uses Vernier acuity for performing measurements
  - principle:

    A doubling prism allows two corneal images in optic section to be juxtaposed. The distance between the opposing corneal surfaces is measured as the corneal thickness.
- *Laser Tomography* is based on the principle of low-coherence interferometry
  - optical waves are used to obtain two-dimensional, cross-sectional images of the eye with approximately 10 μm lateral and longitudinal resolution and sensitivity to weakly back-scattered light exceeding 95dB (I.Zatt *et al.*, 1994).

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REFRACTIVE INDEX

1.376 (corneal substance)

(Patel *et al.*, 1995)

Epithelium:	1.401 (± 0.005)
Anterior stroma:	1.380 (± 0.005)
Posterior stroma:	1.373 (± 0.001)

94065-9S.PPT

1L294065-9

Refractive Index

- The refractive index for the cornea has been generally known to be 1.376 (corneal substance).
- Recent studies by Patel *et al.* (1995) reveal the following refractive indices for the epithelium and stroma:

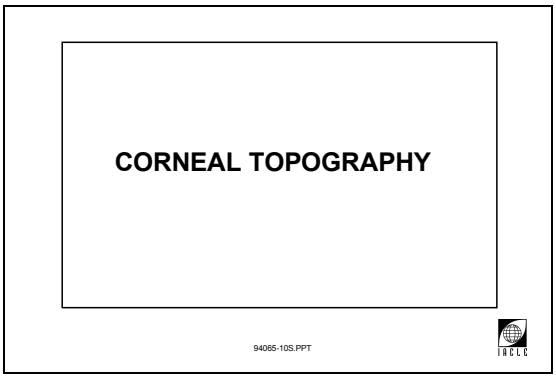
– epithelium: 1.401 (SD ± 0.005)

– anterior stroma: 1.380 (SD ± 0.005)

– posterior stroma: 1.373 (SD ± 0.001).

I.B Corneal Topography

12



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Corneal Topography *(title slide)*

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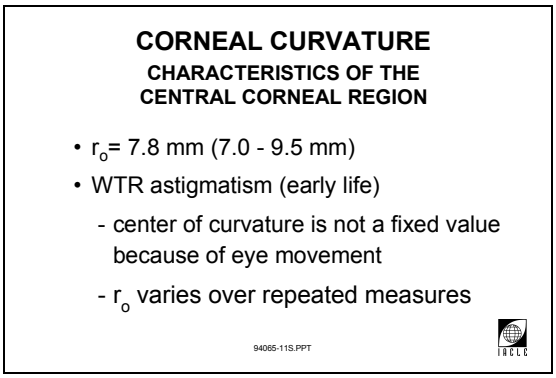

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Characteristics of the Central Corneal Region

- Average central radius of curvature, r_o is 7.8 mm (7.0 - 9.5 mm) at the central cap region.
- In the young, the cornea is found to have with-the-rule astigmatism.
- Centre of curvature, is constantly changing (with eye movements) to a new position with the centres of curvature forming a locus of points (called the evolute) from the central point to an off-axis position.
- Radius of curvature, r_o, is constantly varying over repeated measures because the eye is never in a fixed position.

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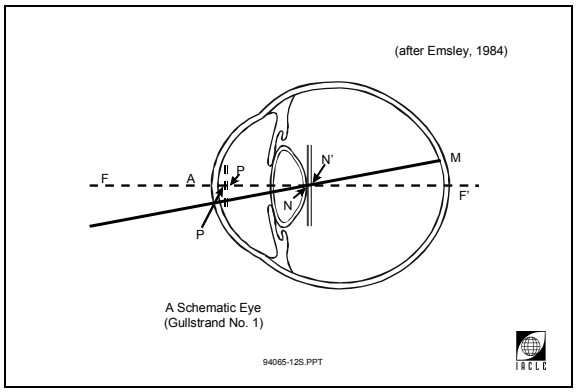

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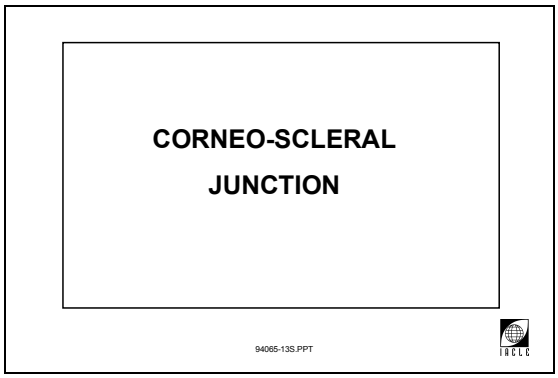
Gullstrand's Schematic Eye No.1
(Emsley, 1953)

- Schematic Eye No. 1 is considered the 'exact' eye by Gullstrand.
- The crystalline lens is taken as a homogeneous structure and the cornea is taken as a single surface. This is done by compensating for the posterior corneal surface by a slight decrease in the anterior curvature of the cornea.
- Surface Curvature:
  - anterior: 7.7 mm/+48.83 D
  - posterior: 6.8 mm/-5.88 D.
- Total/Equivalent Corneal Power:
  - 2/3 of eye power
  - +43.05 D.

15



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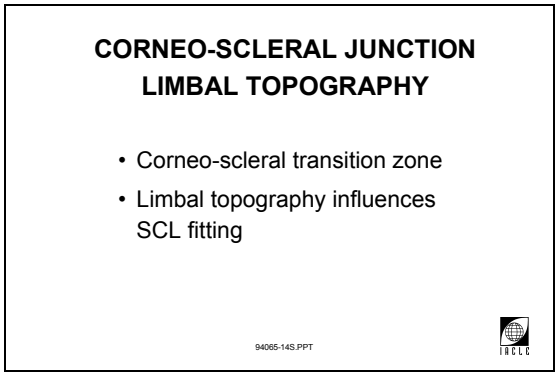
Corneo-Scleral Junction *(title slide)*

16



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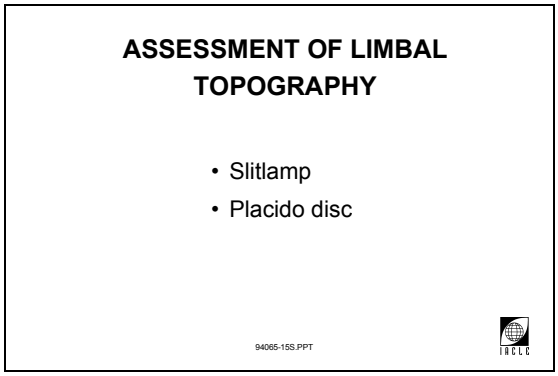
Limbal Topography

- The limbus forms part of the global topography.
- The transition at the limbus usually accounts for the variable behaviour of contact lenses on eyes with similar refraction and corneal curvature.
- Limbal topography, especially with a shallow junction, is seen to influence soft contact lens fitting.

17



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Assessment of Limbal Topography

- *Slit-lamp*, by assessing continuity of the slit beam at the corneo-scleral junction.
- *Placido disc*, by assessing the mire distortion at the corneo-scleral junction.

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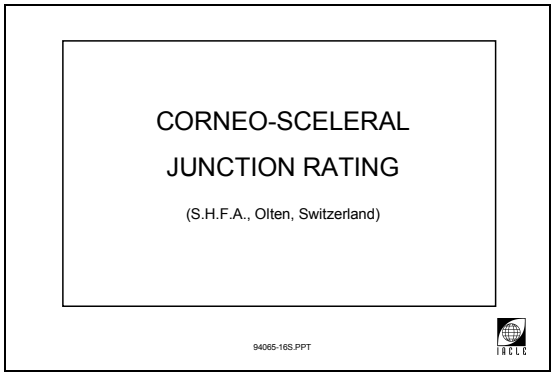

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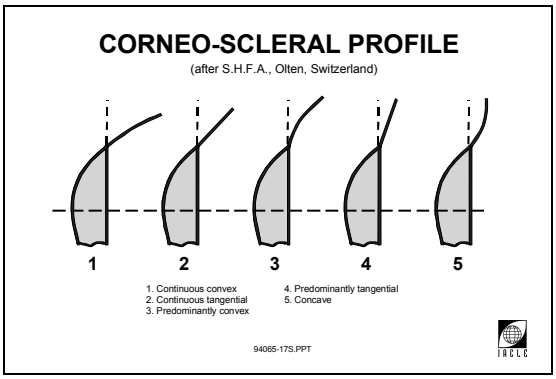
Corneo-scleral Junction Rating
(SHFA - Olten, Switzerland, 1988)

A 1 - 5 scale is used, with 1 being a very shallow junction and 5 a large difference in curvature between the cornea and sclera.

19



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Corneo-scleral Junction Profile

A schematic representation of the corneo-scleral profile is used as a grading scale when assessing the depth of the junction.

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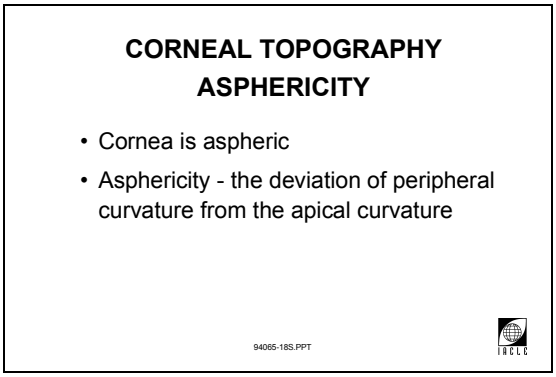

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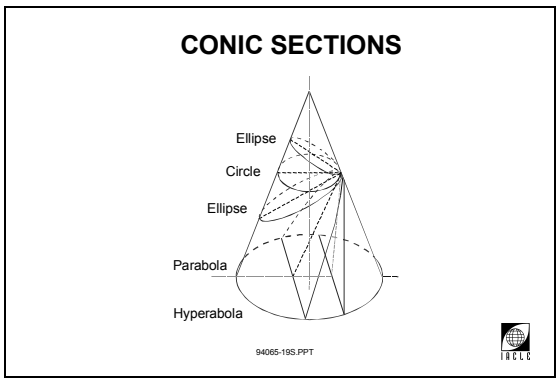
Asphericity

- The cornea is an aspheric surface.
- Asphericity is a measure of the deviation of the peripheral surface curvature from the apical radius of curvature.

21



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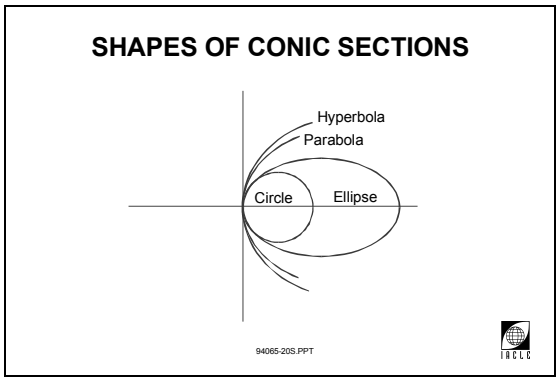
Conic Sections

Corneal norms for asphericity follow the elliptical shape. Slide 22 shows the shapes of conic sections.

22



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23

CONICOID

- Revolution of a conic about an axis of symmetry
- Normals to the surface form an evolute

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1L294065-21

Conicoid

- Revolution of a conic about an axis of symmetry.
- Normals to the surface form an evolute.

24

CORNEAL APEX

The point of maximum curvature or shortest radius

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Corneal Apex

The corneal apex is described as the point of maximum curvature or shortest radius. Any point taken away from the spherical corneal region will have a greater radius of curvature than the corneal apex point.

25

MEASURES OF ASPHERICITY

Eccentricity	= *e*
Shape Factor	= *p*
Asphericity Parameter	= Q

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1L294065-23

Measures of Asphericity

Asphericity has been expressed in many ways in the literature, but the most common are: the eccentricity (*e*), the shape factor (*p*) and an asphericity parameter (Q). Each can be derived from the others as described below.

26

ECCENTRICITY

- Degree of peripheral asphericity

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Eccentricity

- Rate of deviation of the curvature from a circle or a spherical surface.
- Degree/rate of peripheral flattening/steepening.

27

ECCENTRICITY VALUES OF CONIC SECTIONS

Circle	$e = 0$
Ellipse	$0 < e < 1.0$
Parabola	$e = 1.0$
Hyperabola	$e > 1.0$

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1L294065-25

Eccentricity Values of Conic Sections

- Circle $e = 0$
- Ellipse $0 < e < 1.0$
- Parabola $e = 1.0$
- Hyperbola $e > 1.0$

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p-VALUE/ECCENTRICITY VALUE

$e = 1 - e^2$

$e = \sqrt{1 - p}$

$e^2 = 1 - p$

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1L294065-26

p-Value/Eccentricity Value

$p = 1 - e^2$

$e = \sqrt{1 - p}$

$e^2 = 1 - p$

NOTE: $-e^2$ is sometimes referred to in the literature as Q, an asphericity parameter.

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AIM OF DETERMINING THE p-VALUE

- Mathematically define the eccentricity of the corneal surface
- The p-value is defined as the mathematical derivation of the corneal surface eccentricity

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1L294065-27

Aim of Determining the p-value:

- To give a quantitative representation of the corneal shape.
- To mathematically define the asphericity of the corneal surface.

30

CORNEAL ASPHERICITY

- The cornea is an aspherical surface
- Ellipsoidal periphery
- Not necessarily symmetrical

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1L294065-28

Corneal Asphericity

- The cornea is an aspheric surface.
- It has an ellipsoidal periphery.
- It is not necessarily laterally or radially symmetrical.

31

ECCENTRICITY VALUE OF THE HUMAN CORNEA

- The human cornea is an ellipsoid
- Eccentricity values that have been give are:
  - range: 4.41 - 0.58
  - average: 0.47

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1L294065-29

Eccentricity Value of the Human Cornea

- The human cornea is an ellipsoid.
- Eccentricity values that have been measured are:
  - range: 0.41 - 0.58 (Holden, 1970; Kiely *et al.*, 1984; and Guillon *et al.*, 1986)
  - average: 0.47

32

REGIONS OF CORNEAL ASPHERICITY

1. Central region or corneal cap
2. Mid-peripheral region
3. Peripheral region

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1L294065-30

Regions of Corneal Asphericity

Attempts have been made in the past to identify and divide the cornea into different regions. The schematic shows these regions as derived from Sampson, *et al.* (1965):

- Central region or corneal cap.
- Mid-peripheral region.
- Peripheral region.

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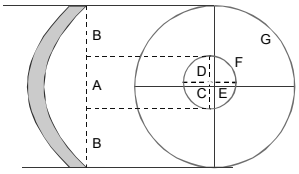
CORNEAL NOMENCLATURE

(Sampson *et al.*, 1965)



A. Apical zone
B. Transitional zones
C. Visual centre
D. Apical centre
E. Geometric centre
F. Limiting margin
G. Keratometric limbus

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CORNEAL CAP

Diameter:	4 mm approx.
Decentred by:	0.2 - 0.6 mm nasally
	0.2 mm superiorly
Shape:	irregular

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1L294065-32

Corneal Cap

- Approximate diameter: 4 mm.
- Approximate position: decentred by 0.2 to 0.6 mm nasally and 0.2 mm superiorly.
- If decentration is large enough it can affect the fit of contact lenses.
- The shape is irregular as the distance of the edge from the centre varies in different meridians.

35

ASSUMPTIONS OF THE CORNEAL CAP

- Limited degree of flattening
- Meridional curvature variation is insignificant
- K reading is not at the geometric centre
- Mid-peripheral non-alignment with monocurve lenses

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1L294065-33

Assumptions of the Corneal Cap

The concept of the corneal cap has met scepticism but is assumed based on the following reasons:

- Flattening close to the centre of the cornea is so small that the central region may be assumed to be spherical in each principal meridian.
- Variation in meridional curvature in the central region is very limited and not significant.
- The keratometer reading is not taken at the exact geometric centre but 1.2 to 1.8 mm to each side and is, therefore, the approximate mean value.
- Mid-peripheral non-alignment with monocurve rigid lenses is clinical evidence of the variation in curvature between the central and peripheral regions.

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MID-PERIPHERAL REGION
(Clark, 1974)

- Region of greater flattening
- Evidence of negative asphericity

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1L294065-34

Mid-peripheral Region

- The region of greater flattening.
- There is evidence of some negative asphericity before the cornea starts to steepen at the extreme periphery at the nasal semi-meridian (Clark, 1974).

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PERIPHERAL REGION
(Clark, 1974)

- 90% of semi-meridians had positive asphericity
- Remainder - zero or negative
- Nasal and superior-nasal asphericities were greater than the other semi-meridians

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1L294065-35

Peripheral Region

Clark (1974) studied the mean topographical values of the human cornea in terms of asphericity.

For the peripheral corneal region he found:

- It had a positive asphericity in 90% of the semi-meridians tested. The remainder were either of zero or negative asphericity.
- Eight semi-meridians were measured and from these, the nasal and superior-nasal asphericities were greater than the other semi-meridians.

I.C Measurement and Errors

38

MEASUREMENT APPLICATIONS

- Estimation of refractive errors
- Assessment of pathology
- Contact lens fitting
- Assessing effects of contact lenses and refractive surgery

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1L294065-36

Applications of Measurements

- Estimation of refractive errors.
- Assessment of pathology.
- Contact lens fitting.
- Assessing effects of contact lenses.
- Assessing effects of refractive surgery.

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PROBLEMS OF MEASUREMENT
KERATOMETER

- Fixation
- Accuracy required
- Instrument errors
- Operator variability

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1L294065-37

Problems of Measurement

- Eye movement, especially with a patient who fixates poorly.
- Accuracy is required and errors may be minimised by averaging measurements.
- Slight instrument error because of assumptions used in keratometer equations.
- Operator variability. Calibration and repeatability of operator measurement must be reliable.

40

SOURCES OF ERROR
INSTRUMENTATION

- Assumptions
- Uses paraxial theory
- Assumes focal length = image distance
- Object source comes from a flat plane
- Reproducibility
- Assumes the cornea is spherocylindrical

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1L294065-38

Sources of Error: Instrumentation

Because the paraxial theory is used...

- Areas of mire image reflections are too far from the axis($\geq$ 1 mm - 1.7 mm) to be considered as being in the paraxial zone (reflecting power of the cornea: -260 D)
  this results in error from a third-order (and higher order) aberration
  - longer peripheral radii readings are approximately 0.05 mm more in a normal eye.
- Assumption that the distance from object to cornea/focal point is the same as the distance from object to image
  - eliminated by making the mires the targets of a collimating system.
- Calibration is based on the assumption that light from the mires comes from a spherical surface
  - reduce error by reducing the separation of the mires (Noble, 1962 and Mandell, 1962 and 1965).
- Limit of reproducibility of the keratometer on the basis of diffraction is not lower than 0.2 D with greater individual spread in the radius with a smaller mire separation (Charman, 1972).

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SOURCES OF ERROR
OPERATOR

- Focusing
- Proximal accommodation
- Alignment errors
- Orientation of instrument

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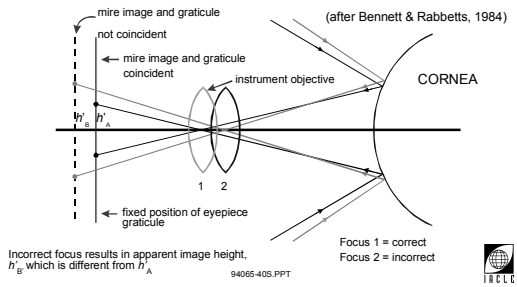
EFFECT OF FOCUSING ERROR WITH THE KERATOMETER



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Sources of Error: Examiner/Operator

Focusing

- Defocused mire images can cause incorrect radius measurements. The object-image separation is subtended at a greater or smaller angle at the centre of curvature and affecting the height of the mire images.
- Use collimated mires and fully telecentric viewing system or Scheiner disc.

Proximal accommodation can be avoided by:

- Keeping both eyes open to relax accommodation.
- Focusing the eyepiece from plus (+).
- Keratometry should start with the instrument as far as possible from the patient to ensure that relaxed accommodation is maintained.

Uncorrected refraction of examiner

- More errors can result, especially with marked spherical aberration or irregular refraction.

Alignment errors

- Because of the aspheric nature of the cornea and the separation of mires, measurement of corneal curvature away from the area of the optic cap can increase the image height and, therefore, radius measurement.

Orientation of the instrument

- Inaccurate meridional positioning of the keratometer can cause focusing errors and incorrect radius measurement.

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SOURCES OF ERROR
PATIENT

- Corneal distortions cause mire distortions
- Fixation steadiness

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1L294065-41

Sources of Error: Patient

- Local distortion of the cornea in the region of the reflected area or areas causes mire distortion, especially with Scheiner disc doubling.
- Unsteady fixation by the patient gives an unstable mire image appearance, increasing the risk of errors during the actual measurement.

I.D Instrumentation

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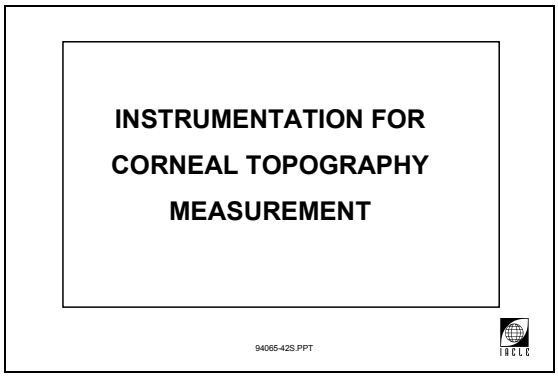

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Instrumentation for Corneal Topography Measurement
(title slide)

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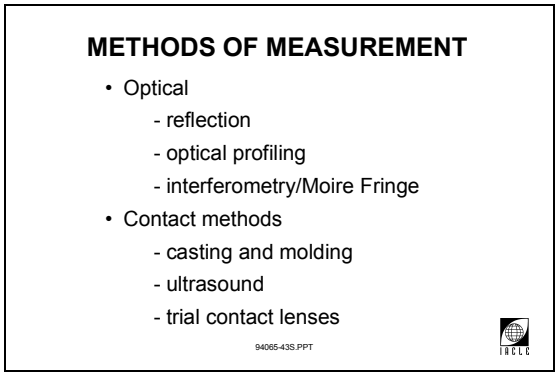

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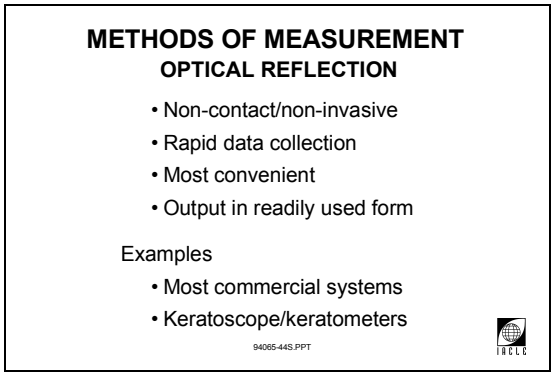
Methods of Measurement

- Optical
  - reflection
  - optical profiling
  - interferometry/Moire fringes.
- Contact methods
  - casting/molding
  - ultrasound
  - trial contact lenses.

46



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Methods of Measurement

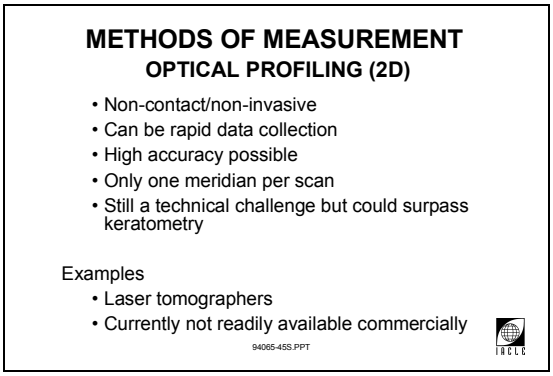
Optical Reflection

- Non-contact/non-invasive.
- Rapid data collection.
- Most convenient.
- Output in readily used form.

Examples

- Most commercial systems.
- Keratoscope/keratometers.

47



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Methods of Measurement

Optical Profiling (2D)

- Non-contact/non-invasive.
- Rapid data collection.
- High accuracy can be achieved.
- Only one meridian per scan.
- Technical challenges remain; however could surpass keratometry.

Examples

- Laser tomographers.
- Currently not readily available commercially.

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METHODS OF MEASUREMENT
OPTICAL PROFILING (3D)

- Some are non-contact
- Can be rapid data collection
- Very high accuracy possible
- 3D scan (single scan only)
- Some technical difficulties

Examples
- Laser interferometers (e.g. Twyman-Green)
- Moiré fringe techniques (e.g. Brass 2 - Rotlex)

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Methods of Measurement

Optical Profiling (3D)

- Some are non-contact.
- Provides rapid data collection.
- Very high accuracy possible.
- 3D scan (single scan only).
- Some technical difficulties.

Examples

- Laser interferometers (e.g. Twyman-Green).
- Moiré fringe technique (e.g. Brass 2 - Rotlex).

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METHODS OF MEASUREMENT
CONTACT METHOD

- Contact may distort topography
- Time consuming
- On some methods only qualitative result possible
- Data can be difficult to interpret

Examples
- Casting/molding
- Ultrasound
- Trial contact lens

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Methods of Measurement

Contact Methods

- Contact may distort topography.
- Time consuming.
- On some methods only qualitative results are possible.
- Data can be difficult to interpret.

Examples

- Casting/molding.
- Ultrasound.
- Trial contact lens.

50

INSTRUMENTS TO MEASURE
CORNEAL TOPOGRAPHY

- Placido disc
- Photokeratoscope
- Keratometer
- Computer-assisted topographic analysis

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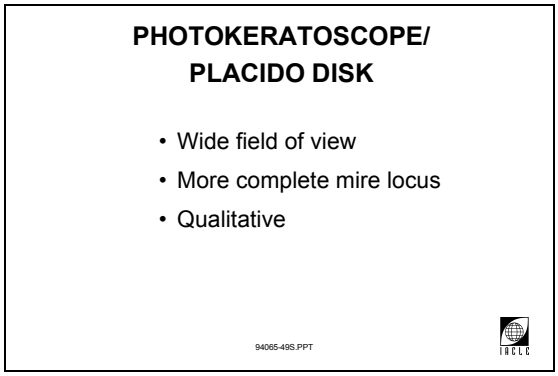
Instruments to Measure Corneal Topography

All based on optical reflection method:

- Placido disc.
- Photokeratoscope.
- Keratometer.
- Computer-assisted topographic analysis.

I.D.1 Keratoscopy

51



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Photokeratoscope/Placido Disc

- Used to study the corneal contour over a large area, thus providing more information. This is its advantage over the keratometer.
- The Placido disc has more complete mire locus.
- Can also provide qualitative information.

52

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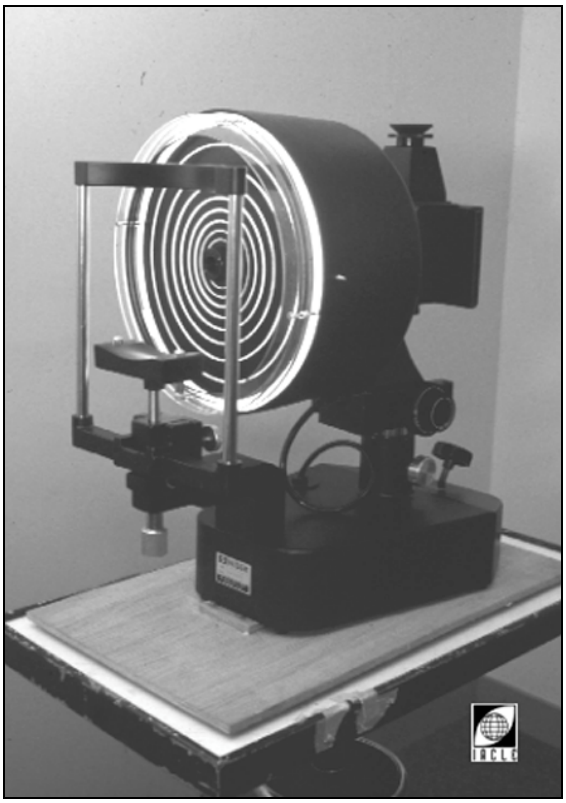
Placido Disc

- Qualitative assessment.
- Gross changes only.

53



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Sun Nidek Photokeratoscope

A polaroid camera or video is attached to record images of the mires on the patient's cornea.

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PHOTOKERATOSCOPE/ PLACIDO DISK
PRINCIPLES

- 1st Purkinje image reflection of bright rings
- Central viewing through magnifying lens
- Outer rings subtend a wider angle

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1L294065-50

Principles of the Placido Disc

- Utilises corneal reflections (Purkinje image #I) of bright rings.
- Viewing is done through the central magnifying lens.
- Outer rings subtend a wider angle, creating a defocus of peripheral mire images.

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PHOTOKERATOSCOPE IMAGES

Elliptical	- astigmatism
Distorted	- scars, irregularity
Asymmetrical	- keratoconus

94065-51S.PPT

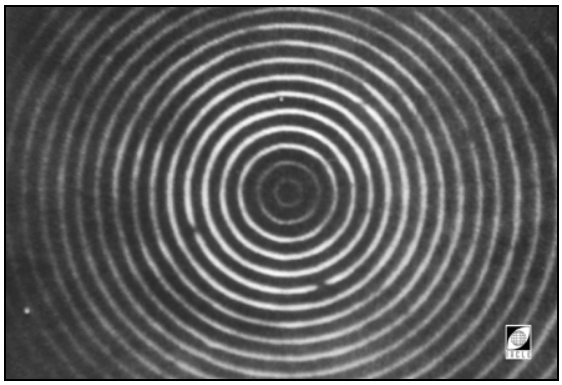
1L294065-51

Images Seen Through the Photokeratoscope/Placido Disc

- Elliptical - astigmatism.
- Distorted - scars, irregularity.
- Asymmetric - keratoconus.

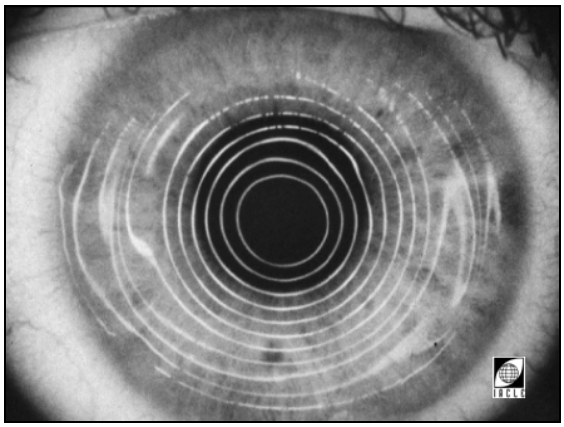
Slides 57 and 58 illustrate photokeratoscope mire images of normal and astigmatic corneas respectively. Distortion of the mire images may also be caused by the tear film so that instructing patients to blink before capturing the image is recommended.

56



1L20994-93

57



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58

PLACIDO DISK
DISADVANTAGES

- Corneal astigmatism is not quantified
- Absence of central mire reflection
- Limited depth of focus during photography
- Anatomy of nose or orbit may limit field size

94065-52S.PPT

1L294065-52

Disadvantages of the Placido Disc

- Clinically significant amounts of corneal cylinder (up to 3.00 D) can be present in a cornea and may not be diagnosed.
- Subtle irregularities cannot be detected.
- The centrally positioned lens obstructs the central mire reflections.
- There is limited depth of focus during photography because of the curved image surface.
- Anatomy of the nose or orbit may limit field size and restrict the corneal area that can be examined.

I.D.2 Keratometers

59

KERATOMETERS
MAIN FUNCTION

- Measure radius of curvature of the optic cap

94065-53S.PPT

1L294065-53

Keratometers

- Measure the front surface corneal radii. They can give the total corneal power on the assumption that the back surface of the cornea has 10% of the power of the front surface, using a calibration/refractive index of 1.3375.
- Main function is the measurement of the radius of curvature of the central portion (optic cap).

60

KERATOMETERS

Information provided:

- Front surface corneal radii
- Total corneal power

94065-54S.PPT

1L294065-54

Keratometers

Information provided:

- Front surface corneal radii.
- Total corneal power.

61

USES OF THE KERATOMETER

- Contact lens fitting
- Monitoring corneal shape
- Verification of contact lens parameter

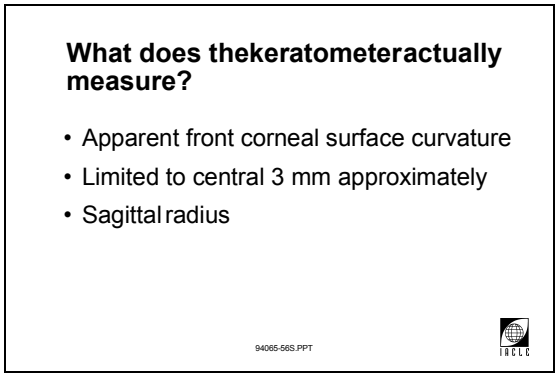
94065-55S.PPT

1L294065-55

Uses of the Keratometer

- CL fitting, choice of trial lens.
- Monitoring corneal shape.
- Verification of contact lens parameters.

62

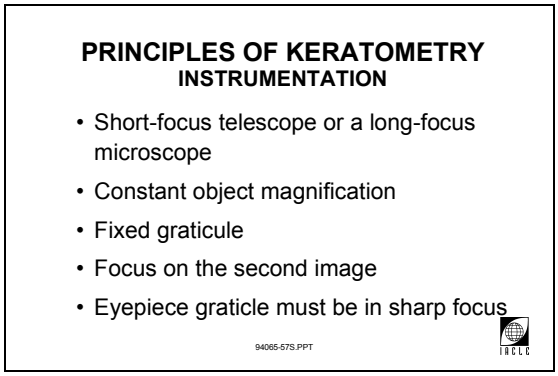


1L294065-56

What Does the Keratometer Actually Measure?

- The keratometer gives the apparent front corneal surface curvature (central 3 mm):
  - tear lens does not fully negate the refractive effect of the front cornea, only 90% or 0.336/0.376 of its power is neutralised.
  - it is difficult to tell if the back surface of the cornea matches the contour and shape of the front surface. Rivett and Ho (1991) have measured the posterior corneal topography. Their study showed that the posterior corneal surface is hyperbolic and the radius of curvature measurements were 6.16 $\pm$ 0.29 mm (RE) and 6.10 $\pm$ 0.30 mm (LE).
- Determines the power and location of the steepest meridian and the meridian 90° away, based on the assumption that the cornea is sphero-cylindrical.
- The keratometer gives the sagittal radius reading.

63



1L294065-57

Principles of Keratometry - Instrumentation

- Keratometry is based on measuring the image height of the object source. This image is inaccessible for direct measurement because it lies in the anterior chamber of the eye.
- A short-focus telescope (long-focus microscope) is used whose objective forms a second image (of the mires) which is accessible for measurement.
- Magnification of the objective lens must be constant.
- A fixed graticule is positioned at the plane in conjugate focus with the object distance from the first principal point.
- The keratometer is moved towards the patient until the second image is seen in sharp focus on the graticule.
- The test object is fixed and moves with the instrument. Therefore, the distance of the object from first virtual image on the cornea is attained simultaneously with the second focal length.
- It is crucial that the eyepiece graticule crosshairs be in sharp focus.

64

PRINCIPLES OF KERATOMETRY
OPTICAL

- Measures angular size of reflected image (1st Purkinje image)
- Image size formation at a specific distance from the object plane
- Virtual image formation behind the cornea
- Doubling principle

94065-58S.PPT

1L294065-58

Principles of Keratometry - Optical

- Anterior corneal reflection is called the Purkinje Image #I.
- Illuminated object mires are reflected from the front surface of the cornea which acts as a convex mirror.
- Based on measuring the image size of the reflected image (Purkinje Image #I) formed by the cornea of an object of known linear size.
- The object may have a linear height which is fixed or measurable at a predetermined distance from the image plane.

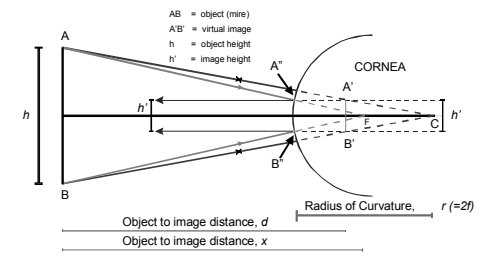
  Object of specific size forms an image just in front of the posterior focal plane of the cornea by reflection

  – which forms an image a specific distance from the object plane

  – the virtual image formed by the cornea is minified and upright, and appears to be located within the anterior chamber of the eye.

65

OPTICAL PRINCIPLE OF KERATOMETRY



94065-59S.PPT

1L294065-59

Equation for Determining Radius from Image Height

Keratometry is based on measuring the apparent image height of the mire target formed by the cornea (actually the anterior surface of the tear film) behaving as a convex mirror.

Referring to triangles: ABF and A´B´F

$$\frac{h'}{h} = \frac{f}{x} = \frac{r/2}{x}$$

For a mirror, the focal length is equal to half the radius of curvature.

But... $x \approx d$ (Most instrument working distances are large relative to the corneal radii of curvature)

66

EQUATION USED FOR DETERMINING RADIUS FROM IMAGE HEIGHT
Referring to Δs ABF & A"B"F

$$\frac{h'}{h} = \frac{f}{x} = \frac{r/2}{x}$$

But $x \approx d$

$$\therefore r = \frac{2dh'}{h}$$

94065-60S.PPT

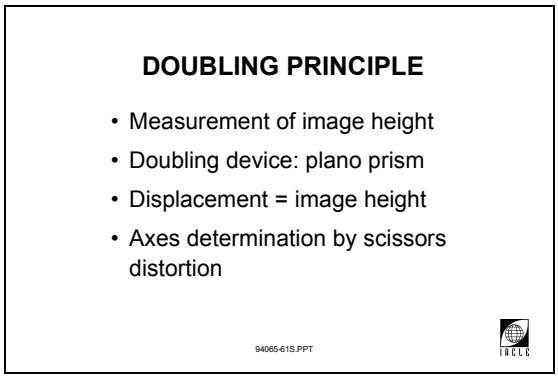
1L294065-60

$$\therefore r = \frac{2dh'}{h}$$

where:

r	=	corneal radius of curvature
d	=	object to image distance
h'	=	image height
h	=	mire separation
f	=	corneal focal length

67

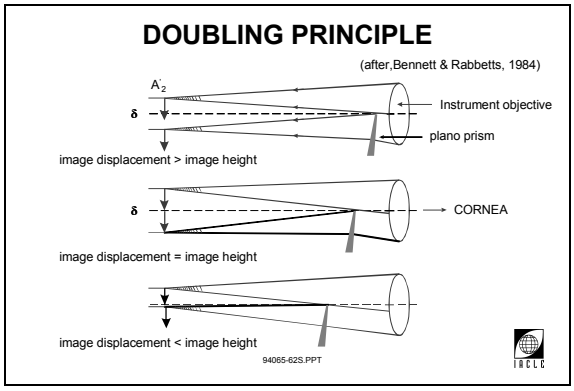


1L294065-61

Doubling Principle

- Measurement of image height:
  - achieved by utilising a doubling prism positioned in the observation field. The doubled images created are seen adjacent to one another.
  - central images are superimposed.
- The use of the doubling prism which is midway in the observation system remedies the effects of eye movement because both images move with the eye.
- Plano prism causes a displacement proportional to the distance from the objective
  - at some point along the axis the image height/size and displacement caused by the prism will be the same.
- The principal meridians in astigmatism are determined by the scissors distortion of mires from an astigmatic surface.

68



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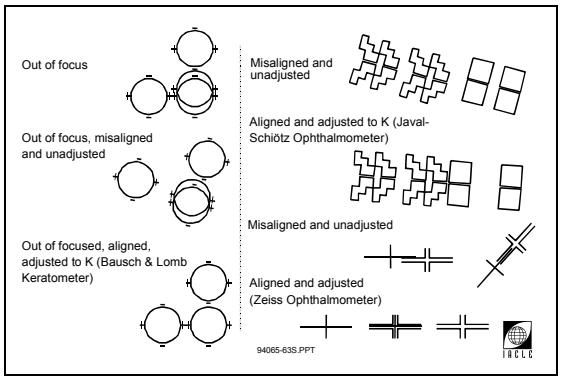
Doubling Principle

69



1L294065-63

Mires Seen Through Keratometers

70

TYPES OF DOUBLING SYSTEMS

- Fixed doubling
- Variable doubling
- Divided doubling
- Full doubling

94065-64S.PPT

1L294065-64

Types of Doubling Systems

- Fixed.
- Variable.
- Divided.
- Full.

71

FIXED DOUBLING

VARIABLE

- Image size and mire separation

FIXED

- Object height and doubling device distance

94065-65S.PPT

1L294065-65

Fixed Doubling

This is done by altering the image height and mire separation of the object to make the second image equal to the fixed amount of doubling while object height, power and doubling prism are fixed.

72

VARIABLE DOUBLING

VARIABLE

- Distance of doubling device

FIXED

- Mire separation and image size

94065-66S.PPT

1L294065-66

Variable Doubling

- The object/mire separation and image size are fixed. The power of doubling device or its distance from image plane is varied until image height is determined by the amount of doubling required.
- This is done by moving the prism along the axis of the instrument between the objective and eyepiece.

73

DIVIDED DOUBLING

- Telescope objective:
  separate transmission

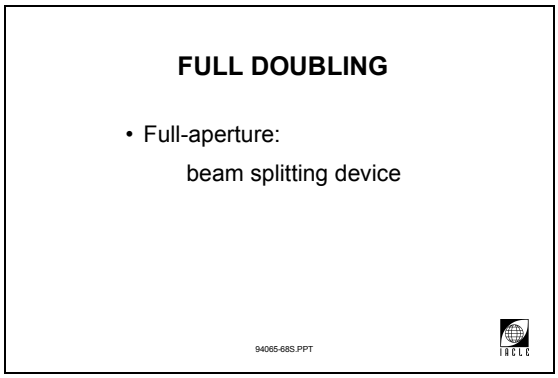
94065-67S.PPT

1L294065-67

Divided Doubling

The telescope objective is divided into two separate fields, each transmitting only a portion of the incident reflected beam.

74



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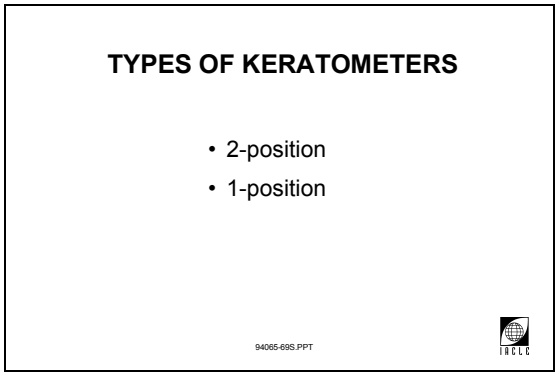
Full Doubling

The doubling is achieved with the aid of a full-aperture beam splitting device.

75

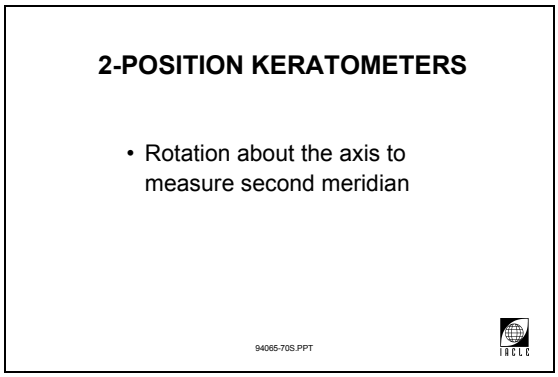


1L294065-69

Types of Keratometers

- Two-position keratometers:
  - require rotation about the axis to measure each of the principal meridians.
- One-position keratometers:
  - simultaneous doubling of perpendicular pairs of mires is produced by doubling devices in each of the corresponding meridians
  - the principal meridians are assumed to be at right angles to each other.

76



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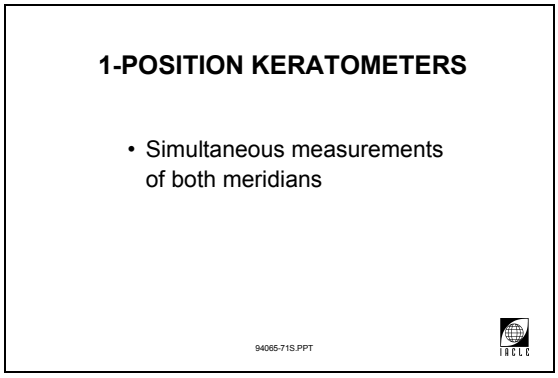
77



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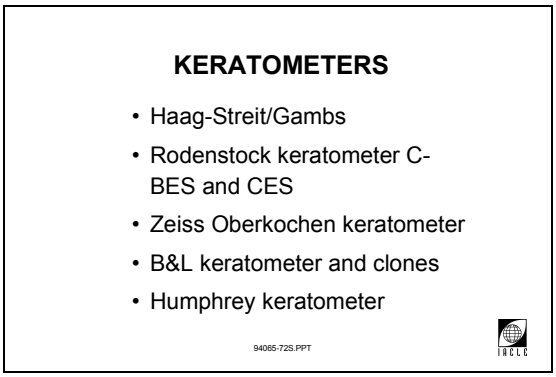
78

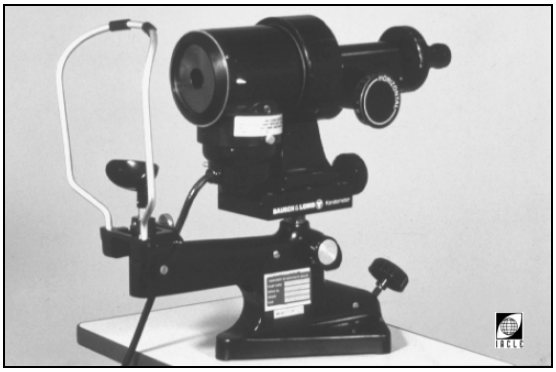


1L294065-72

Keratometers

- Haag-Streit/Gambs.
- Rodenstock keratometer C-BES and CES.
- Zeiss Oberkochen keratometer.
- B&L keratometer (slide 79).
- Humphrey keratometer (slide 80).

79



1L21120-91

Bausch & Lomb Keratometer (a one-position instrument)

80

1L21714-94

Humphrey Auto-Keratometer

81

KERATOMETRY CALIBRATION

Spherical steel/glass balls

94065-73S.PPT

1L294065-73

Keratometry Calibration

Calibration:

- Image-forming rays are reflected from the cornea at a height of at least 1 mm from the vertex.
- Calibration is done with precision spherical steel/glass balls of known radii.

82

KERATOMETRY CALIBRATION INDEX

- Uses specific refractive index
- Calibration index: 1.332 or 1.3375

94065-74S.PPT

1L294065-74

Keratometry

Calibration Index:

- The keratometer uses a specific refractive index to account for both the front and back surface corneal curvatures.
- The calibration index adopted is normally 1.332 or 1.3375.

83

KERATOMETRY CALIBRATION FORMULA

$r = \frac{2dh'}{h}$

Where:

r = radius

d = image distance

h' = image height

h = mire separation

94065-75S.PPT

1L294065-75

Keratometry

Calibration Formula (keratometric equation):

$$r = \frac{2dh'}{h}$$

where:

r	=	radius
d	=	image distance
h'	=	image height
h	=	mire separation

84

MEASURING RIGID CL RADII WITH THE KERATOMETER

- Prism or mirror attachment on headrest
- Use 45° prism
- Equivalent mirror value

94065-76S.PPT

1L294065-76

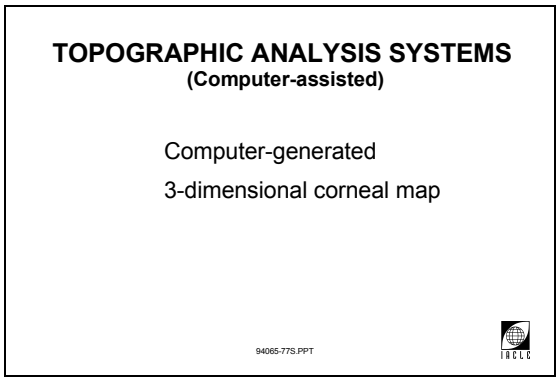
Measuring Rigid Contact Lens Radii with the Keratometer

- Utilises a prism or mirror attachment on the headrest.
- 45° prism is used and positioned at the headrest so that light can be reflected back from the contact lens surface to the instrument.
- It is necessary to have a bright light and fine mires for better precision.

The keratometer readings are converted to the equivalent mirror value (see slide number 113 of notes in Tutorial 1.2).

I.E Topography Analysers

85



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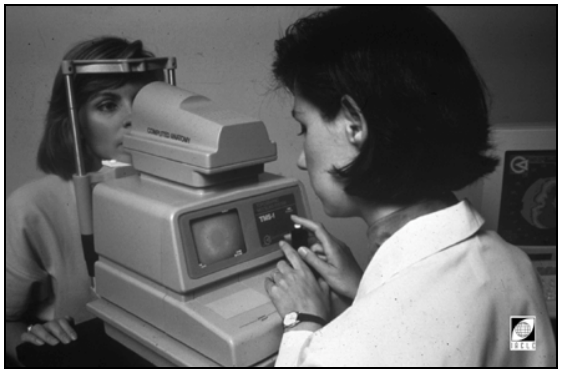
Topographic Analysis Systems *(computer-assisted)*

Computer-assisted algorithms create a three-dimensional reconstruction of the corneal surface of the image digitised by the CCD camera of the video photokeratoscope.

86



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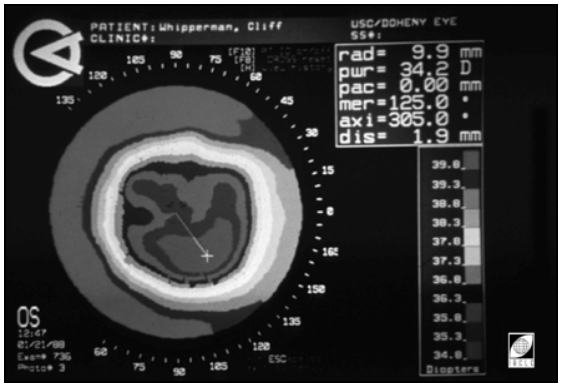
Topographic Modelling System (TMS) and Map Printout

by Computed Anatomy Inc.

87



1L21715-94

88

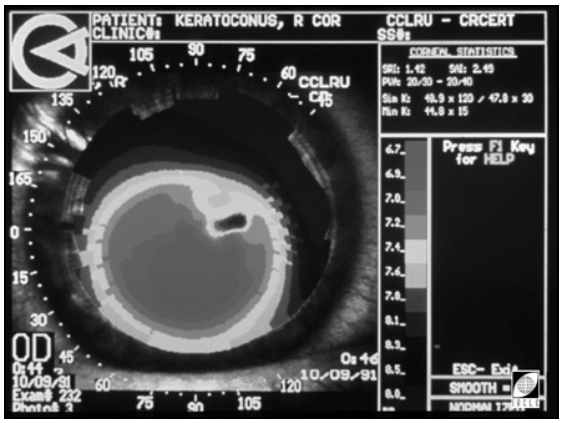
TOPOGRAPHIC ANALYSIS SYSTEMS
(Computer-assisted)

- LSU Corneal Topography Systems (LUCTS)
- Topographic Modelling System (TMS)
- Computerized Corneal Topographer EH-270 (CCT)
- Corneal Analysis System (CAS)

94065-78S.PPT

1L294065-78

89



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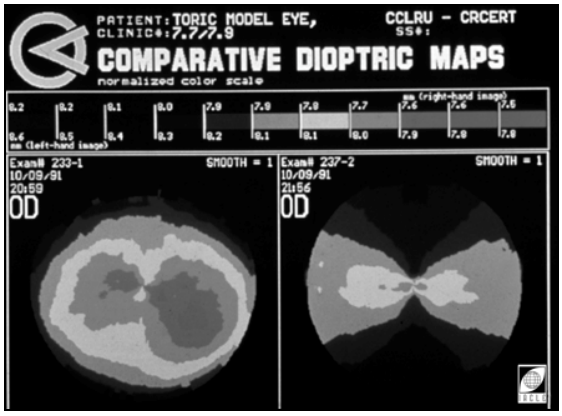
90

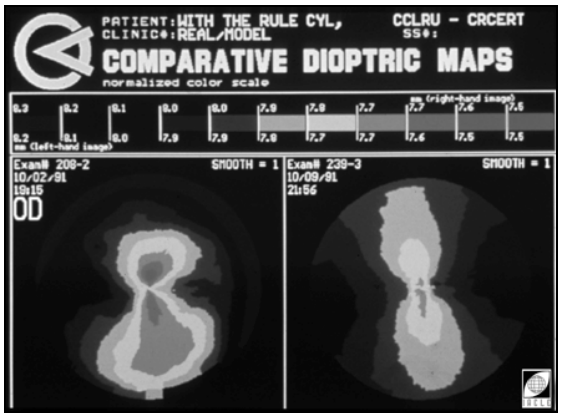


1L20962-95

Topographic Analysis Systems (computer-assisted*)*

- Louisiana State University (LSU) Corneal Topography Systems (LUCTS)
  - LUCTS use manual digitization to capture data for computer analysis
  - manual digitising equipment (HIPAD from Houston Instruments, Austin, TX) with 2000 lines per frame resolution = 0.3 D of resolution on corneal surface
  - the measurement process is tedious. The PKS 1000 photokeratoscope is unable to cover the centre and far periphery of the cornea.
- Topographic Modelling System (TMS), (Computer Anatomy Inc., NY)
  - TMS uses a 32-ring videokeratoscope. It provides a central fixation that is used as a reproducible reference for the computerised statistical image analysis of the power of points on the videokeratoscope rings.
  - operator-monitored automated digitisation with approximately 500 lines per frame resolution. Statistical procedures are utilised by the computerised algorithms to provide resolution on the corneal surface of less than 0.25 D.
  - unable to analyse severely distorted keratoscope mires.
- Computerised Corneal Topographer EH-270 (CCT), (Visioptic Inc., Houston, Texas)
  - designed by El Hage
  - duplicates the corneal contour based on computer-assisted analysis of photokeratoscopic images
  - provides several video displays that include a corneal contour map, meridional contour map and astigmatic map.
- Corneal Analysis System (CAS), (EyeSys Laboratories, Houston, Texas)
  - 16-ring videokeratoscope with fast image processing time (three seconds) and colour-coded contour map plots
  - it allows for data fusion displays, profile plots and data overview
  - comparative and differential maps can be generated by the computer to look at pre- and post-surgical effects as well as data between eyes
  - contact lens data for apical clearance, spherical and aspheric fitting can be generated by the computer. It is of limited reliability for high torics and irregular corneas.

91



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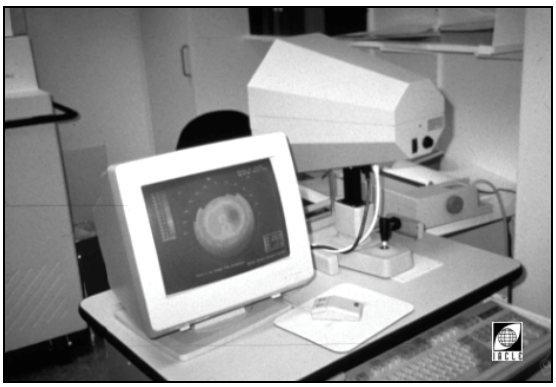
- later versions run in Windows for user-friendly interface as well as generation of simulated fluorescein patterns.

92



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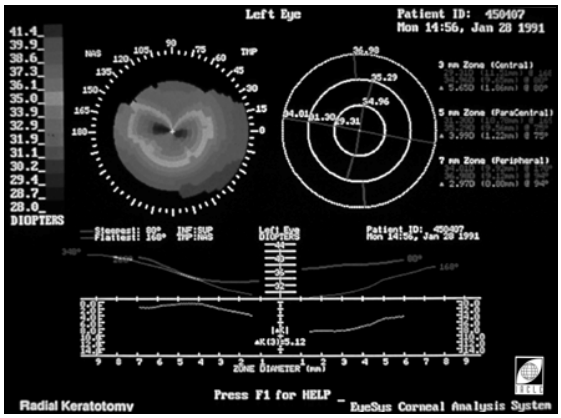
Corneal Analysis System (CAS) by EyeSys Laboratories

93



1L21050-92

CAS Corneal Map

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TOPOGRAPHIC ANALYSIS SYSTEMS
PARAMETRIC DESCRIPTORS

- Simulated keratometry value (Sim K)
- Surface asymmetry index (SAI)
- Surface regularity index (SRI)

94065-79S.PPT

1L294065-79

Topographic Analysis Systems

Parametric Descriptors:

- Simulated keratometry value (Sim K)
  - provides the power and location of the steepest and flattest meridians from a reconstructed corneal surface, analogous to values provided by the keratometer
  - this can be obtained from photokeratoscope ring numbers 7, 8, 9 as this approximates location of measurements of the standard keratometer.
- Surface asymmetry index (SAI)

- centrally weighted summation of differences in corneal power between corresponding points. These points are 180° apart, on 128 equally spaced meridians that cross the four central photokeratoscope mires.
- SAI approaches zero for perfectly spherical surfaces.

- Surface regularity index (SRI)
  - determined from a summation of local fluctuations in power along 256 equally spaced hemi-meridians on the 10 central mires
  - this approaches zero for a normally smooth corneal surface.

95

USES OF COMPUTER-ASSISTED TOPOGRAPHIC SYSTEMS

- Study normal topography
- Study effects of disease
- Pre-post surgical comparisons
- Study effects of contact lenses
- Compare changes with refractive surgery
- Document changes with orthokeratology

94065-80S.PPT

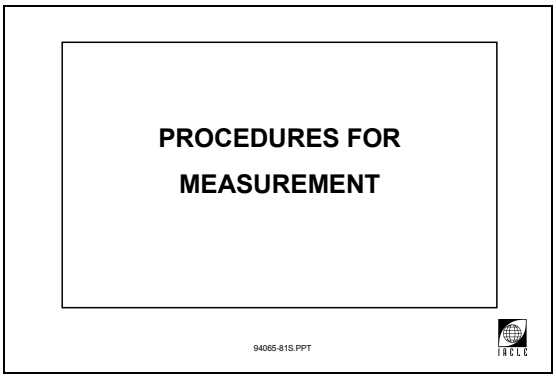
1L294065-80

Uses of Computer-assisted Topographic Systems

- Study normal topography
  - research instrument for measuring detailed topography and image data analysis
  - as a clinical instrument in practice, it has minimal advantages because of cost.
- Study the effects of disease
  - monitor progressive changes, especially in keratoconus.
- Pre and post surgical comparisons
  - penetrating keratoplasty surgery (corneal graft).
- Study the effects of contact lenses
  - monitor changes caused by different contact lens wear modalities.
- Compare changes brought about by refractive surgery techniques
  - excimer laser surgery
  - radial keratotomy.

I.F Clinical Applications

96



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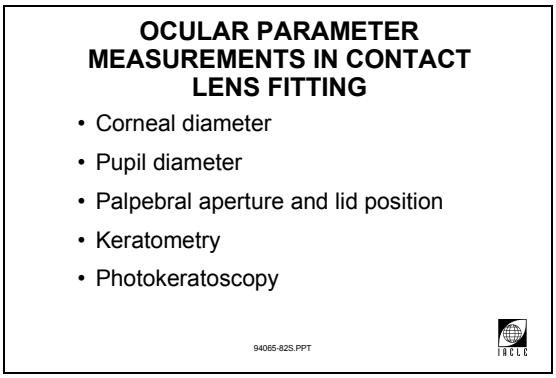
Procedures for Measurement
(title slide)

97



1L294065-82

Ocular Parameter Measurements in Contact Lens Fitting

- Corneal diameter:
  - in association with topographical measurements is useful in determining the extent of corneal curvature changes that may affect the contact lens fit
  - two diameter readings are taken:
  - horizontal visible iris diameter (HVID)
  - vertical visible iris diameter (VVID).
- Pupil diameter:
  - measurement is done under standard room illumination (approximately 200 lux) and low illumination (< 100 lux)
  - useful for determining the appropriate optic zone diameter when doing trials and ordering contact lenses.
- Palpebral aperture and lid position:
  - normal lid aperture size and position is useful for ascertaining how it affects the contact lens fit. This will influence the choice of an appropriate lens design.
- Keratometry
  - corneal curvature measurements of the principal meridians
  - this provides the most useful information for lens fitting, although limited to central (3 - 4 mm) curvature measurements
  - sophisticated topographical techniques can show a corneal map
  - *procedures for measurement are detailed in Practical 1.2.*
- Photokeratoscopy
  - some modern systems can assist in choosing the design for fitting
  - more recent systems can ‘prescribe’ certain designs.

98

PROCEDURES FOR MEASUREMENT CLINICAL RECORDING

- Radius (mm) and/or diopters (D)
- Record principal meridional reading
- Average of 3 readings

94065-83S.PPT

1L294065-83

Clinical Recording

Measurement can be done in millimetre radius (mm) or
dioptres (D).

Meridional measurements are taken and the average of three readings computed.

Example:

First Reading

FLAT K @ MERIDIAN	44.00 D @ 180	7.67 @ 180
STEEP K @ MERIDIAN	45.00 D @ 90	7.50 @ 90

Second Reading

FLAT K @ MERIDIAN	44.25 D @ 180	7.63 @ 180
STEEP K @ MERIDIAN	45.50 D @ 90	7.42 @ 90

Third Reading

FLAT K @ MERIDIAN	44.50 D @ 180	7.58 @ 180
STEEP K @ MERIDIAN	45.00 D @ 90	7.50 @ 90

Mean K: 7.55 mm (44.70 D)

99

INTERPRETATION OF RESULTS ABNORMAL CORNEAL TOPOGRAPHY

- Keratoconus
- Keratoglobus
- Irregular corneal astigmatism
- Irregular cornea

94065-84S.PPT

1L294065-84

Abnormal Corneal Topography

- Keratoconus.
- Keratoglobus.
- Irregular corneal astigmatism.
- Irregular cornea.

100

KERATOCONUS

- Non-inflammatory thinning and protrusion
- Incidence: 1:3,000 - 1:80,000
- Distortion of mires

94065-85S.PPT

1L294065-85

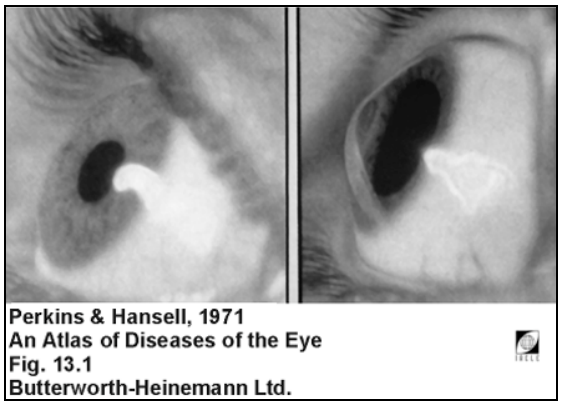
Keratoconus

- Non-inflammatory thinning and protrusion of the cornea

  becomes manifest in the adolescent years

  high degree of irregular myopic astigmatism.
- Rigid contact lenses are the correction of choice.
- Incidence has been reported to be as high as:
  - 1:286 in Germany (Catsch, 1938)
  - 1:3000 in Switzerland (Jaensch, 1929)
  - 1:10,000 at Moorfields Eye Hospital, England (Ruben, 1978)
  - reports of gender difference with a greater incidence amongst the male population have been reported since the 1960s.
- Incidence results depend on:
  - type of population surveyed
  - tests used to identify the condition
  - criteria for diagnosis.
- Distortion of mire reflexes observed during

101



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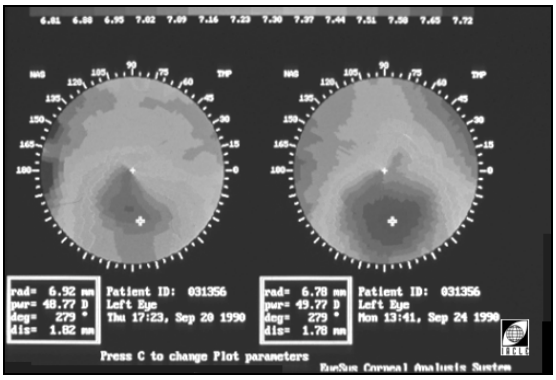

1L21060/92

keratometry.

- Photokeratoscope ring images are also distorted, with narrower ring separations at the area of greatest steepening.
- Gross cases of keratoconus can be corrected by a surgical procedure, penetrating keratoplasty (PK) which involves grafting a donor cornea into the host.

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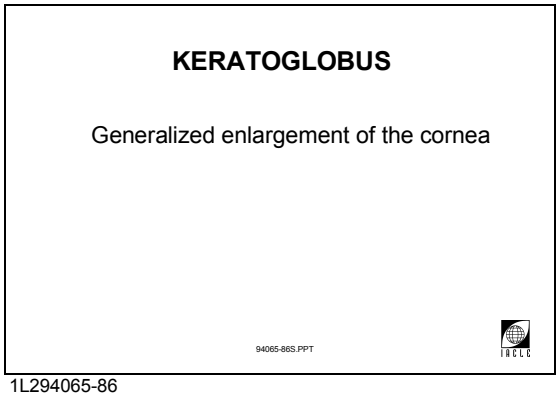

1L294065-86

104

1L20588-95

Keratoglobus

A non-inflammatory and non-progressive thinning of the cornea due to systemic collagen abnormality. The generalised thinning gives the appearance of an enlarged cornea which protrudes and is surrounded by a misshapen sclera.

I.G Contact Lens Applications

105

OPTICAL CHANGES OF THE EYE

Contact lens wear can cause changes in the following:

- curvature/power
- refractive index
- thickness

94065-87S.PPT

1L294065-87

Optical Changes of the Eye

Contact lens wear can cause changes in the following:

- Curvature/power.
- Refractive index.
- Thickness.

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STUDIES OF REFACTIVE CHANGES INDUCED BY HARD/PMMA CONTACT LENS WEAR

(Carney, 1975)

- All hard/PMMA lenses tend to mould the cornea to their own shape
- Lenses that cause oedema produce greater changes in central thickness resulting in:
  - steepening
  - increased myopia (masked by contact lenses)

94065-88S.PPT

1L294065-88

Studies of Refractive Changes Induced by Hard/PMMA Contact Lens Wear

Carney (1975)

- All hard/PMMA lenses tend to mold the cornea to their own shape.
- Lenses causing central corneal oedema cause greater changes in thickness centrally, leading to:
  - central steepening
  - increase in myopia:

    this increase is masked by contact lenses because it is neutralised by the tear lens.

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STUDIES OF REFACTIVE CHANGES INDUCED BY HARD/PMMA CONTACT LENS WEAR

(Stone, 1973/Gordon & Rengstorff, 1965)

- Curvature change similar to hard (negative) CL during hydration/dehydration cycle
- Oedema causes small increase in myopia
  - Decreased refractive index of cornea causes power increase (+0.01 to 0.12D) because:
    - back surface has lens neutralizing effect on front surface power

94065-89S.PPT

1L294065-89

Stone (1973), Gordon (1965)

- Contact lens-related change has been likened to the curvature change of a hard negative corneal lens during the hydration/ dehydration cycle.
- Oedema causes a small increase in myopia.
- Lowering of refractive index of the cornea causes power increase (+0.01 to 0.12 D) because back surface of cornea has no effect as a negative powered surface and has less neutralizing effect on the front surface power.

108

STUDIES OF CURVATURE CHANGES INDUCED BY HARD/PMMA CONTACT LENS WEAR

({Mandell & Poise, 1969}/ Polse, 1972)

- PMMA wear
  → central corneal oedema and steepening
- Discontinuing lens wear
  → thinning and flattening

94065-90S.PPT

1L294065-90

Studies of Curvature Changes Induced by Hard/PMMA Contact Lens Wear

Mandell and Polse (1969) and Polse (1972)

- Hard contact lenses (PMMA) cause central corneal oedema and steepening.
- The removal of the contact lens causes thinning and flattening as the corneal shape returns to normal.

109

STUDIES OF CURVATURE CHANGES INDUCED BY PMMA CONTACT LENS WEAR

(Phillips & Stone, 1989)

CIRCADIAN VARIATIONS

- With adaptation cornea steepens then decreases over the first year
- Cornea steepens 0.50 D in both meridians when contact lenses are worn overnight
- Cornea steepens: first 8 hrs of wear, fit changes during the day

94065-91S.PPT

1L294065-91

Studies of Curvature Changes Induced by PMMA Contact Lens Wear

Circadian Variations:

Phillips and Stone, (1989)

- During contact lens adaptation, corneal curvature steepens then decreases over the first year (Rengstorff, 1969; Grosvenor, 1972 Hill, 1975)
- Corneal curvature flattens overnight 0.75 D especially along the horizontal meridian when lenses are not worn (Rengstorff, 1971).
- Curvature steepens by 0.50 D in both meridians when contact lenses are worn overnight (Rengstorff, 1971).
- Corneal curvature steepens for the first eight hours of wear and the fit changes during the day. The extent of these changes depends on the number of years the contact lenses have been worn and daily wearing time.

110

STUDIES OF REFRACTIVE CHANGES INDUCED BY PMMA CONTACT LENS WEAR

(Phillips & Stone, 1989)

WITHDRAWAL VARIATIONS

- Corneas flattens by 0.75 D
- Increase in WTR astigmatism
- Stability after 3 wks

94065-92S.PPT

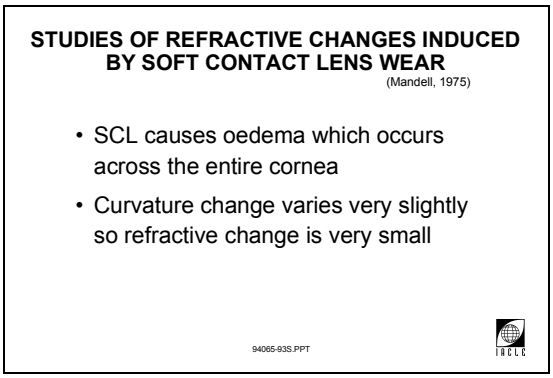
1L294065-92

Studies of Refractive Changes Induced by PMMA Contact Lens Wear

Cessation of Lens Wear:
Phillips and Stone, (1989)

- Flattening by 0.75 D (Carney, 1975).
- Increase in with-the-rule astigmatism (Pratt-Johnson and Warner, 1965).
- Stability occurs after three weeks (Rengstorff, 1967) on average but may be considerably longer in some cases.

111



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Studies of Refractive Changes Induced by Soft Contact Lens Wear

Mandell (1975)

- Soft contact lenses also cause oedema, but the thickening occurs over the entire cornea.
- The result is dependent on the degree of oedema. However curvature changes are usually minimal, so refractive change is very small.

I.H Keratometry and Contact Lenses

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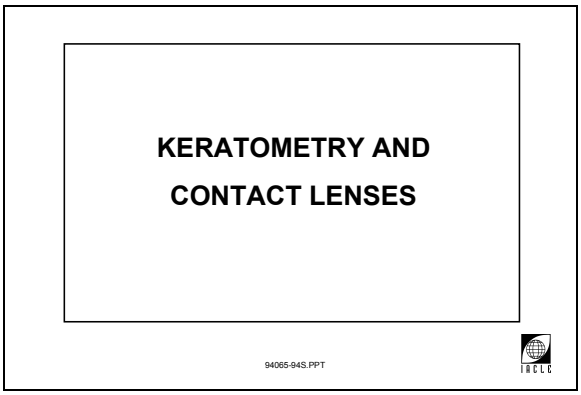

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Keratometry and Contact Lenses *(title slide)*

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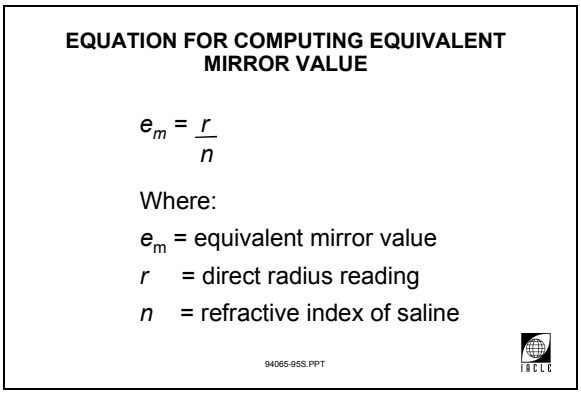

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Measuring Contact Lens Radii with the Keratometer

- Utilises a prism attachment on the headrest.
- 45° prism is used and positioned at the headrest so that light can be reflected back from the contact lens surface to the instrument.
- It is necessary to have a bright light and fine mires for better precision.
- The keratometer readings are converted to the **equivalent mirror value**:

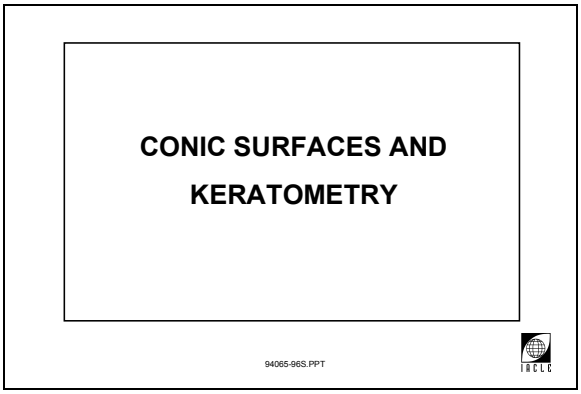
$$e_m = \frac{r}{n}$$

where:

r = direct radius reading

n = index of refraction of medium (saline)

114



1L294065-96

Conic Surfaces and Keratometry
(*title slide*)

115

PRINCIPAL RADII OF CURVATURE OF A CONIC SURFACE

- Sagittal radius
- Tangential radius

94065-97S.PPT

1L294065-97

Principal Radii of Curvature of a Conic Surface

- Any point (P) on a conic surface will have two principal meridians and two principal radii:
  - sagittal radius
  - tangential radius.
- A keratometer measures the sagittal radius any point (P) away from the corneal vertex.

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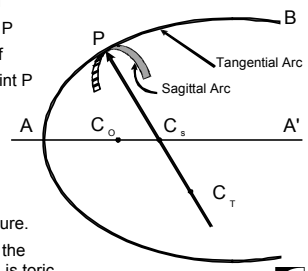
C_oA = Apical radius of curvature (r.o.c.) (after Bennett & Rabbetts, 1984)
C_sP = Instantaneous r.o.c. of sagittal cruve at point P
C_TP = Instantaneous r.o.c. of tangential curve at point P



Since $C_sP < C_TP$ the sagittal curvature > tangential curvature.
∴ Curvature @ any point on the surface, other than the apex, is toric.

94065-98S.PPT

1L294065-98

Principal Radii of a Peripheral Point on a Conicoid Surface (*Bennett & Rabbetts, 1984*)

The principal meridians of a peripheral point on a conicoid surface are perpendicular to each other.

- When refracted at the temporal or nasal periphery, light rays parallel to the optical axis of a flattening conic surface cause with-the-rule astigmatism.
- With vertical decentration of the corneal apex, the effect is against-the-rule astigmatism.

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SAGITTAL RADIUS

The normal perpendicular to the tangential radius extending from point P on the conic surface to its intersection with the optic axis

94065-99S.PPT

1L294065-99

Sagittal Radius

The normal perpendicular to the tangential radius extending from point P on the conic surface to its intersection with the optic axis.

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SAGITTAL RADIUS EQUATION

$$r_s = \sqrt{r_o^2 + (1 - p)y^2}$$

94065-100S.PPT

1L294065-100

Sagittal Radius Equation

$$r_s = \sqrt{r_o^2 + (1 - p)y^2}$$

where:

r_s = sagittal radius

r_o = radius of central curvature

p = eccentricity

y = conical value (see reference textbooks for equation)

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TANGENTIAL RADIUS

The normal perpendicular to the sagittal radius extending from point P on the conic surface to the tangential point on the evolute

94065-101S.PPT

1L294065-101

Tangential Radius

The normal perpendicular to the sagittal radius extending from point P on the conic surface to the tangential point on the evolute.

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TANGENTIAL RADIUS EQUATION

$$r_t = r_S^3 / r_O^2$$

94065-102S.PPT

1L294065-102

Tangential Radius Equation

$$r_t = r_s^3 / r_o^2$$

where:

r_t = tangential radius

r_o = radius of central curvature

r_s = sagittal radius

Practical 1.2

(3 Hours)

Keratometry

Schedule of Practical Sessions

Preliminary

Brief Review of:

- Keratometer principles
- Keratometer operations (controls, patient set-up and demonstration)
- Recording findings

Video Presentation: *Introduction to Keratometry*

Practical Session 1

Instructions: Students are to be divided into six groups and rotated to each of the stations to perform the exercises outlined below:

Station 1:	Keratometry on steel balls
Station 2:	Keratometry on human eye
Station 3:	Placido disc
Station 4:	Sun photokeratoscope
Stations 5 and 6:	Auto-keratometers

Practical Session 2

Instructions: Students are to work in pairs measuring the following ocular parameters:

1. Horizontal visible iris diameter
2. Pupil size (high and low illumination)
3. Palpebral aperture size

Discussion and Summary of Practical Sessions

Practical Session 1

Instructions: Perform calibration of the keratometer prior to commencing the practical sessions (see next page for calibration procedure).

Station 1: Keratometry on Steel Balls

Aim: Become familiar with the operation of a conventional keratometer.

1. Fix smaller steel ball to the head-post of the keratometer.
2. Carry out keratometry on the smaller steel ball.
3. Record your measurement of the smaller steel ball in Result 1.1 (comparison of readings with known curvature of the steel ball will confirm the need for recalibration of the keratometer).
4. Fix larger steel ball to the head-post of the keratometer.
5. Attempt to measure the larger steel ball.
6. Fix negative lens to keratometer and measure the larger steel ball.
7. Record your measurement of the larger steel ball in Result 1.2.
8. Answer Questions 1.1. and 1.2.

Result 1.1 Smaller Steel Ball	Result 1.2 Larger Steel Ball
@ @	@ @

Question 1.1: Why did you need the negative lens to measure the larger steel ball?

Question 1.2: Are the results for the larger steel ball valid?

Calibration of the Keratometer

The keratometer must be calibrated with a steel ball of known radius before making precise measurement of a contact lens.

Calibration Procedure

1. Measure the actual diameter of a precision steel ball and calculate its radius or use a steel ball which has already been calibrated. Use the following formula:

$$r = \frac{diameter}{2}$$

2. Calculate the dioptric value of the steel ball using $n = 1.3375$ for which the keratometer is calibrated and apply the following formula:

$$F = \frac{n-1}{r} \times 1000 = D \quad \text{(r in mm)}$$

3. Set the horizontal and vertical power wheels at the measured radius or dioptric value of the steel ball (depending on the scale shown on your keratometer).
4. Place the steel ball in the adaptor, and focus the mire images. If the mires are not aligned turn the eyepiece anticlockwise (maximum plus). The mires will now be further apart. Rotate the eyepiece clockwise slowly until the mires are aligned (plus signs overlap) and focused.
5. See if the minus signs are also aligned. If not, adjust the vertical measurement knob until they align and record the amount of misalignment. For example, if the steel ball measures 42.50, the horizontal knob will be set at 42.50 (from step 4) and the vertical measurement, if the instrument is out of calibration, may for example, measure 43.00. Therefore, 0.50D must be deducted from each vertical reading.
6. Replace the steel ball with the contact lens and measure its concave and convex surfaces. Note that separate concave and convex conversion tables are required. These are provided on page 149. The difference between convex (the intended application) and concave is due to the effect of the differing abberators caused by the two different surface forms (Phillips & Stone,1989).

Station 2: Keratometry on Human Eye

Aim: Measure the *in vivo* corneal radii of one eye.

1. Sit patient at keratometer.
2. Focus the eyepiece.
3. Measure the radii of the two primary meridians of one eye.
4. Record corneal radii in Result 2.1.
5. Convert radii to equivalent dioptres and record in Result 2.2.
6. Calculate the amount of corneal astigmatism and record in Results 2.3.
7. Answer Question 2.1.

EYE OD or OS	Result 2.1 Radius of Curvature	Result 2.2 Equivalent Power	Result 2.3 Corneal Astigmatism

Question 2.1: Did your patient have WTR or ATR corneal astigmatism?

Station 3: Placido Disc (see Keratoscopy and Photokeratoscopy on next page)

Aim: Qualitatively assess the topography of one eye and note the effect of peripheral fixation.

I. View the reflex of the Placido disc of one eye of your patient while the patient is looking at the central lens.

II. Sketch the reflex (Sketch 3.1) paying attention to:

   A. How many rings are seen.

   B. How circular (or *non-circular*) each ring is.

   C. How uniformly spaced the rings are.

III. Ask the patient to look at the outer-most ring of the Placido disc.

IV. Repeat Step 2 (Sketch 3.2) with this peripheral fixation.

V. Answer Question 3.1.

Question 3.1: ***What causes the differences in reflex appearance on peripheral fixation?***

Keratoscopy and Photokeratoscopy

INTRODUCTION
The cornea can be assessed quantitatively by keratometers and the more sophisticated corneal mapping systems. Although current technology has provided us with advanced instrumentation for measuring and observing the corneal curvature there is still a place for simple devices such as the **Placido disc** and the **Klein keratoscope** for the examining large areas of the cornea qualitatively. The logical development of these simple devices led to the photokeratoscope allowing photo images (e.g. Sun photokeratoscope) of the topography of the corneal surface to be recorded. Photokeratoscopy is the photographic recording of the keratoscopic image for qualitative and quantitative analysis.

Its clinical application lies in its ability to show not only the central cornea but the more peripheral region as well. Irregularities of the corneal surface may constitute a contraindication to contact lens or suggest the use of a specific lens design. An irregular or asymmetrical corneal contour suggest the possibility of a less than optimum visual acuity which may or may not be correctable with contact lenses or spectacles. The degree and type of keratoconus can also be gauged by the appearance of the ring image pattern from the corneal surface.

PLACIDO DISC
The Placido disc is a hand-held device made of a flat disc with alternating white and black rings each pair equidistant from one another. Placido discs require an external light source positioned adjacent to the patient's head and directed at the disc. The disc itself has a central viewing aperture equipped with a +5.00 D lens through which the images of the white rings reflected from the corneal surface can be observed. Later versions, like the Klien keratoscope, have a built-in light source.

Procedure
1. The patient and examiner should be seated comfortably opposite each other and on the same level.
2. The disc is held by the examiner some 15 - 20 cm in front of the patient making sure that the centre of the disc is normal to the patient's corneal apex. Misalignment of the disc can lead to false interpretation.
3. The patient is instructed to steadily fixate the center of the disc.
4. The examiner observes the reflection of the rings through the disc aperture, moving the disc's position to focus the rings if necessary. If observation of the more peripheral cornea or corneo-scleral junction is desired, the patient is instructed to fixate on one of the outer rings. This will allow observation of the ring images formed by reflection from the limbus. Note that some distortion of the ring images will occur due to the obliquity of viewing. The discontinuity of the corneal and scleral curvatures at the limbus will also be apparent.
5. Observation is recorded by drawing a sketch of the contour of the rings and taking note of the distances between them in the various meridians of the cornea. It is also important to record the eye being observed (i.e. R or L).

Observation
1. A symmetrical contour and circular shape indicates an approximately normal and regular corneal surface.
2. A regular but oval or elliptical shape indicates significant corneal astigmatism and where the rings having the greater separations indicates the meridian of flatter curvature.
3. Distortion of the rings indicates an irregular cornea. The tear film may the impression of irregularity, especially in patients with short tear break-up times (TBUTs) and/or mucoid floaters so it is advisable to ask the patient to blink just before assessing the appearance.
4. Ring contours that appear elongated in one direction and shortened in the opposite direction with some distortion are often indicative of a keratoconic cornea. The position of the apex can often be gauged from the apparent centre of the ring images.

Station 4: Sun Photokeratoscope

Aim: Become familiar with the controls of a conventional photokeratoscope.

1. Sketch the SUN photokeratoscope (overleaf) labelling all important features and controls.
2. Set up patient on photokeratoscope and sketch the view through the eyepiece.
3. Answer Questions 4.1, 4.2 and 4.3.

Question 4.1: ***The view through the eyepiece shows that not all rings are in focus at the same time. Why is this so?***

Question 4.2: ***Which ring should you focus on? Does it matter? (Hint: look at the size of the reflected rings as you focus on different rings).***

Question 4.3: ***Are the outer (more peripheral) rings complete? If not, what caused them to be incomplete?***

Stations 5 and 6: Auto Keratometers

Aim: Measure one eye on two different auto-keratometers.

Note: For these Stations (5 and 6) you must use two of the following auto-keratometers: Topcon/Canon/Humphrey

1. Measure the corneal topography of one eye of your patient. You should measure the same eye on both instruments.
2. Record the results for each of the two auto-keratometers in Results 5.1 and 6.1.
3. Answer Question 6.1.

EYE OD or OS	Result 5.1 Auto-Keratometer 1	Result 6.1 Auto-Keratometer 2

Question 6.1: ***Did the results from the two auto-keratometers agree? What are the probable sources of difference in results?***

Practical Session 2

Name of Examiner: _____

Name of Subject: _____ Date: _____

Background: Asian / Caucasian / Hispanic / Black / Other_____

A. Ocular Parameter Measurement: **RIGHT** **LEFT**

1. Horizontal Visible Iris Diameter _____ _____

2. Pupil Size:

High illumination (HI) _____ _____

Low illumination (LI) _____ _____

3. Palpebral Aperture Size:

Horizontal (H) _____ _____

Vertical (V) _____ _____

B. Calculate the class mean and standard deviation of the parameters measured using data from right and left eyes and enter the results in the table below.

Descriptive	**HVID**	**Pupil Size** (mm)		**Palpebral Aperture** (mm)	
Statistics	(mm)	High Illum.	Low Illum.	Horizontal	Vertical
Maximum					
Minimum					
Mean					
SD					

C. **1. Compare your calculated class data with another class and list three possible reasons for the differences between classes.**

_____

_____

_____

_____

2. Compare your class data with your own subject's data and tick the appropriate boxes below:

		well above average	above average	average	below average	well above average
HVID		☐	☐	☐	☐	☐
Pupil Size:	HI	☐	☐	☐	☐	☐
	LI	☐	☐	☐	☐	☐
Pal. Aper:	H	☐	☐	☐	☐	☐
	V	☐	☐	☐	☐	☐

Procedure for Keratometry

1. Eyepiece focus	Wind the eyepiece fully counter clockwise (most plus direction). View the graticule through the eyepiece, and slowly turn it back clockwise until the graticule crosshairs are in sharp focus. Then stop.
2. Patient comfort	Adjust instrument height and chin rest height so that your patient is comfortable with head against the forehead rest. Check that the patient's outer canthus is more-or-less level with the eye-level mark on the headrest.
3. Instrument alignment	Move the instrument vertically so that the height is level with the subject.
4. Patient fixation	Patient looks down the objective and may see (a) a reflection of their own eye, or (b) a small fixation light. You may have to adjust the instrument for them to fixate properly. If no fixation target is visible, the patient should look down the objective, at the centre of the aperture. Some patients prefer to have their other eye occluded.
5. Mire alignment	Use the vertical and horizontal drums to adjust the mires centrally in your view through the eyepiece. Move the keratometer in and out of focus.
6. Axis location	Rotate the body of the keratometer until the axis markers on the mires are correctly aligned. If you make an incorrect adjustment at this stage you will be able to correct it later.
7. Doubling adjustment	Adjust the doubling until the mires just touch.
8. Other meridian adjustment	With one position instruments, adjust and align the second meridian in exactly the same way as you adjusted the first. With two position instruments, rotate the body of the keratometer through 90 degrees to locate and align the second meridian.
9. Recording your results	You should now record all the information from the keratometer as follows:

FLAT K @ MERIDIAN	eg.	44.00 D @ 180 or	7.80 mm @ 180
STEEP K @ MERIDIAN		45.00 D @ 90	7.70 mm @ 90
(FLAT K - STEEP K) X FLAT		-1.00 D x 180*	-0.10 mm x 180

*This is the lens power required to neutralize corneal astigmatism. This astigmatic power, however, may differ in amount, axis and even sign from that which the patient finally accepts as the subjective refraction (i.e. corneal astigmatism ≠ refractive astigmatism).

NOTE:

- Obtain readings quickly to minimise accommodation.
- Take three readings of each eye. Measured values should be within 0.50 dioptres and 5 degrees of each other.
- Internal astigmatism (usually from the crystalline lens) averages - 0.50D x 90 for the population.

Keratometery Conversion Table

(*n*=1.3375, CONVEX Surfaces)

Radius	K	Radius	K	Radius	K	Radius	K	Radius	K
6.49	52.00	7.10	47.54	7.71	43.77	8.32	40.56	8.93	37.79
6.50	51.92	7.11	47.47	7.72	43.72	8.33	40.52	8.94	37.75
6.51	51.84	7.12	47.40	7.73	43.66	8.34	40.47	8.95	37.71
6.52	51.76	7.13	47.34	7.74	43.60	8.35	40.42	8.96	37.67
6.53	51.68	7.14	47.27	7.75	43.55	8.36	40.37	8.97	37.63
6.54	51.61	7.15	47.20	7.76	43.49	8.37	40.32	8.98	37.58
6.55	51.53	7.16	47.14	7.77	43.44	8.38	40.27	8.99	37.54
6.56	51.45	7.17	47.07	7.78	43.38	8.39	40.23	9 00	37.50
6.57	51.37	7.18	47.01	7.79	43.32	8.40	40.18	9.01	37.46
6.58	51.29	7.19	46.94	7.80	43.27	8.41	40.13	9.02	37.42
6.59	51.21	7.20	46.88	7.81	43.21	8.42	40.08	9.03	37.38
6.60	51.14	7.21	46.81	7.82	43.16	8.43	40.04	9.04	37.33
6.61	51.06	7.22	46.75	7.83	43.10	8.44	39.99	9.05	37.29
6.62	50.98	7.23	46.68	7.84	43.05	8.45	39.94	9.06	37.25
6.63	50.90	7.24	46.62	7.85	42.99	8.46	39.89	9.07	37.21
6.64	50.83	7.25	46.55	7.86	42.94	8.47	39.85	9.08	37.17
6.65	50.75	7.26	46.49	7.87	42.88	8.48	39.80	9.09	37.13
6.66	50.68	7.27	46.42	7.88	42.83	8.49	39.75	9.10	37.09
6.67	50.60	7.28	46.36	7.89	42.78	8.50	39.71	9.11	37.05
6.68	50.52	7.29	46.30	7.90	42.72	8.51	39.66	9.12	37.01
6.69	50.45	7.30	46.23	7.91	42.67	8.52	39.61	9.13	36.97
6.70	50.37	7.31	46.17	7.92	42.61	8.53	39.57	9.14	36.93
6.71	50.30	7.32	46.11	7.93	42.56	8.54	39.52	9.15	36.89
6.72	50.22	7.33	46.04	7.94	42.51	8.55	39.47	9.16	36.84
6.73	50.15	7.34	45.98	7.95	42.45	8.56	39.43	9.17	36.80
6.74	50.07	7.35	45.92	7.96	42.40	8.57	39.38	9.18	36.76
6.75	50.00	7.36	45.86	7.97	42.35	8.58	39.34	9.19	36.72
6.76	49.93	7.37	45.79	7.98	42.29	8.59	39.29	9.20	36.68
6.77	49.85	7.38	45.73	7.99	42.24	8.60	39.24	9.21	36.64
6.78	49.78	7.39	45.67	8 00	42.19	8.61	39.20	9.22	36.61
6.79	49.71	7.40	45.61	8.01	42.13	8.62	39.15	9.23	36.57
6.80	49.63	7.41	45.55	8.02	42.08	8.63	39.11	9.24	36.53
6.81	49.56	7.42	45.49	8.03	42.03	8.64	39.06	9.25	36.49
6.82	49.49	7.43	45.42	8.04	41.98	8.65	39.02	9.26	36.45
6.83	49.41	7.44	45.36	8.05	41.93	8.66	38.97	9.27	36.41
6.84	49.34	7.45	45.30	8.06	41.87	8.67	38.93	9.28	36.37
6.85	49.27	7.46	45.24	8.07	41.82	8.68	38.88	9.29	36.33
6.86	49.20	7.47	45.18	8.08	41.77	8.69	38.84	9.30	36.29
6.87	49.13	7.48	45.12	8.09	41.72	8.70	38.79	9.31	36.25
6.88	49.06	7.49	45.06	8.10	41.67	8.71	38.75	9.32	36.21
6.89	48.98	7.50	45.00	8.11	41.62	8.72	38.70	9.33	36.17
6.90	48.91	7.51	44.94	8.12	41.56	8.73	38.66	9.34	36.13
6.91	48.84	7.52	44.88	8.13	41.51	8.74	38.62	9.35	36.10
6.92	48.77	7.53	44.82	8.14	41.46	8.75	38.57	9.36	36.06
6.93	48.70	7.54	44.76	8.15	41.41	8.76	38.53	9.37	36.02
6.94	48.63	7.55	44.70	8.16	41.36	8.77	38.48	9.38	35.98
6.95	48.56	7.56	44.64	8.17	41.31	8.78	38.44	9.39	35.94
6.96	48.49	7.57	44.58	8.18	41.26	8.79	38.40	9.40	35.90
6.97	48.42	7.58	44.53	8.19	41.21	8.80	38.35	9.41	35.87
6.98	48.35	7.59	44.47	8.20	41.16	8.81	38.31	9.42	35.83
6.99	48.28	7.60	44.41	8.21	41.11	8.82	38.27	9.43	35.79
7.00	48.21	7.61	44.35	8.22	41.06	8.83	38.22	9.44	35.75
7.01	48.15	7.62	44.29	8.23	41.01	8.84	38.18	9.45	35.71
7.02	48.08	7.63	44.23	8.24	40.96	8.85	38.14	9.46	35.68
7.03	48.01	7.64	44.18	8.25	40.91	8.86	38.09	9.47	35.64
7.04	47.94	7.65	44.12	8.26	40.86	8.87	38.05	9.48	35.60
7.05	47.87	7.66	44.06	8.27	40.81	8.88	38.01	9.49	35.56
7.06	47.80	7.67	44.00	8.28	40.76	8.89	37.96	9.50	35.53
7.07	47.74	7.68	43.95	8.29	40.71	8.90	37.92		
7.08	47.67	7.69	43.89	8.30	40.66	8.91	37.88		
7.09	47.60	7.70	43.83	8.31	40.61	8.92	37.84		

Radius is presented as the **independent variable** because keratometers actually measure radius of curvature. Keratometers ***do not*** measure dioptric power, they only estimate it.

Keratometery Conversion Table

(*n*=1.3375, CONVEX & CONCAVE Surfaces)

R Cx	K	R Cv	R Cx	K	R Cv	R Cx	K	R Cv	R Cx	K	R Cv	R Cx	K	R Cv
6.49	52.00	6.51	7.10	47.54	7.12	7.71	43.77	7.74	8.32	40.56	8.35	8.93	37.79	8.97
6.50	51.92	6.52	7.11	47.47	7.13	7.72	43.72	7.75	8.33	40.52	8.36	8.94	37.75	8.98
6.51	51.84	6.53	7.12	47.40	7.14	7.73	43.66	7.76	8.34	40.47	8.37	8.95	37.71	8.99
6.52	51.76	6.54	7.13	47.34	7.15	7.74	43.60	7.77	8.35	40.42	8.38	8.96	37.67	9.00
6.53	51.68	6.55	7.14	47.27	7.16	7.75	43.55	7.78	8.36	40.37	8.39	8.97	37.63	9.01
6.54	51.61	6.56	7.15	47.20	7.17	7.76	43.49	7.79	8.37	40.32	8.40	8.98	37.58	9.02
6.55	51.53	6.57	7.16	47.14	7.18	7.77	43.44	7.80	8.38	40.27	8.41	8.99	37.54	9.03
6.56	51.45	6.58	7.17	47.07	7.19	7.78	43.38	7.81	8.39	40.23	8.42	9.00	37.50	9.04
6.57	51.37	6.59	7.18	47.01	7.20	7.79	43.32	7.82	8.40	40.18	8.43	9.01	37.46	9.05
6.58	51.29	6.60	7.19	46.94	7.21	7.80	43.27	7.83	8.41	40.13	8.44	9.02	37.42	9.06
6.59	51.21	6.61	7.20	46.88	7.22	7.81	43.21	7.84	8.42	40.08	8.45	9.03	37.38	9.07
6.60	51.14	6.62	7.21	46.81	7.23	7.82	43.16	7.85	8.43	40.04	8.46	9.04	37.33	9.08
6.61	51.06	6.63	7.22	46.75	7.24	7.83	43.10	7.86	8.44	39.99	8.47	9.05	37.29	9.09
6.62	50.98	6.64	7.23	46.68	7.25	7.84	43.05	7.87	8.45	39.94	8.48	9.06	37.25	9.10
6.63	50.90	6.65	7.24	46.62	7.26	7.85	42.99	7.88	8.46	39.89	8.49	9.07	37.21	9.11
6.64	50.83	6.66	7.25	46.55	7.28	7.86	42.94	7.89	8.47	39.85	8.50	9.08	37.17	9.12
6.65	50.75	6.67	7.26	46.49	7.29	7.87	42.88	7.90	8.48	39.80	8.51	9.09	37.13	9.13
6.66	50.68	6.68	7.27	46.42	7.30	7.88	42.83	7.91	8.49	39.75	8.52	9.10	37.09	9.14
6.67	50.60	6.69	7.28	46.36	7.31	7.89	42.78	7.92	8.50	39.71	8.53	9.11	37.05	9.15
6.68	50.52	6.70	7.29	46.30	7.32	7.90	42.72	7.93	8.51	39.66	8.54	9.12	37.01	9.16
6.69	50.45	6.71	7.30	46.23	7.33	7.91	42.67	7.94	8.52	39.61	8.55	9.13	36.97	9.17
6.70	50.37	6.72	7.31	46.17	7.34	7.92	42.61	7.95	8.53	39.57	8.56	9.14	36.93	9.18
6.71	50.30	6.73	7.32	46.11	7.35	7.93	42.56	7.96	8.54	39.52	8.57	9.15	36.89	9.19
6.72	50.22	6.74	7.33	46.04	7.36	7.94	42.51	7.97	8.55	39.47	8.58	9.16	36.84	9.20
6.73	50.15	6.75	7.34	45.98	7.37	7.95	42.45	7.98	8.56	39.43	8.59	9.17	36.80	9.21
6.74	50.07	6.76	7.35	45.92	7.38	7.96	42.40	7.99	8.57	39.38	8.60	9.18	36.76	9.22
6.75	50.00	6.77	7.36	45.86	7.39	7.97	42.35	8.00	8.58	39.34	8.62	9.19	36.72	9.23
6.76	49.93	6.78	7.37	45.79	7.40	7.98	42.29	8.01	8.59	39.29	8.63	9.20	36.68	9.24
6.77	49.85	6.79	7.38	45.73	7.41	7.99	42.24	8.02	8.60	39.24	8.64	9.21	36.64	9.25
6.78	49.78	6.80	7.39	45.67	7.42	8.00	42.19	8.03	8.61	39.20	8.65	9.22	36.61	9.26
6.79	49.71	6.81	7.40	45.61	7.43	8.01	42.13	8.04	8.62	39.15	8.66	9.23	36.57	9.27
6.80	49.63	6.82	7.41	45.55	7.44	8.02	42.08	8.05	8.63	39.11	8.67	9.24	36.53	9.28
6.81	49.56	6.83	7.42	45.49	7.45	8.03	42.03	8.06	8.64	39.06	8.68	9.25	36.49	9.29
6.82	49.49	6.84	7.43	45.42	7.46	8.04	41.98	8.07	8.65	39.02	8.69	9.26	36.45	9.30
6.83	49.41	6.85	7.44	45.36	7.47	8.05	41.93	8.08	8.66	38.97	8.70	9.27	36.41	9.31
6.84	49.34	6.86	7.45	45.30	7.48	8.06	41.87	8.09	8.67	38.93	8.71	9.28	36.37	9.32
6.85	49.27	6.87	7.46	45.24	7.49	8.07	41.82	8.10	8.68	38.88	8.72	9.29	36.33	9.33
6.86	49.20	6.88	7.47	45.18	7.50	8.08	41.77	8.11	8.69	38.84	8.73	9.30	36.29	9.34
6.87	49.13	6.89	7.48	45.12	7.51	8.09	41.72	8.12	8.70	38.79	8.74	9.31	36.25	9.35
6.88	49.06	6.90	7.49	45.06	7.52	8.10	41.67	8.13	8.71	38.75	8.75	9.32	36.21	9.36
6.89	48.98	6.91	7.50	45.00	7.53	8.11	41.62	8.14	8.72	38.70	8.76	9.33	36.17	9.37
6.90	48.91	6.92	7.51	44.94	7.54	8.12	41.56	8.15	8.73	38.66	8.77	9.34	36.13	9.38
6.91	48.84	6.93	7.52	44.88	7.55	8.13	41.51	8.16	8.74	38.62	8.78	9.35	36.10	9.39
6.92	48.77	6.94	7.53	44.82	7.56	8.14	41.46	8.17	8.75	38.57	8.79	9.36	36.06	9.40
6.93	48.70	6.95	7.54	44.76	7.57	8.15	41.41	8.18	8.76	38.53	8.80	9.37	36.02	9.41
6.94	48.63	6.96	7.55	44.70	7.58	8.16	41.36	8.19	8.77	38.48	8.81	9.38	35.98	9.42
6.95	48.56	6.97	7.56	44.64	7.59	8.17	41.31	8.20	8.78	38.44	8.82	9.39	35.94	9.43
6.96	48.49	6.98	7.57	44.58	7.60	8.18	41.26	8.21	8.79	38.40	8.83	9.40	35.90	9.44
6.97	48.42	6.99	7.58	44.53	7.61	8.19	41.21	8.22	8.80	38.35	8.84	9.41	35.87	9.45
6.98	48.35	7.00	7.59	44.47	7.62	8.20	41.16	8.23	8.81	38.31	8.85	9.42	35.83	9.46
6.99	48.28	7.01	7.60	44.41	7.63	8.21	41.11	8.24	8.82	38.27	8.86	9.43	35.79	9.47
7.00	48.21	7.02	7.61	44.35	7.64	8.22	41.06	8.25	8.83	38.22	8.87	9.44	35.75	9.48
7.01	48.15	7.03	7.62	44.29	7.65	8.23	41.01	8.26	8.84	38.18	8.88	9.45	35.71	9.49
7.02	48.08	7.04	7.63	44.23	7.66	8.24	40.96	8.27	8.85	38.14	8.89	9.46	35.68	9.50
7.03	48.01	7.05	7.64	44.18	7.67	8.25	40.91	8.28	8.86	38.09	8.90	9.47	35.64	9.51
7.04	47.94	7.06	7.65	44.12	7.68	8.26	40.86	8.29	8.87	38.05	8.91	9.48	35.60	9.52
7.05	47.87	7.07	7.66	44.06	7.69	8.27	40.81	8.30	8.88	38.01	8.92	9.49	35.56	9.53
7.06	47.80	7.08	7.67	44.00	7.70	8.28	40.76	8.31	8.89	37.96	8.93	9.50	35.53	9.54
7.07	47.74	7.09	7.68	43.95	7.71	8.29	40.71	8.32	8.90	37.92	8.94			
7.08	47.67	7.10	7.69	43.89	7.72	8.30	40.66	8.33	8.91	37.88	8.95			
7.09	47.60	7.11	7.70	43.83	7.73	8.31	40.61	8.34	8.92	37.84	8.96			

For a concave surface measure the radius of curvature in the usual manner. Use the table above to estimate its actual radius of curvature. For example: the keratometer power drum shows a radius of 7.67 mm (or 44.00D depending on the instrument). Thistable suggests that the actual concave radius is 7.70 mm.

Tutorial 1.2

(1 Hour)

Interpretation of Keratometry Results

Interpretation of Keratometry Results

Instructions: The class will be divided into groups of four to six students and a moderator assigned for each group to lead the group members. The following cases should be discussed while attempting to answer the questions after each case. At the end of the discussion period the leader is to present the group analysis of the cases to the class.

Case 1: A patient has a refraction of -2.50 D Sph -1.00 D Cyl x 180 in the right eye. Unaided visual acuity for this eye was reported to be 6/38. After refraction the visual acuity was 6/6. Keratometry on three attempts gave the following readings:

1	2	3
43.00 D @ 180	43.12 D @ 180	43.25 D @ 180
45.50 D @ 90	44.87 D @ 90	45.37 D @ 90

The patient above is interested in being fitted with contact lenses and asks you these questions:

1. Why is my vision not good without glasses?
2. Will I have better vision with contact lenses? Why or why not?
3. If I wear contact lenses, what type of lenses would be most suitable for me? Why?

Case 2: The following keratometry findings were revealed using different methods:

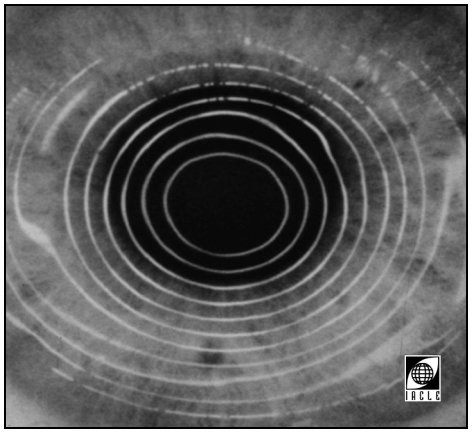
BL Keratometer:

1	2	3
44.00 D @ 20	44.00 D @ 15	43.87 D @ 10
44.62 D @ 110	44.87 D @ 105	45.00 D @ 100

Automated Keratometer (Humphrey):

Central K	43.50 D @ 24
	45.37 D @ 114
Apical K	43.50 D @ 29
	45.75 D @ 119
Shape Factor (e^2)	+0.02
Confidence	65%

Photokeratoscope:



1T20195A/92

1. What will be the final computation for the mean K of this patient? Explain why.

_____

_____

_____

_____

_____

2. Which of the techniques above gives the practitioner a picture of the corneal apical contour?

_____

_____

_____

_____

_____

3. What clinical significance will the above findings have when fitting contact lenses?

_____

_____

_____

_____

_____

🕮 References

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Unit 1.3

(4 Hours)

Lecture 1.3: Examination of the Anterior Segment

Practical 1.3: Measurement and Assessment of Ocular Parameters

Course Overview

Lecture 1.3: Examination of the Anterior Segment

I. Examination of the Anterior Segment

II. Examination Routine

III. Eye Examination Techniques

Practical 1.3: Measurement and Assessment of Ocular Parameters

- Utilising Instruments and Devices.
- Recording Information.
- Lid Eversion Technique.

Suggested Evaluation Techniques

- Performance assessment of external examination conducted by the student on his/her partner.
- Quiz.

Lecture 1.3

(2 Hours)

Examination of the Anterior Segment

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Examination of the Anterior Segment

I Examination of the Anterior Segment

I.A Why Assess the Anterior Eye?

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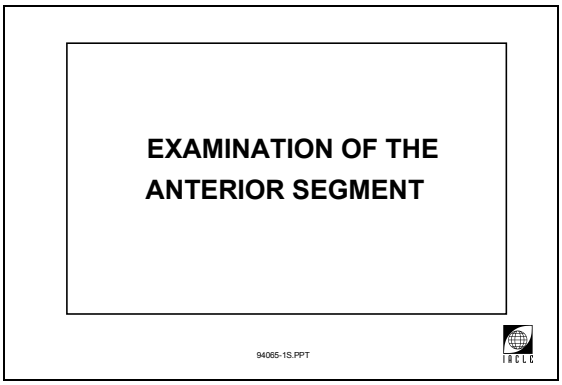

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Examination of the Anterior Segment
(*title slide*)

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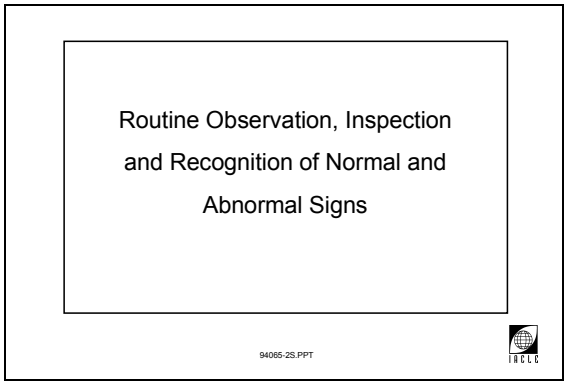

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Routine Observation, Inspection and Recognition of Normal and Abnormal Signs
(title slide)

3

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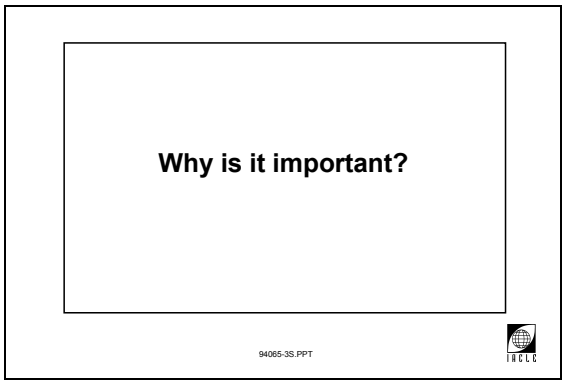
The Eye Magnified

4



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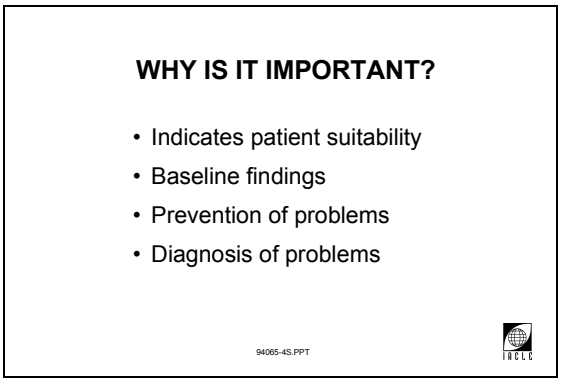
Why is it Important? (*title slide*)

5



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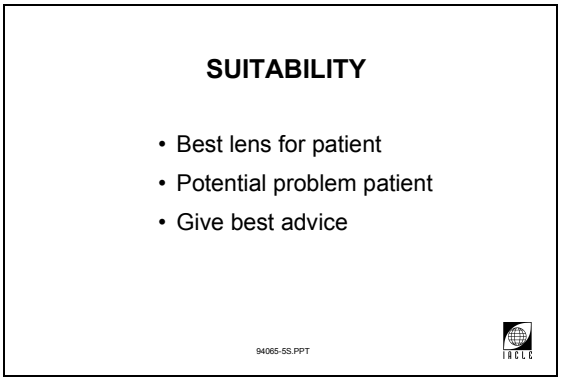
Why is it Important?

- To determine patient suitability for contact lenses.
- To provide baseline findings.
- For prevention of problems.
- For diagnosis of problems.

6



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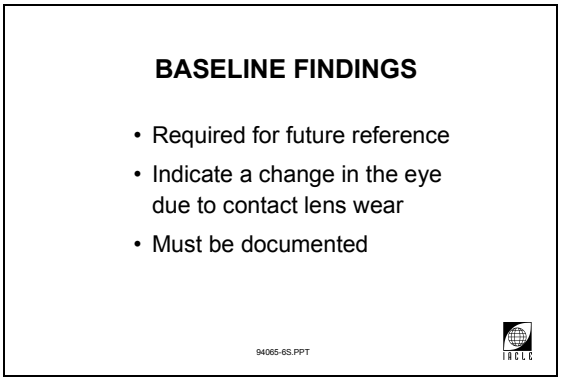
Suitability

- To decide on the best lens for the patient.
- To recognise the potential problem patient.
- To give the best advice to the patient.

7



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Baseline Findings

- Required for future reference and therefore must be documented.
- Indicate a change in the eye due to contact lens wear.

8

PREVENTION OF PROBLEMS

- Early intervention
- Regular aftercare
- Selection of biocompatible contact lenses
- Change wearing schedule
- Change lens care routine

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1L394066-7

Prevention of Problems

- Early intervention to prevent complications.
- Regular aftercare to monitor ocular changes arising from contact lens wear.
- Maintain normal corneal integrity by selection of the most bio-compatible contact lenses.
- Change wearing schedule when indicated by early diagnosis of potential problems.
- Change lens care routine when indicated by patient lifestyle and early diagnosis of potential problems.

9

DIAGNOSIS OF PROBLEMS

- Confirm patient report
- Detect unknown problem
- Indication of cause of problem

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1L394066-8

Diagnosis of Problems

- Confirm patient report.
- Detect unknown problem.
- Gain an indication of the cause of the problem.

I.B What Do We Assess?

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What do we assess? (*title slide*)

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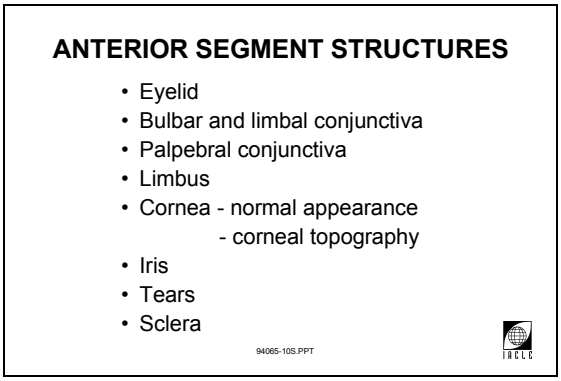

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Anterior Segment Structures

Eyelids.

Bulbar and limbal conjunctiva.

Palpebral conjunctiva.

Limbus.

Cornea

normal appearance

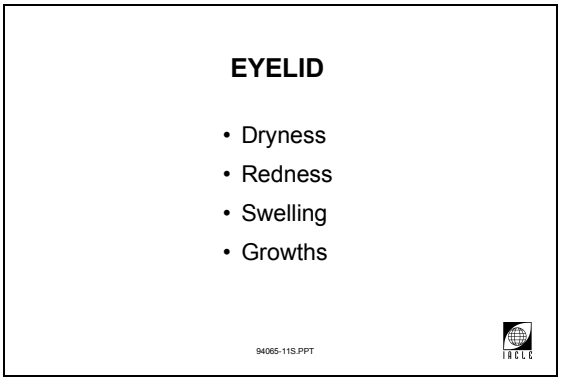
corneal topography.

Iris.

Tears.

Sclera.

12



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Skin

- Dryness.
- Redness.
- Swelling.
- Growth.

13

BLEPHARITIS
SIGNS AND SYMPTOMS

- Scales
- Granulations
- Conjunctivitis
- Keratitis

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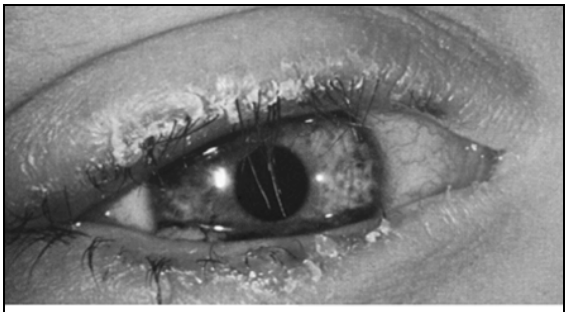


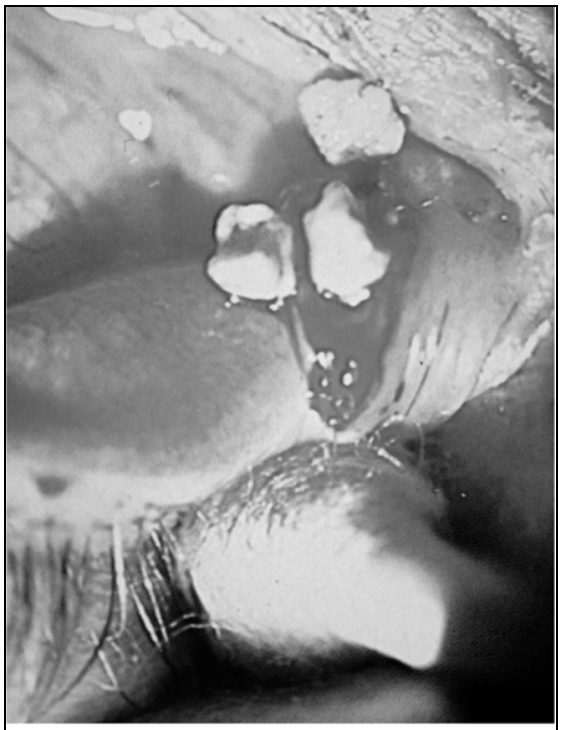
Perkins & Hansell, 1971
An Atlas of Diseases of the Eye
Fig. 5.2
Butterworth-Heinemann Ltd.

1L30903-91

Blepharitis

- Inflammation of the lid margins.
- Patient complains of eyelids sticking together in the morning and eyelashes sticking together. Crusts are found sticking to the lid margins.
- There are two types:
  - staphylococcal (non-ulcerative)
  - seborrhoeic (ulcerative).
- Signs and symptoms:
  - Scales
  - Granulations
  - Conjunctivitis
  - keratitis.

15



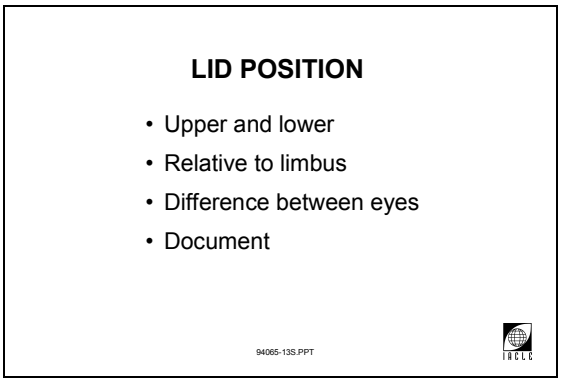
Kanski, 1989
Clinical Opthalmology: Systemic Approachh
Fig 3.17
Butterworth-Heinemann Ltd.

1L31607-96

Inflammation of the Canaliculi
(Vaughan et al., 1989)

- This condition is uncommon, and is due to a unilateral viral infection.
  - varicella, herpes simplex, adenovirus
  - obstruction.
- Appears as an elevated or raised area of swelling in the region of the canaliculus. The skin is inflamed and the cutaneous blood vessels are obvious.
- Signs and symptoms:
  - mildly red and irritated eyes
  - slight discharge
  - inflammation of the puncta and discharge which can be expressed if pressure is applied.

16



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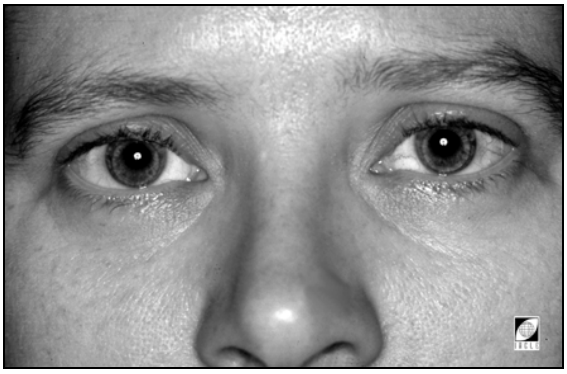
Lid Position

- Upper and lower.
- Relative to limbus.
- Difference between eyes.
- Should be documented.

17



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Normal Lid Position

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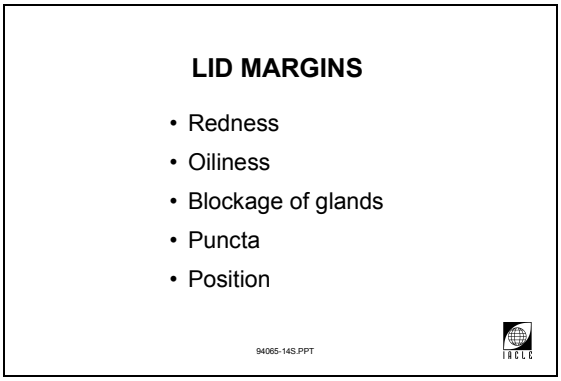

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Lid Margins

Observe:

- Redness.
- Oiliness.
- Blockage of glands.
- Puncta.
- Position.

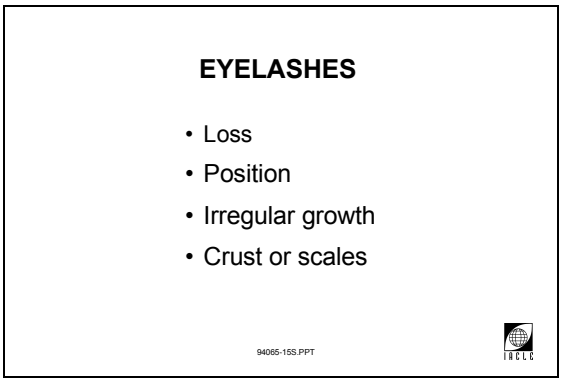
19

1L30145-93

Meibomitis

- Inflammation of the Meibomian glands.
- Associated with blepharitis.
- Signs and symptoms:
  - red eyes
  - conjunctivitis
  - yellow discharge which can be expressed from the orifice of the gland.

20



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Eyelashes

Observe:

- Loss.
- Unusual position.
- Irregular growth.
- Crusts or scales.

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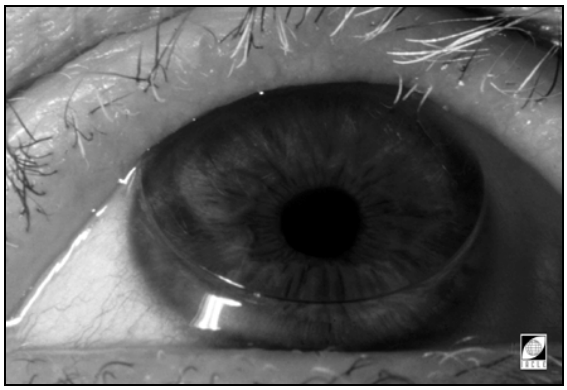
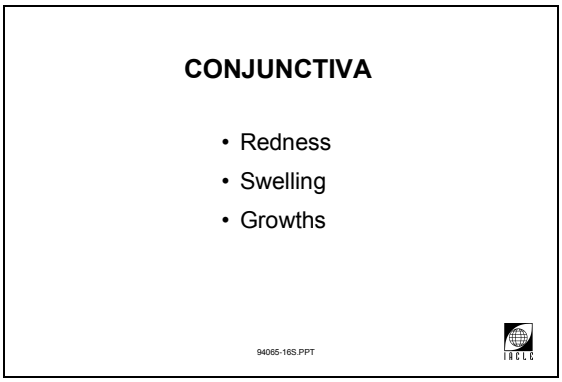


1L30156-95

Trichiasis

- Inward growth of eyelashes.
- Sometimes present among cases of abnormal eyelid conditions.
- Causes corneal abrasions.

22



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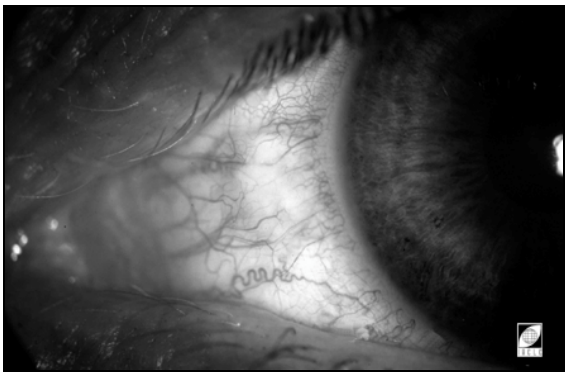
Conjunctiva

Observe:

- Redness.
- Swelling.
- Growths.

23



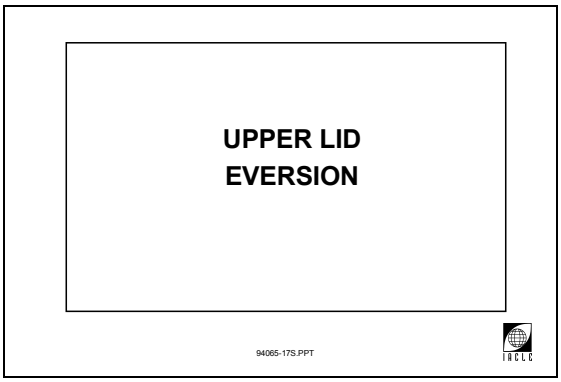
1L31353-91

Pinguecula/Pterygium

- Raised or elevated nodule in the nasal or temporal conjunctiva.
- This is composed of hyaline and fatty deposition in the conjunctiva.
- Irritation (eg. wind, dust) of the pinguecula may cause blood vessel dilation.
- If position of pinguecula/pterygium is close to the limbus it may affect contact lens fit (especially RGP).

I.B.1 Upper Lid

24



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Upper Lid Eversion *(title slide)*

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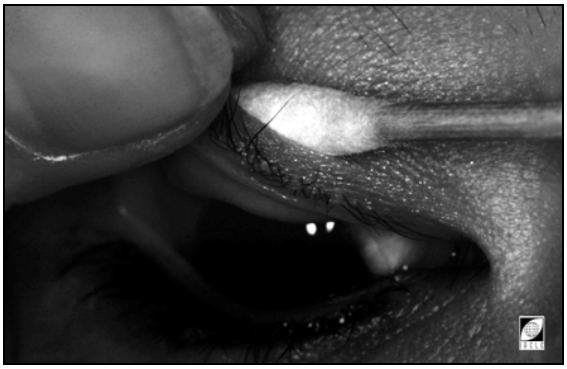
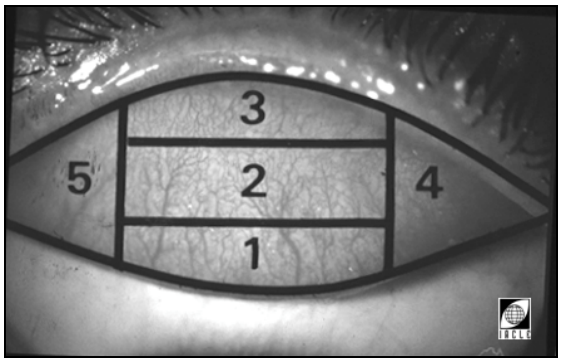


1L30158-93

Upper Lid Eversion

- It is necessary to examine the palpebral conjunctival tissue. This may reveal subtle lid changes or irritation related to contact lenses. It will also assist in the differential diagnosis of lid disease.
- Grasp the upper lid lashes with the thumb and forefinger of one hand. Pull down at an angle of 45°.
- The other hand pushes the upper tarsus of the lid downwards with a cotton-tipped bud, at the same time gently pulling the lashes out and upwards.
- Hold the eyelashes against the skin while doing the examination.
- Ask the patient to continue to look down when pulling the lid back to its normal position. This will lessen discomfort.

27



1L31840-93

Areas of the Everted Upper Lid

1: Upper tarsal area

2: Central tarsal area

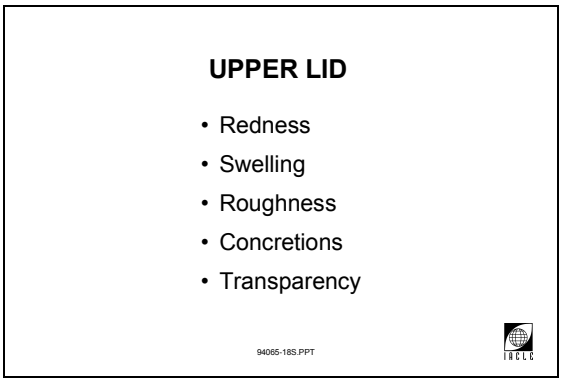
3: Lower tarsal area

4: Nasal junctional area

5: Temporal junctional area.

NOTE: The description of the areas are based on the tarsal plate in the non-everted upper lid.

28



1L394066-18

Upper Lid

Observe:

- Redness.
- Swelling.
- Roughness.
- Concretions.
- Transparency.

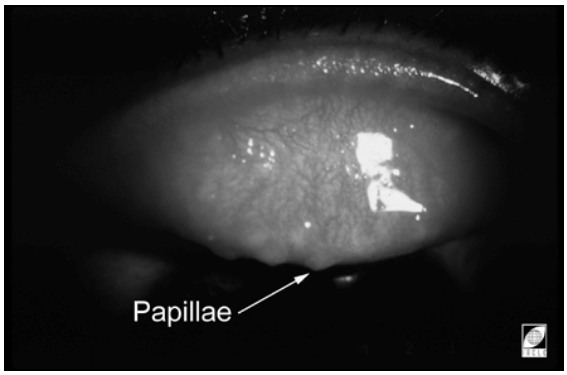
29

1L31606-92

Upper Lid Redness

- Palpebral injection or redness of the conjunctiva.
- Compare with normal lid redness and other eye.
- Increased redness may indicate inflammation.

30

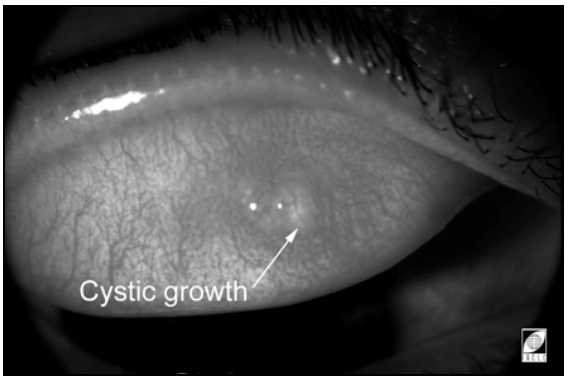


1L31347-91

Papillae

- Cobblestone-like nodules of the palpebral conjunctiva arising from irritation brought about by contact lens wear or solutions.
- Advanced cases of papillary growth on the upper lid may be brought about by an immunological reaction to deposition on a contact lens, as in giant papillary conjunctivitis (GPC).
- Small papillae are normal.

31



1L30159-93

Cystic Growth

Cystic growths on the eyelid appear as raised nodules that may point towards the skin or conjunctiva.

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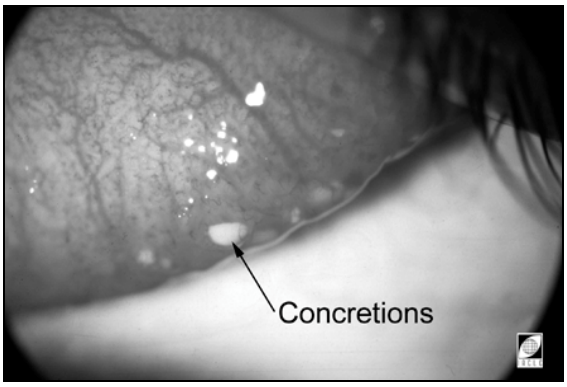


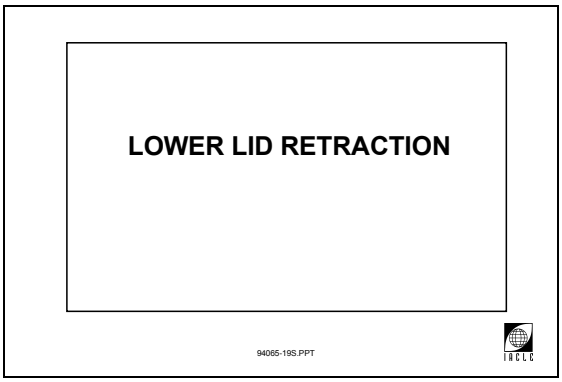
1L31265-91

Concretions

- Small deposits of calcium.
- They are usually asymptomatic.
- May give rise to a foreign body sensation.

I.B.2 Lower Lids

33



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Lower Lid Retraction (*title slide*)

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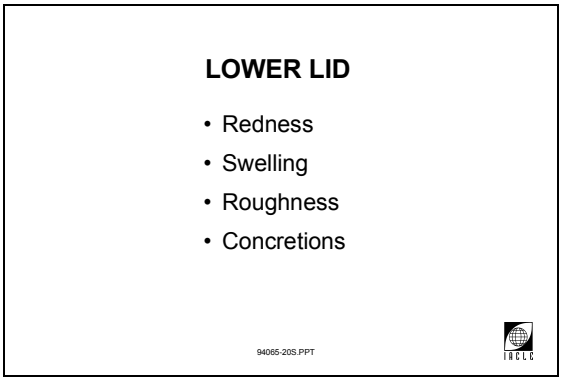
1L32931-93

Lower Lid Retraction

- The lower lid is retracted by gently pulling down the skin with the thumb or forefinger and exposing the inner palpebral conjunctiva.
- The patient is instructed to look up while the lower lid is held.
- Avoid touching the lower lid margin or applying too much pressure against the skin.

35



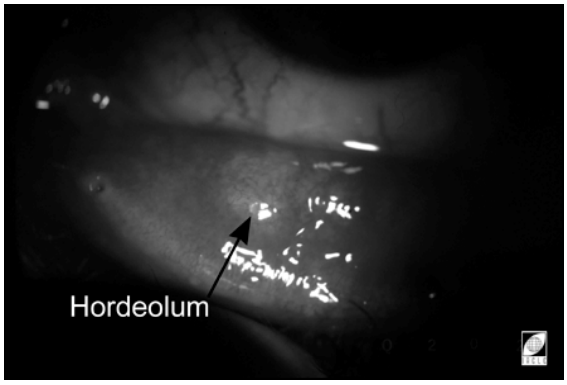
1L394066-20

Lower Lid

Observe:

- Redness.
- Swelling.
- Roughness.
- Concretions.

36



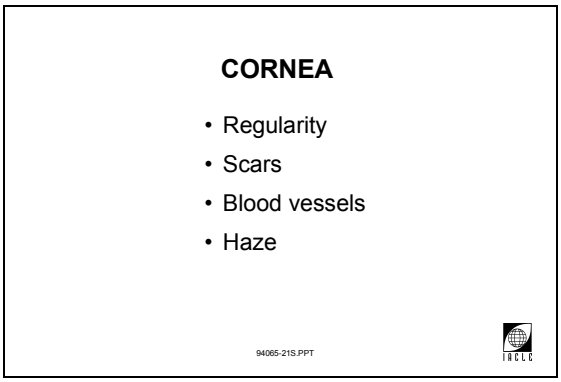
1L31366-91

Hordeolum Internum

- *Staphylococcus aureus* infection of the Meibomian glands.
- Swelling of the lid may be directed towards the conjunctiva or skin. There are two types:
  - external
  - internal.
- Treatment is the application of hot compresses, antibiotics. Surgical incision may be necessary if abscess is large.

I.B.3 Cornea

37



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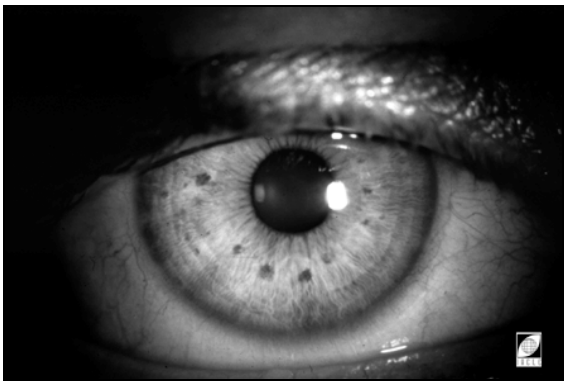
Cornea

Observe:

- Regularity.
- Scars.
- Blood vessels.
- Haze.

38



1L30020-94

The Normal Cornea

Characteristics are:

- Regular shape.
- Transparency.
- Lustre.
- Absence of blood vessels.
- Bright corneal reflex/convex reflecting surface.

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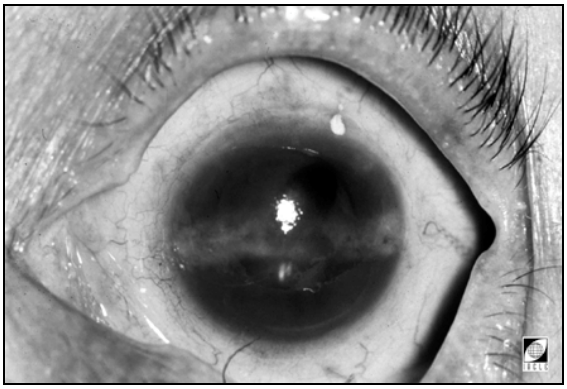
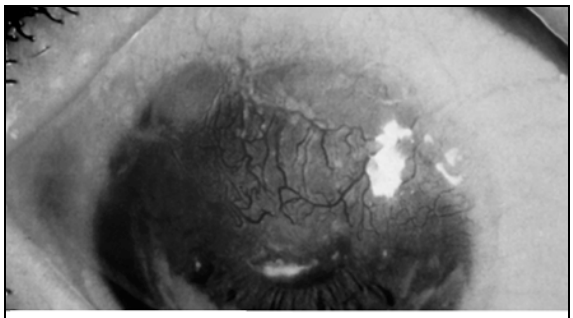


1L31441-92

Calcific Band Keratopathy

- Condition associated with rheumatoid arthritis.
- Calcium salt deposits are found on the anterior cornea extending into the stroma in a band formation.
- Signs and symptoms:
  - irritation
  - infection
  - blurring.

40



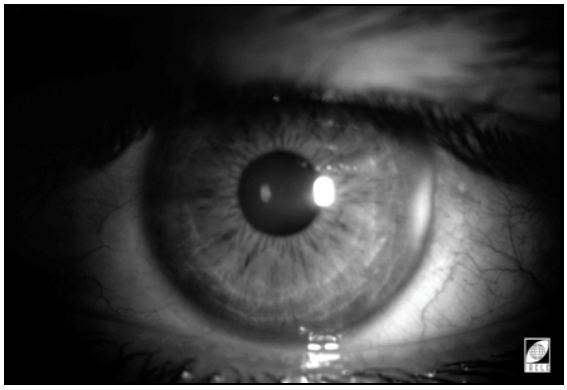
Perkins & Hansell, 1971
An Atlas of Diseases of the Eye
Fig. 9.4
Butterworth-Heinemann Ltd.

1L30899-91

Trachomatous Pannus

- This condition is found in established cases of trachoma.
- Accompanied by limbal follicles and Herbert's pits (domes or elevations surrounded by pannus).
- Signs and symptoms:
  - tearing
  - photophobia
  - pain
  - exudates
  - lid oedema and follicles
  - hyperaemia.

41



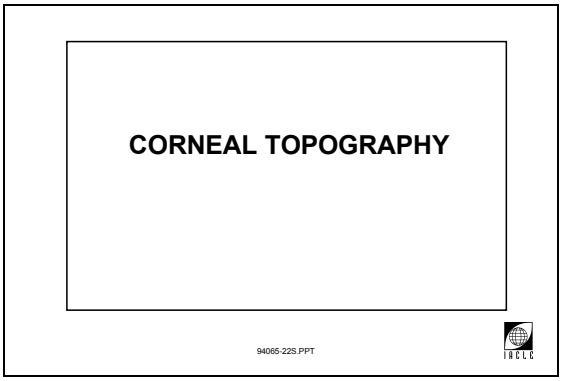
1L31358-91

Corneal Haze

Corneal haze may be caused by one or more of the following:

- Arcus senilis.
- Scars/opacities.
- Oedema/central corneal clouding.
- Arcus juvenilis.
- Limbal girdle of Vogt.

42



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Corneal Topography (*title slide*)

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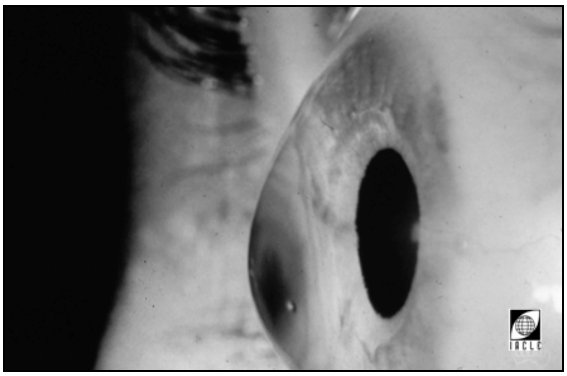

1L30990-93

Keratoconus

- Characterised by thinning and ectasia of the cornea.
- Keratometry and corneal mapping show excessive steepening of the apical cone, and a very toric cornea.
- Signs and symptoms:
- irregular mire reflection during keratometry and photokeratoscopy
  - shadows around letters
  - flare around lights
  - retinoscopic reflex is scissors-like or swinging.
- Corneal hydrops/Munson's sign in late stage.
- Best corrected with RGP lenses.

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TOPOGRAPHICAL INSTRUMENTS

- Placido disc
- Photo/video keratoscope
- Keratometer
- Computer assisted topographical analysis system

94065-23S.PPT

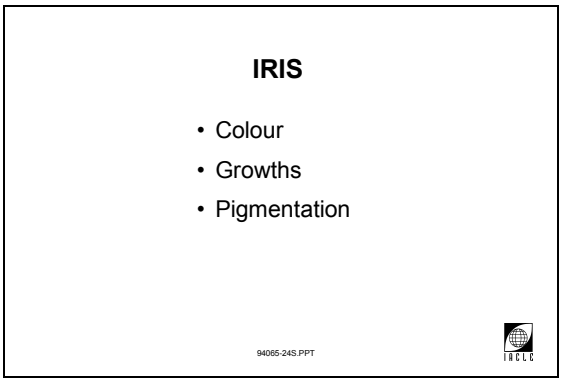
1L394066-23

Instruments for Assessing Corneal Topography

- Placido disc.
- Photokeratoscope/ videokeratoscope.
- Keratometer.
- Computer-assisted topographical analysis systems.

I.B.4 Iris

45



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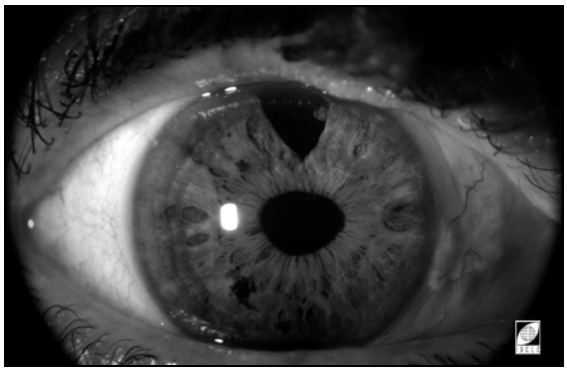
Iris

Observe:

- Colour.
- Growths.
- Pigmentation.

46



1L32923-93

Iridectomy

Partial loss of the iris due to iris surgery or trauma.

This is usually found in glaucoma patients, where surgery has been used to normalise the level of intra-ocular pressure.

I.B.5 Tears

47

1L394066-25

Tears

Observe:

- Stability.
- Tear production.
- Viscosity.
- Break-up time.

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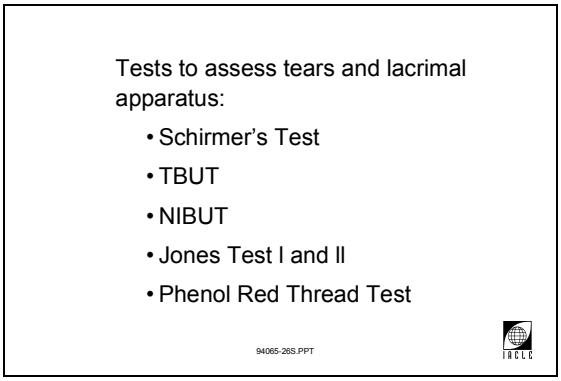


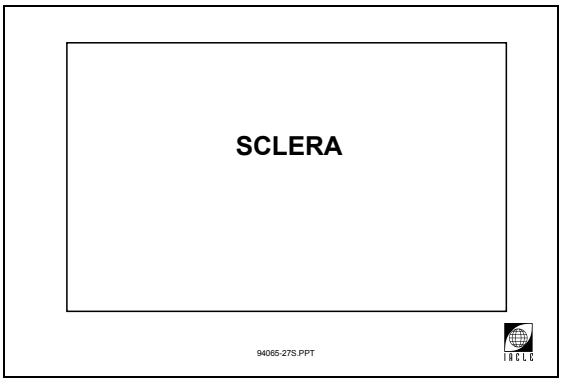
1L394066-26

Tests to Assess the Tears and Lacrimal Apparatus Integrity

- Schirmer Test.
- Tear Break-up Time (TBUT).
- Non-invasive Tear Break-up Time (NIBUT).
- Jones Test I and II.
- Phenol Red Thread Test.

I.B.6 Sclera

49



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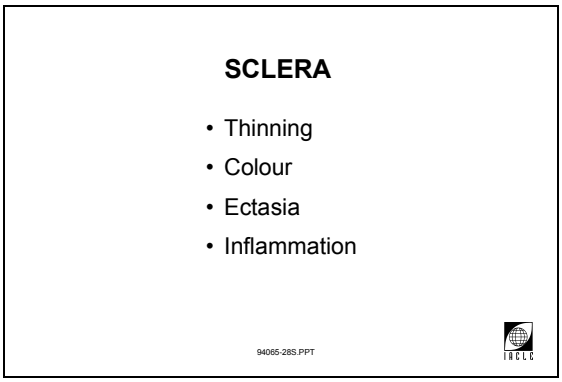
Sclera *(title slide)*

50



1L394066-28

Sclera

Observe:

- Thinning.
- Colour/blue.
- Ectasia/staphyloma.
- Inflammation/episcleritis.

51

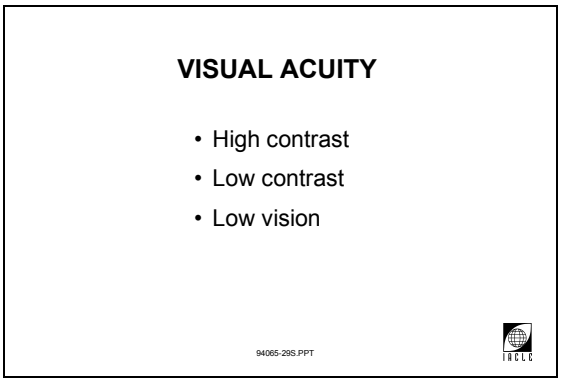
1L30901-91

Scleromalacia

- Thinning of the scleral tissue not accompanied by inflammation.
- Also known as "scleral melting". The uveal tissue is seen through the thin scleral wall as a dark area because of the underlying choroidal pigmentation.

I.B.7 Vision

52



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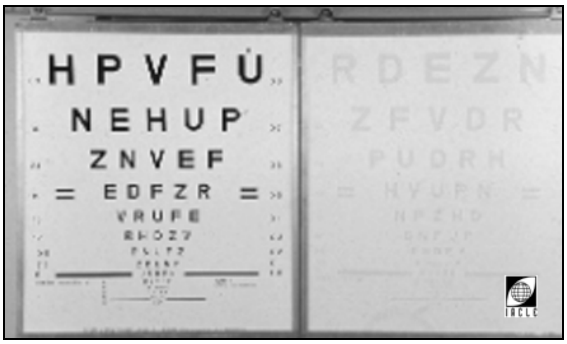
Visual Acuity

Observe:

- High and low contrast visual acuity under high and low illumination.
- Low vision (finger counting, light and movement perception). This must be carefully assessed.

53



1L31716-94

High and Low Contrast Vision Charts

- Bailey-Lovie charts.
- Snellen chart.
- Illiterate or tumbling E chart, Landolt C.
- Kindergarten charts.

I.C Developing A Routine

54

EYE EXAMINATION

It is important to develop a strict routine

94065-30S.PPT

1L394066-30

Eye Examination

- It is important to develop a strict routine.
- Document findings at all visits.

55

MAJOR AREAS IN EYE EXAMINATION

- Subjective
- Objective
- Assessment
- Plan

94065-31S.PPT

1L394066-31

Major Areas in Eye Examination

- Subjective.
- Objective.
- Assessment.
- Plan.

56

EXAMINATION
SUBJECTIVE

- History
- Analysis
- Questioning
- Learning

94065-32S.PPT

1L394066-32

Examination - Subjective

- History.
- Analysis.
- Questioning.
- Learning.

57

EXAMINATION
OBJECTIVE

- Visual examination
- Systematic
- Look, listen, feel
- Document

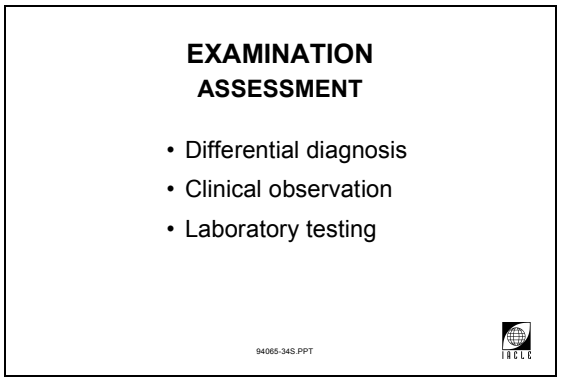
94065-33S.PPT

1L394066-33

Examination - Objective

- Visual examination.
- Systematic.
- Look, listen, feel.
- Document.

58



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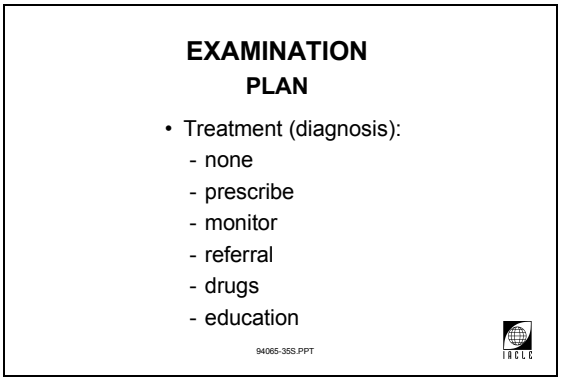
Examination - Assessment

- Differential diagnosis.
- Clinical observation.
- Laboratory testing.

59



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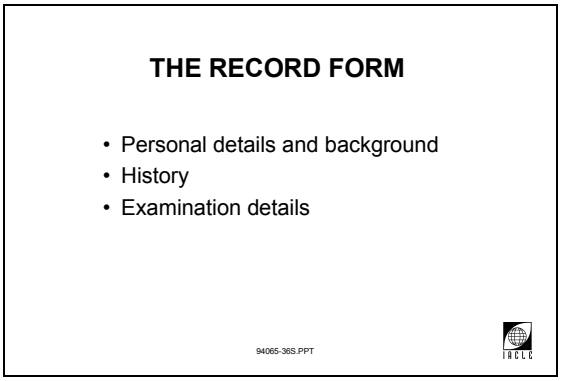
Examination - Plan

Treatment Options

Based on a diagnosis, the following treatment options might be pursued:

- **None**. Do nothing.
- **Prescribe** a lens, care regimen, a wearing schedule etc.
- **Monitor** the condition noting any changes observed over time.
- **Referral**. Refer to an appropriate professional.
- **Drugs**. Use or prescribe appropriate pharmacological agents.
- **Education**. Enhance the knowledge of the patient by personal instruction, printed matter, videos etc.

60



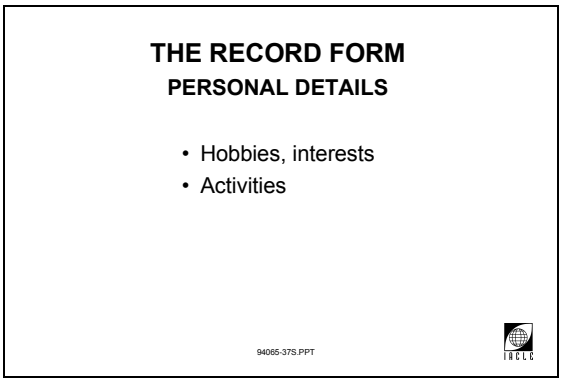
1L394066-36

The Record Form

The record form should provide three general areas for recording information from the patient:

- Personal details and background.
- History.
- Examination details:
  - preliminary examination
  - contact lens examination
  - follow-up information.

61



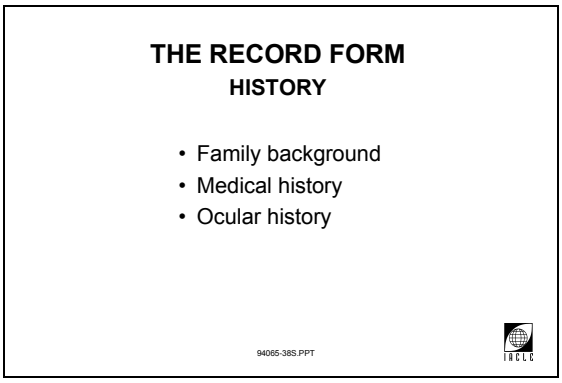
1L394066-37

The Record Form

The record form should specify the personal details of the patient with the following information:

- Hobbies, interests.
- Activities.

62



1L394066-38

The Record Form

A record of the patient's history should contain the following information:

- Family background.
- Medical history (referrals should also be included, as appropriate).
- Ocular history particularly any chief complaint.

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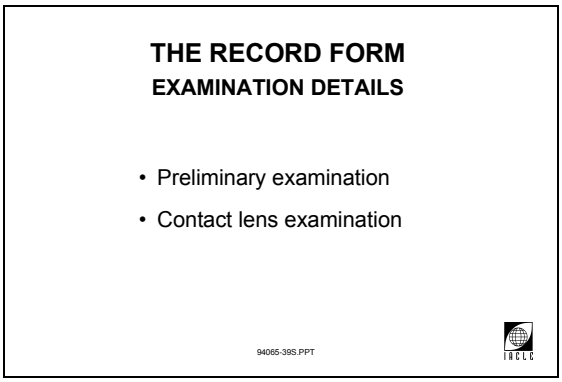


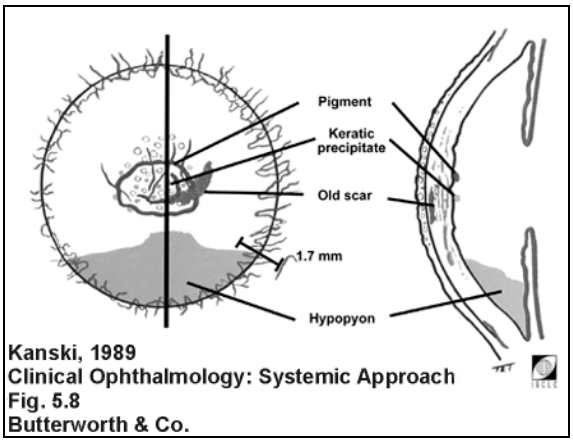
1L394066-39

The Record Form

The examination details on the record form should contain the following information:

- Preliminary examination. This usually includes:
  - intra-ocular pressure
  - binocular vision
  - visual fields
  - refraction and visual acuity
  - ocular motility
  - pupillary reflex tests.
- Contact lens examination. This includes:
  - measurement of ocular parameters necessary for the fitting of contact lenses
  - biomicroscopy
  - details of trial lenses used
  - final lenses to be prescribed.
- Follow-up information:
  - the record form should contain an outline of tests that need to be conducted during the follow-up and aftercare visits.

64



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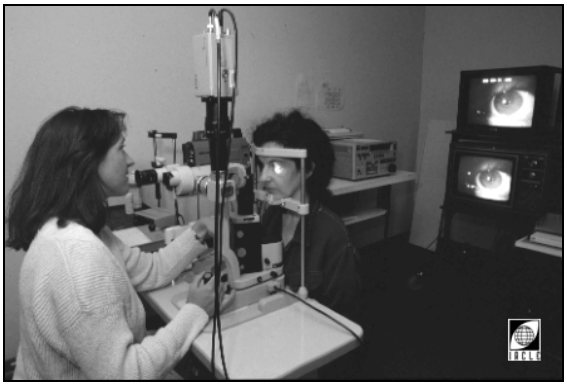


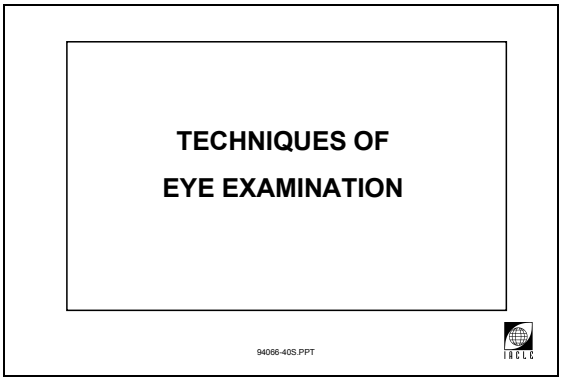
1L31555-95

Drawing Corneal Abnormalities

- A comprehensive record form will usually have a schematic of the important structures to allow ease of recording and visual representation of the conditions observed.
- Recording of conditions at baseline visit and aftercare will allow for comparative analysis of changes that may be caused by the contact lenses.
- Other techniques that accompany the clinical recording process are:
  - photography
  - video recording.

I.D Techniques of Eye Examination

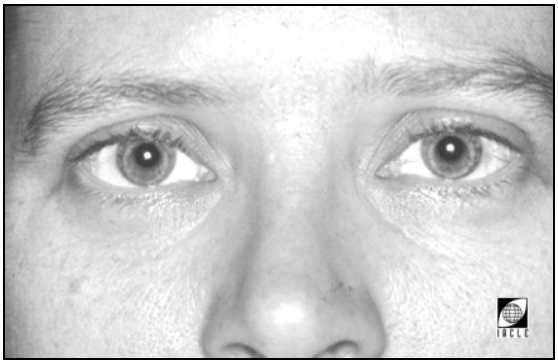
66



1L394066-40

Techniques of Eye Examination
(*title slide*)

67

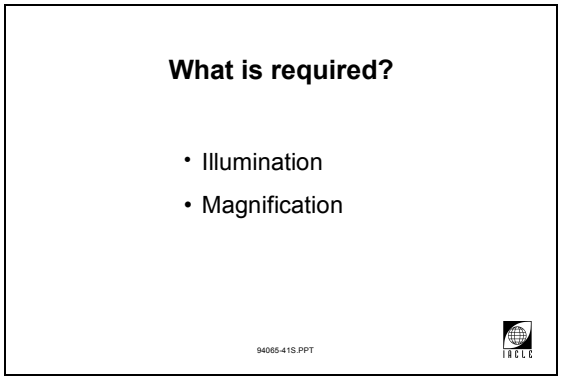


1L32255-93

Eyes in Primary Gaze

The practitioner should be familiar with normal anatomical features. These may vary from one individual to another depending on nationality.

68



1L394066-41

What is Required? (*title slide*)

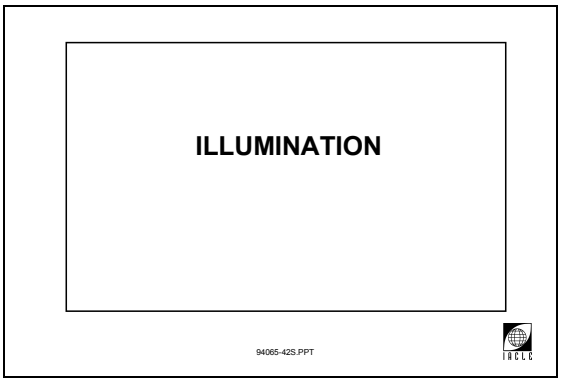
69

1L30155-92

Conventional Devices for Examination

- A variety of instruments and devices can be used to provide the practitioner with different illuminations and magnification levels that may be required for contact lens fitting assessment.
- Although these may not give much detailed information, they can be used in conjunction with the slit-lamp as they are commonly found in most clinics.

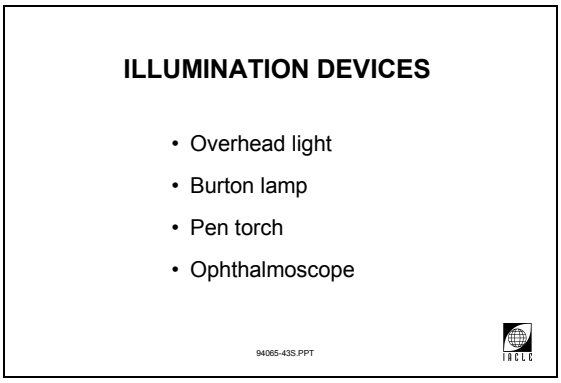
70



1L394066-42

Illumination (*title slide*)

71

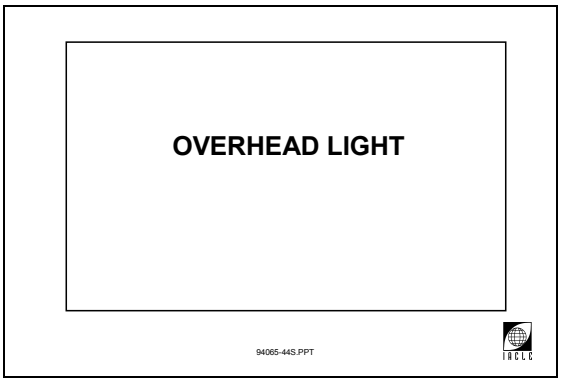


1L394066-43

Illumination Devices

- Overhead light.
- Burton lamp.
- Pentorch/penlight.
- Ophthalmoscope.

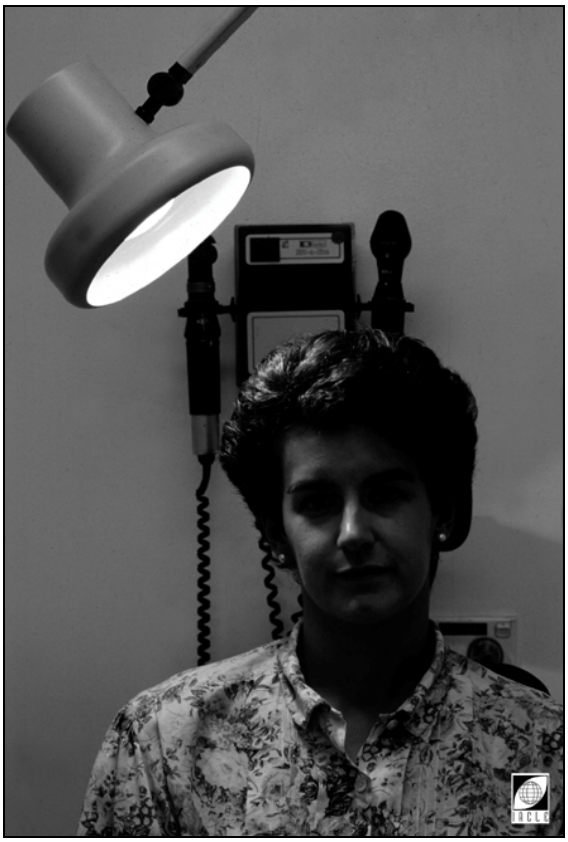
72



1L394066-44

Overhead Light (*title slide*)

73

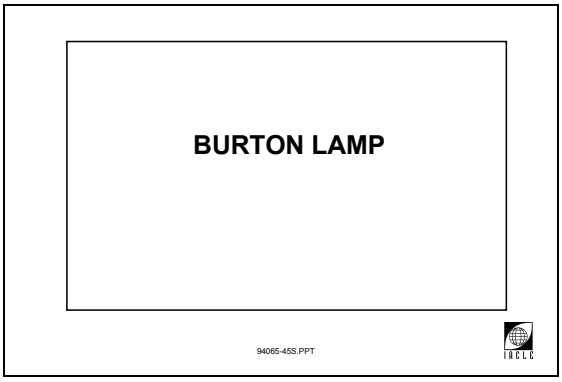


1L30146-92

Overhead Light

- Overhead lights are useful when used in conjunction with a magnifying system.
- General, gross observations can be made. However much detail may be missed with this technique.

74



1L394066-45

Burton Lamp (*title slide*)

75

1L30346-91

Burton Lamp

- This instrument allows for simultaneous magnification and illumination.
- Although it does not allow for variable magnification, it provides a cobalt blue light which is useful for fluorescein examination.

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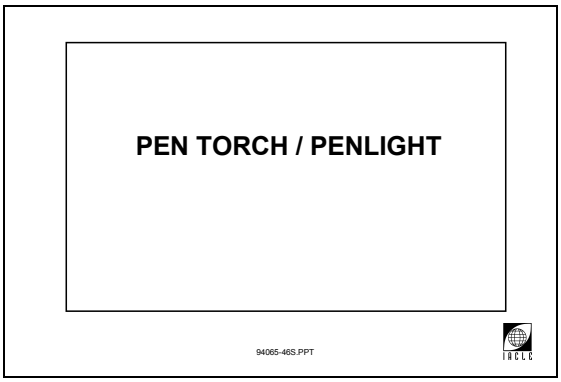

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Pentorch/Penlight (*title slide*)

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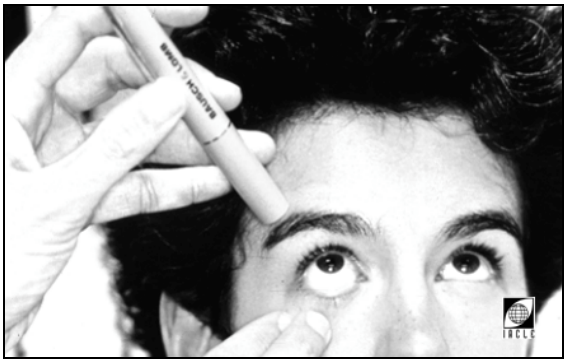

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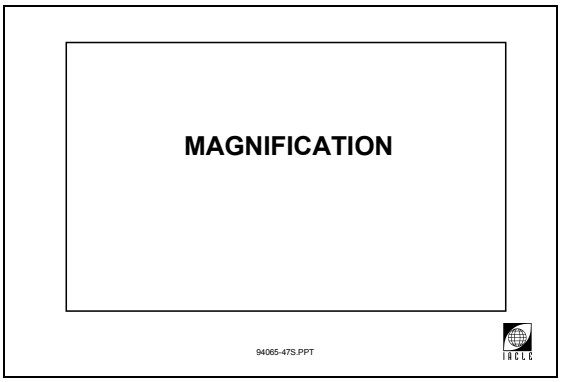
Oblique Illumination

- Oblique illumination is achieved with the penlight held at the temporal canthus so as to avoid shining the light directly in the patient's eye.
- In the absence of a slit-lamp, this method is also used to check the anterior chamber angle.

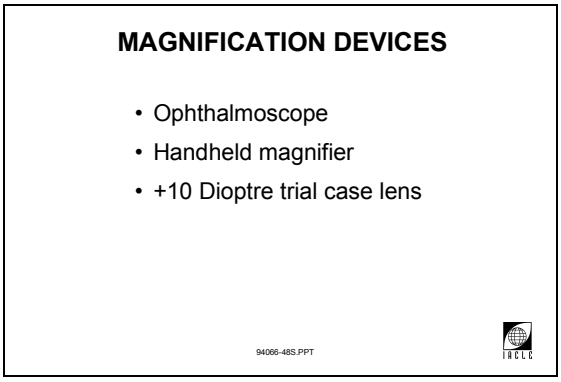
78



1L394066-47

Magnification (*title slide*)

79



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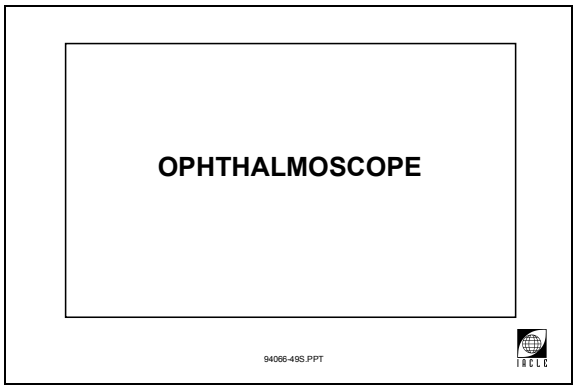
Magnification Devices

- Ophthalmoscope.
- Hand-held magnifying glass.
- +10 D trial case lens.

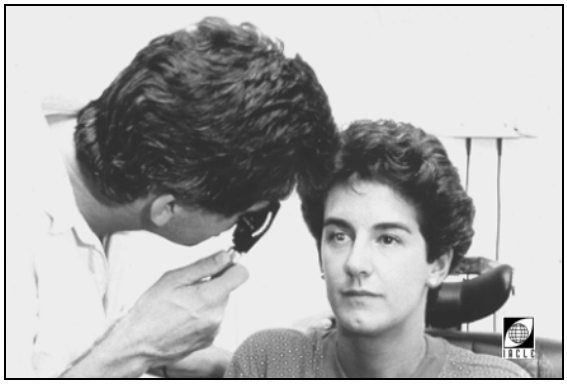
80



1L394066-49

Ophthalmoscope (*title slide*)

81



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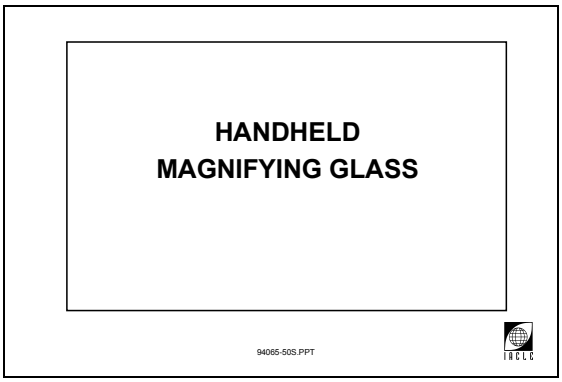
Ophthalmoscopy for External Examination

Observation of the blood vessels and lids can be performed by starting with a high plus power and adjusting the observation distance until a clear view is obtained.

82



1L394066-50

Handheld Magnifying Glass
(*title slide*)

83

1L31369-91

Hand-held Magnifying Glass

Observations with handheld magnifiers can be aided by an overhead light or penlight.

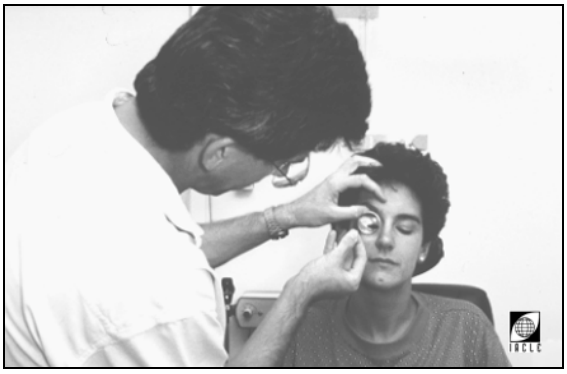
Hand-held magnifiers allow a wide field of view for observation.

84

1L394066-51

+10 Dioptre Trial Case Lens
(*title slide*)

85



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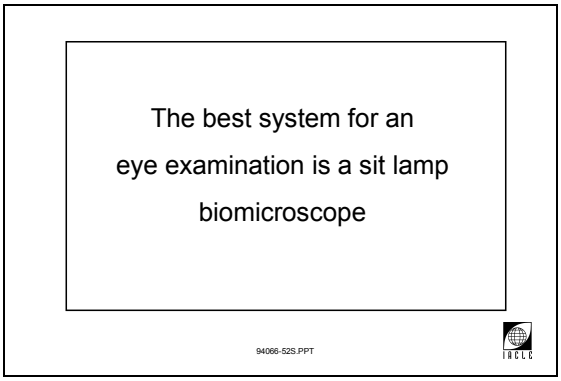
+10 Dioptre Trial Case Lens

Observation area may be limited. It can be aided by an overhead light or penlight.

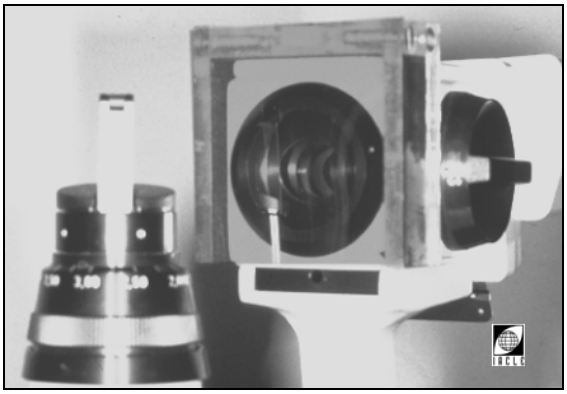
86



1L394066-52

The best system for an eye examination is a slit-lamp biomicroscope (*title slide*)

87



1L30135-92

Slit-lamp Biomicroscope

- This table-top instrument is made up of two coordinated systems:
  - observation system
  - illumination system.
- The system allows for varying degrees of magnification and light beam widths, respectively, for different observation perspectives of the eye.
- Accessories such as filters and graticules enhance observations.

`Practical 1.3

(2 Hours)

Measurement and Assessment of Ocular Parameters

Schedule of Practical Sessions

Preliminary

Video Presentation: Techniques for the Basic Ocular Examination

Demonstration: Upper lid eversion

Practical Session 1

Instructions: The class is divided into four groups. After assigning a different student as a 'patient' for each station, each group should spend ten minutes at each station.

Practical Session 2

Instructions: Students will work in pairs and examine each other on the different features listed. Findings will be recorded on the form provided.

Findings should be recorded for:

1. Eyelid skin appearance
2. Eye position in primary gaze
3. Lid margin appearance
4. Eyelash hygiene and direction of growth
5. Bulbar conjunctival redness and appearance
6. Palpebral conjunctival redness and roughness (lid eversion)
7. Corneal condition (light reflection)
8. Blink frequency and completeness
9. Iris colour and pigmentation

Discussion and Summary of Practical Sessions

Practical Session 1

Station 1: Naked Eye Examination

Aim: To observe the vascular architecture of the conjunctiva and sclera, corneal transparency and lid appearance without the aid of any instrument.

1. Observe the following structures in one eye:
    - scleral and conjunctival blood vessels
    - cornea
    - upper and lower lids.
2. In the box on the next page, draw to scale what you see.

Station 2: Hand-Held Magnifier

Aim: To observe the vascular architecture of the conjunctiva and sclera, corneal transparency and lid appearance with the aid of a hand-held magnifier.

1. Observe the following structures in one eye:
    - scleral and conjunctival blood vessels
    - cornea
    - upper and lower lids.
2. In the box on the next page, draw to scale what you see.

Station 3: Hand-Held Magnifier and Penlight

Aim: To observe the vascular architecture of the conjunctiva and sclera, corneal transparency and lid appearance with the aid of a handheld magnifier and penlight using temporal/oblique illumination.

1. Observe the following structures in one eye:
    - scleral and conjunctival blood vessels
    - cornea
    - upper and lower lids.
2. In the box on the next page, draw to scale what you see.

Station 4: Burton Lamp

Aim: To observe the vascular architecture of the conjunctiva and sclera, corneal transparency and lid appearance with the aid of a Burton lamp.

1. Observe the following structures in one eye:
    - scleral and conjunctival blood vessels
    - cornea
    - upper and lower lids.
2. In the box on the next page, draw to scale what you see.

Schematic Record of Findings

STATION 1: NAKED EYE EXAMINATION	STATION 2: HANDHELD MAGNIFIER
STATION 3: MAGNIFIER & PENLIGHT	**STATION 4: BURTON LAMP**

Which of the four methods performed provided the most detailed information? Differentiate the findings derived from the four methods.

Practical Session 2

RECORD FORM

Name:_____ Date:_____

Partner:_____ Group:_____

RIGHT	LEFT
Eyelid Skin Appearance: (describe)	
Lid Position in Primary Gaze: (illustrate)	
Lid Margin Appearance: (describe)	
Upper lid margin_____ Lower lid margin_____	Upper lid margin_____ Lower lid margin_____
Eyelash Hygiene and Direction of Growth: (illustrate)	
Bulbar Conjunctival Redness and Appearance: (describe and illustrate)	
Palpebral Conjunctival Redness and Roughness: (lid eversion)	

RIGHT	LEFT
Upper lid Lower lid	Upper lid Lower lid
Corneal Condition:	
Blink Frequency and Completeness:	
Number of blinks per minute_____ Partial ☐ Full ☐	Number of blinks per minute_____ Partial ☐ Full ☐
Iris Colour and Pigmentation:	
Pupil Reflexes	
Direct Consensual Near Pupils Regular Y/N Pupil Size	Direct Consensual Near Pupils Regular Y/N Pupil Size
Anterior Chamber (flare, cells, etc.)	
Angle (Van Herrick)	Angle (Van Herrick)
Crystalline Lens (pigments, deposits, opacities)	

References

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

Smolin G, Thoft RA (Eds.) (1987). *The Cornea: Scientific Foundations and Clinical Practice*, 2nd ed. Little, Brown & Company, Boston.

Vaughan D, Ashbury T, Tabbara KF (1989). *General Ophthalmology*. 12th ed. Appleton & Lange, Norwalk.

Unit 1.4

(9 Hours)

Lecture 1.4: Slit-Lamp Biomicroscopy

Practical 1.4.1: Illumination Techniques

Practical 1.4.2: Examining the Eye

Tutorial 1.4: Review of Slit-Lamp Illumination Techniques

Course Overview

Lecture 1.4: Slit-Lamp Biomicroscopy

I. Features
II. Illumination Techniques and Structures Observed
III. Routine Examination of the Eye Using the Slit-lamp

Practical 1.4.1: Slit-Lamp Biomicroscopy: Illumination Techniques

- Video: An Introduction to Slit-Lamp Biomicroscopy.
- Slit-Lamp Familiarization.
- Examination of a Spectacle Lens.

Practical 1.4.2: Slit-Lamp Biomicroscopy: Examining the Eye

- Video: Introduction to Biomicroscopy (Part II: Examining the External Eye).
- Examining the Eye with a Slit-Lamp.
- Demonstration of Additional Techniques.
- Performing Additional Techniques.

Tutorial 1.4: Review of Slit-Lamp Illumination Techniques

- Slide Series Presentation.

Suggested Evaluation Techniques

- Assess student performance during slit-lamp biomicroscopy.
- Quiz.
- Oral examination.

Lecture 1.4

(2 Hours)

Slit-Lamp Biomicroscopy

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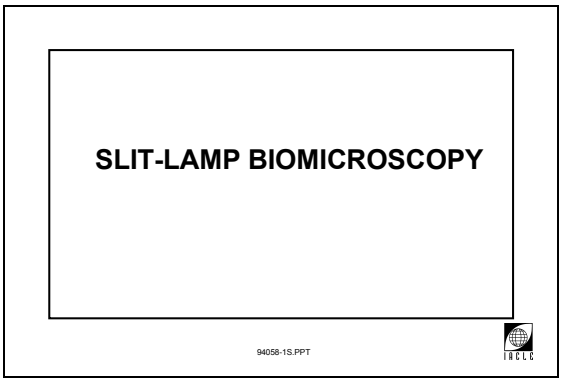
Slit-Lamp Biomicroscopy Procedures

I. The Slit-Lamp

1



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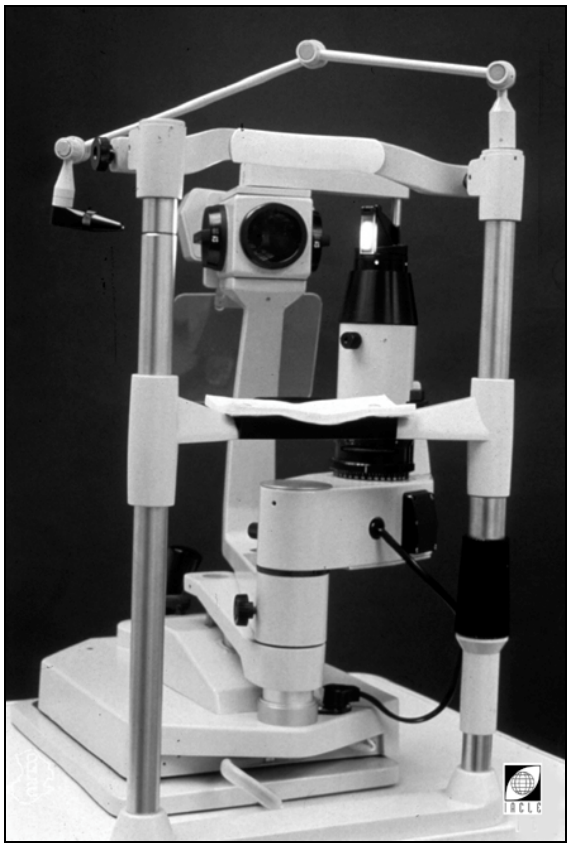
Slit-Lamp Biomicroscopy
(*title slide*)

2



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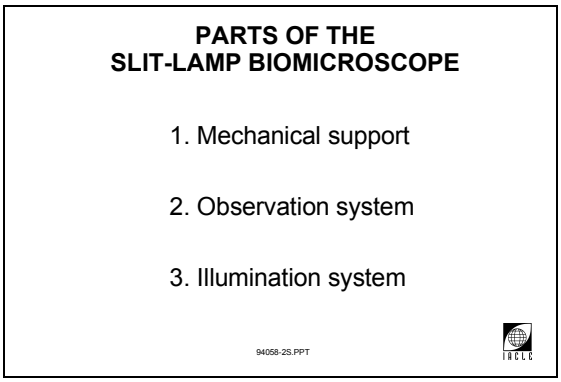
Slit-Lamp Biomicroscope

- The term ‘slit-lamp’ was coined because of the slit beam emitted by the illumination system.
- The slit-lamp is sometimes called the biomicroscope. The instrument combines variable magnification with controlled illumination.

3



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Parts of the Slit-Lamp Biomicroscope

The slit-lamp biomicroscope is composed of the following parts:

- Mechanical support
  - forehead rest
  - chin rest
  - fixation target
  - power supply unit
  - locking controls.
- Observation system
  - binocular eyepieces
  - camera/video adaptor
  - observation tube (demonstration slit-lamps)
  - magnification changer.
- Illumination system
  - lamp housing unit
  - slit width and height control
  - neutral density filter
  - cobalt blue light
  - red-free (green) filter
  - field size control
  - diffuser
  - prism.

4

1L41241-92

Examining a patient using the Slit-Lamp Biomicroscope

5

BIOMICROSCOPE OBSERVATION SYSTEM

FEATURES

- Variable magnification
- Binocular system

94058-3S.PPT

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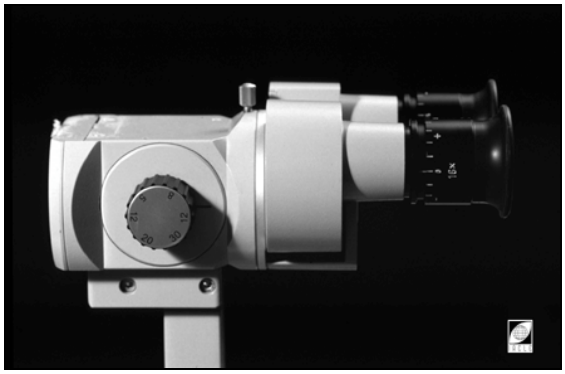
6



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Slit-Lamp Biomicroscopy

Observation System: Features

- Variable magnification (stepped or continuously variable)
  - low
  - medium
  - high.
- Binocular system
  - convergent optical axes (Greenough type); or
  - parallel optical axes.

II. Magnification Ranges

7

SLIT-LAMP BIOMICROSCOPY

Low	7X - 10X	General eye
Medium	20X - 25X	Structure layers
High	30X - 40X	Detail

94058-4S.PPT

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Slit-Lamp Biomicroscopy

- Low magnification:
  7X - 10X : general eye.
- Medium magnification:
  20X - 25X : structure of individual layers.
- High magnification:
  30X - 40X : details.

8

SLIT-LAMP BIOMICROSCOPY
LOW MAGNIFICATION (7x - 10x)

General eye:

- Lids
- Bulbar conjunctiva/sclera
- Cornea/limbus
- Tears
- Anterior chamber/iris/crystalline lens

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Slit-Lamp Biomicroscopy

Low Magnification (7x - 10x): General Eye

- Lids.
- Bulbar conjunctiva/sclera.
- Cornea/limbus.
- Tears.
- Anterior chamber/iris/crystalline lens.

9

1L41700-94

Conjunctival Redness

Limbal and conjunctival redness as a result of 3 and 9 o'clock staining.

10

SLIT-LAMP BIOMICROSCOPY
MEDIUM MAGNIFICATION (20x - 25x)

Structures:

- epithelium
- stroma
- endothelium
- lens fit/surface

94058-6S.PPT

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Slit-Lamp Biomicroscopy

Medium Magnification: 20X - 25X: Structures

- Epithelium/epithelial breakdown.
- Stroma.
- Endothelium.
- Contact lens fit/lens condition.

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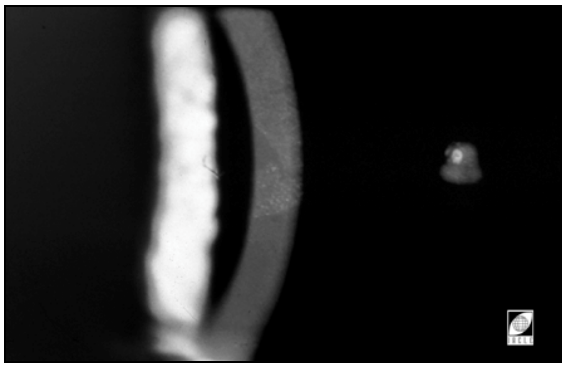

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Medium Magnification: Parallelepiped of Vogt

Corneal debridement viewed using moderate magnification and both direct illumination and retro-illumination (brighter band).

12

SLIT-LAMP BIOMICROSCOPY
HIGH MAGNIFICATION (30x - 40x)

Details:

- epithelial changes
- stromal striae, folds
- endothelial folds, polymegethism

94058-7S.PPT

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Sit-Lamp Biomicroscopy

High Magnification: 30X - 40X: Details

- Epithelium
  - vacuoles
  - microcysts
  - dystrophies.
- Stroma
  - striae
  - folds.
- Endothelium
  - polymegethism
  - guttata
  - blebs
  - cell density.

13

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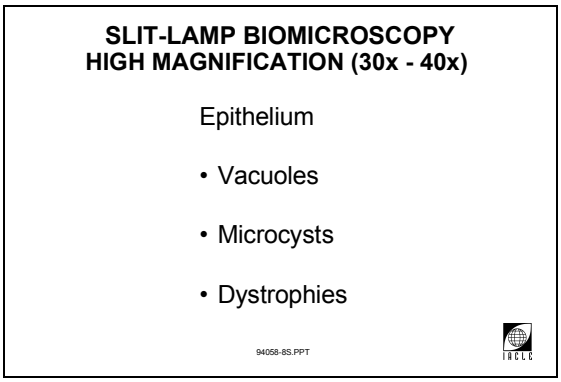
Endothelial Guttata

High magnification view of endothelial guttata using specular reflection. Guttata should not be confused with endothelial blebs. See slide 66.

14



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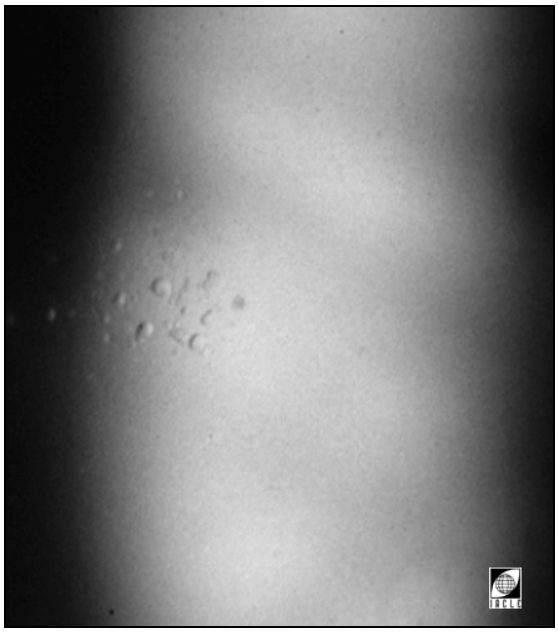

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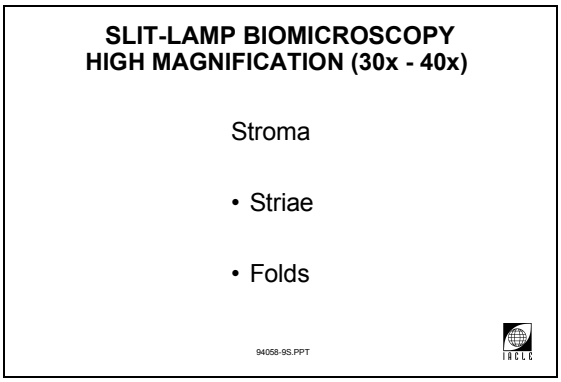
Slit-lamp Biomicroscopy

High Magnification 30x - 40x: Details

Epithelium

- Vacuoles
  - Round in shape, with distinct edges and displaying unreversed illumination. Larger and more discrete than microcysts, vary in size from 20-50 µm.
- Microcysts
  - Thought to be a collection of dead cells and metabolic by-products. They show reversed illumination, which suggests they have a higher refractive index than the surrounding tissue (see slide 15).
- Dystrophies
  - Dystrophies may involve all levels of the cornea. If the barrier functions of the epithelium or endothelium, or the latter's pump function are affected, corneal oedema may result. This may make a slit-lamp examination more difficult.

16



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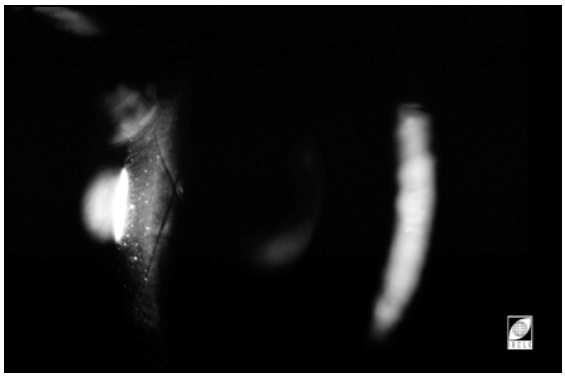
Slit-Lamp Biomicroscopy

High Magnification 30X - 40X: Details

Stroma

- Striae
  - Fine vertical lines, which do not tend to branch. Found in the posterior stroma and occur with corneal swelling of 5% or more.
  - Found in the posterior stroma with the number depending on the degree of oedema.
  - Vogt's striae are commonly observed in moderate to advanced stages of keratoconus (see slide 17).
- Folds
  - Intersecting lines observed in direct illumination which can also be seen against the endothelial mosaic. It is believed they are the optical manifestation of buckling of the posterior (deep) stroma. Folds become

17



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apparent in hypoxia producing corneal swelling of 8% or more. They appear as intersecting dark lines when viewed against the endothelial mosaic.

18

SLIT-LAMP BIOMICROSCOPY
HIGH MAGNIFICATION (30x - 40x)

Endothelium

- Polymegethism
- Guttata
- Blebs
- Dystrophies
- Cell Density

94058-10S.PPT

1L494058-10

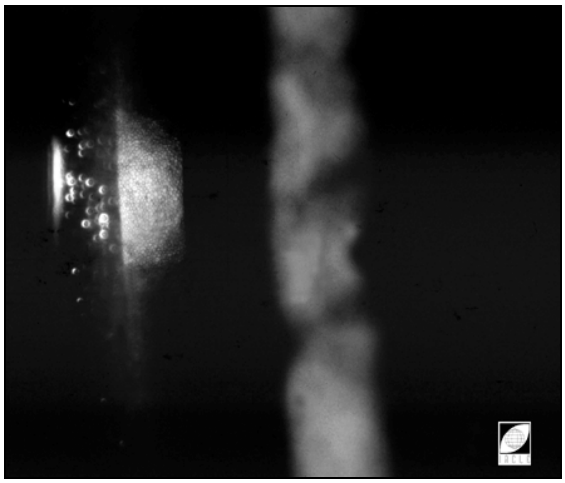
Slit-Lamp Biomicroscopy

High Magnification 30x - 40x: Details

Endothelium

- Polymegethism
  - Variation in endothelial cell size (see slide 19).
- Guttata
  - Thickening of Descemet's membrane. On specular reflection, endothelial guttata are seen as dark spots.
- Blebs
  - Oedema of endothelial cells. Very small black spots in the endothelium seen using specular reflection.
- Dystrophies
  - as in epithelial dystrophies, malfunction of the endothelial pump compromises its integrity.
- Cell density
  - With experience, gross changes in endothelial cell density can be observed with the slit-lamp. Such changes are better observed with the aid of a specular microscope and a cell-density measuring graticule or a photograph from a specular microscope and a cell-density measuring overlay. To quantitify changes induced by contact lens wear, sophisticated image analysis techniques may have to be used.

19



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III. Illumination System

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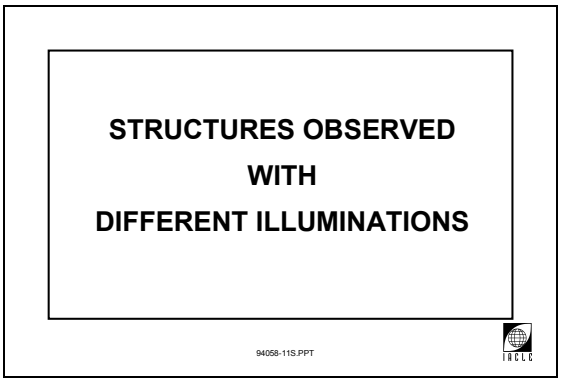

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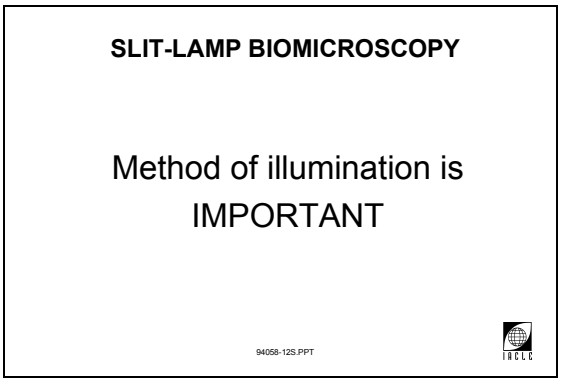
Structures Observed With Different Illuminations (*title slide*)

21



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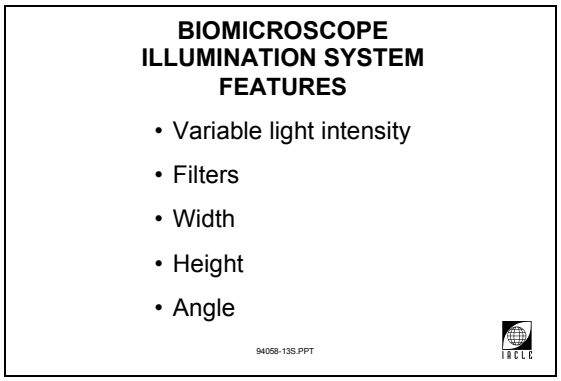
Slit-Lamp Biomicroscopy

The method of illumination is important, as different perspectives seen with varying illumination techniques give the examiner additional information.

22



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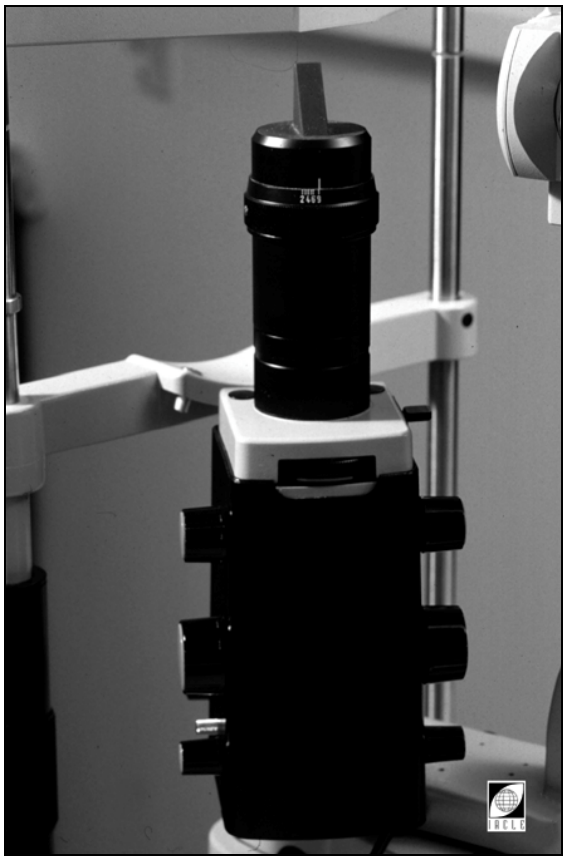
Slit-lamp Biomicroscopy

Illumination System: Features

The following illumination features may vary depending on the type and brand of slit-lamp biomicroscope:

- Variable light intensity
  - low
  - medium
  - high.
- Filters
  - cobalt blue light
  - red-free (green)
  - neutral density filter.
- Width
  - optic section
  - parallelepiped of Vogt
    narrow beam
    broad beam
  - conical beam.
- Height
  - adjustable slit height.

23



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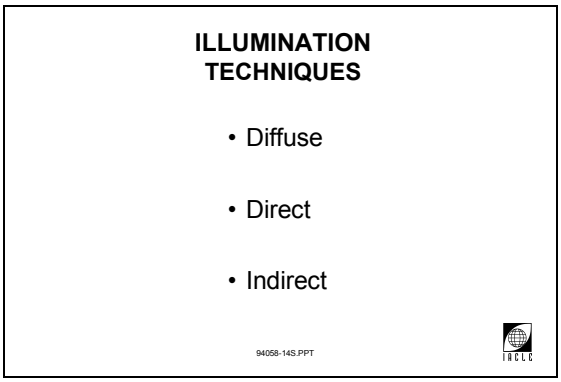
- Angle
  - variable angle formed with the observation system
  - rotation of the prism or mirror enables observation with an alternate illumination technique (especially an indirect method).

IV. Illumination Techniques

24



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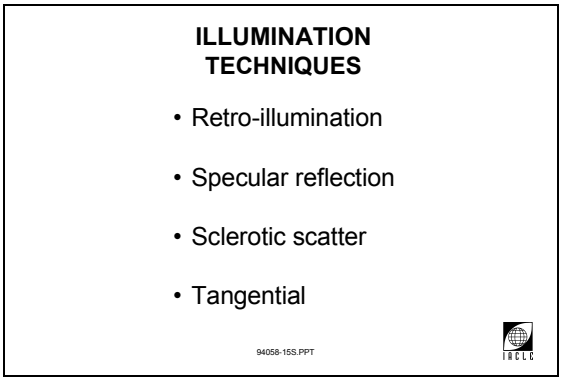

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Illumination Techniques

- Diffuse.
- Direct.
- Indirect.
- Retro-illumination.
- Specular reflection.
- Sclerotic scatter.
- Tangential.

IV.A Diffuse Illumination

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DIFFUSE ILLUMINATION

- 45 degree angle between light and microscope
- Fully open slit
- Diffusing filter
- Variable magnification (low to high)

94058-16S.PPT

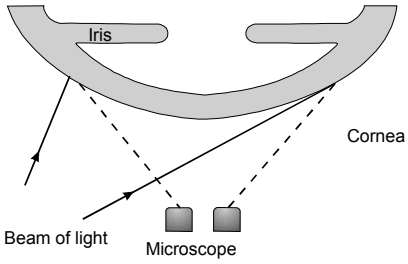
1L494058-16

Diffuse illumination

- Approximately 45 degree angle between light and microscope (observation system).
- The slit-width control is used to open the slit fully.
- The optional use of a diffusing filter reduces glare, widens the field of illumination and distributes the light uniformly.
- Variable magnification (low to high) may be used. Only low magnification can take advantage of the broad field of illumination since a wide field of view and high magnification are mutually exclusive.

27

BROAD BEAM



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28

DIFFUSE ILLUMINATION

Overall view of:

- lids and lashes
- conjunctiva
- cornea
- sclera
- iris
- pupil

94058-18S.PPT

1L494058-18

Diffuse illumination

Overall view of:

- Lids and lashes.
- Conjunctiva.
- Cornea.
- Sclera.
- Iris.
- Pupil.

29

1L40788-91

General View of the Eye

IV.B Direct Illumination

30

DIRECT ILLUMINATION

Observation and illumination systems focused at the same point

94058-19S.PPT

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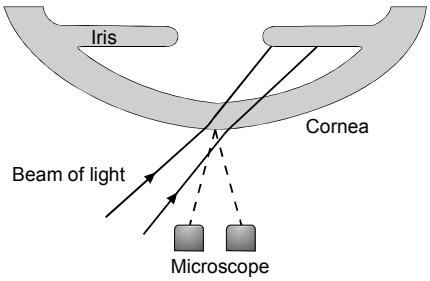
Direct Illumination

Observation and illumination systems are focused at the same point.

31

DIRECT ILLUMINATION



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32

DIRECT ILLUMINATION

- Vary angle of illumination
- Low to high magnification
- Vary width and height of light source

94058-21S.PPT

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Direct Illumination

- Variations in the angle of illumination are made, provided they share the same focus as the observation system.
- Low to high magnification can be used to observe the cornea.
- Variation in the width and/or height of the light source will give the following:
  - optic section
  - parallelepiped
  - conical beam.

33

DIRECT ILLUMINATION

- Optic Section
  - narrow, focused light
- Parallelepiped
  - wider, focused light
- Conical Beam
  - small, circular light

94058-22S.PPT

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Direct Illumination

- Optic Section: narrow, focused slit
  - observe variation in corneal curvature, corneal thickness and depth of visible features within the cornea.
- Parallelepiped: wider beam
  - observe corneal stroma, epithelial breakdown, lens surface and endothelium.
- Conical Beam: small, bright, circular light source. Use with high magnification
  - used for observation of flare and cells in the anterior chamber.

IV.B.1 Optic Section

34

DIRECT ILLUMINATION
OPTIC SECTION

- Indicates depth
- Localise: - nerve fibres
  - blood vessels
  - infiltrates
  - cataracts
- Anterior chamber angle

94058-23S.PPT

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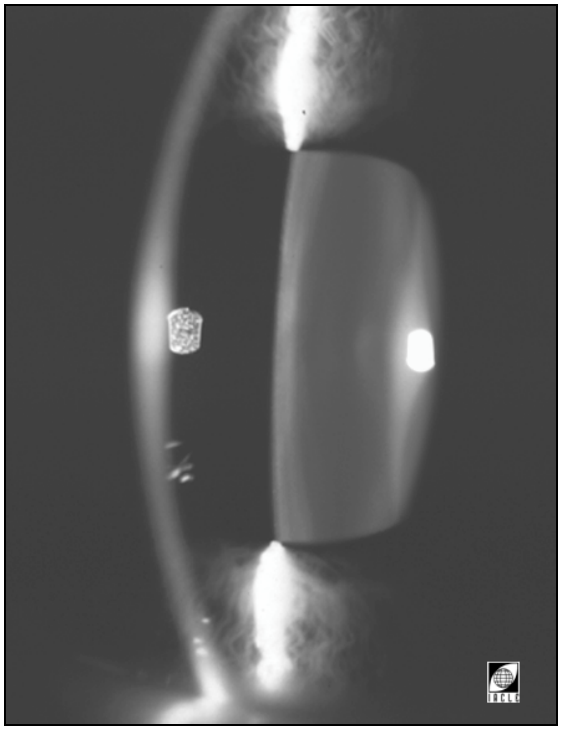
Direct Illumination

Optic Section:

- The optic section highlights the different layers of the cornea so that the depth of any corneal lesions can be determined.
- The optic section allows detailed assessment of the layers and localizes structures within, including:
  - nerve fibres
  - blood vessels
  - infiltrates
  - cataract.
- The angle of the anterior chamber is determined by the van Herick technique. An angle of 60º is set between illumination and observation systems. .A very narrow slit is directed towards the limbus at 3 or 9 o'clock, *normal (90º) to the surface* at the limbus. In thin optic section, the anterior chamber depth is compared with the corneal thickness. Chamber depths less than or equal to a quarter of the corneal thickness are of concern.

35



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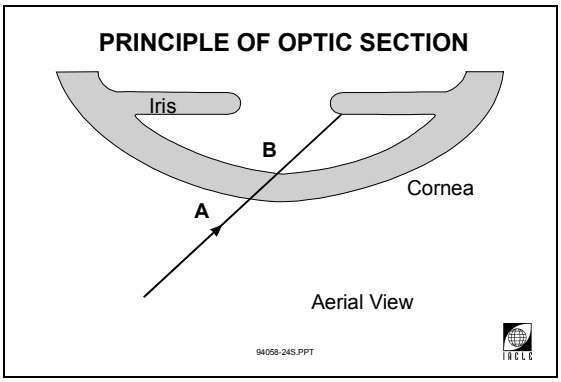
Optic Section of the Cornea and Crystalline Lens

36



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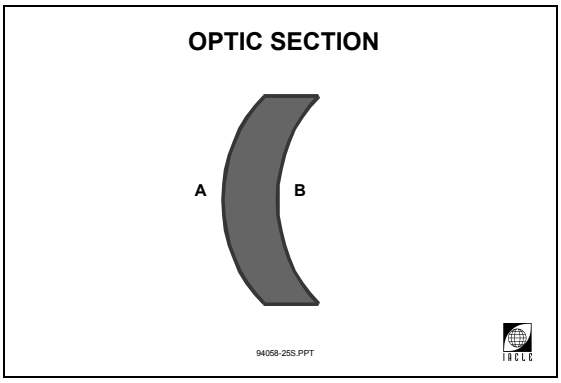
Principle of the Optic Section

37



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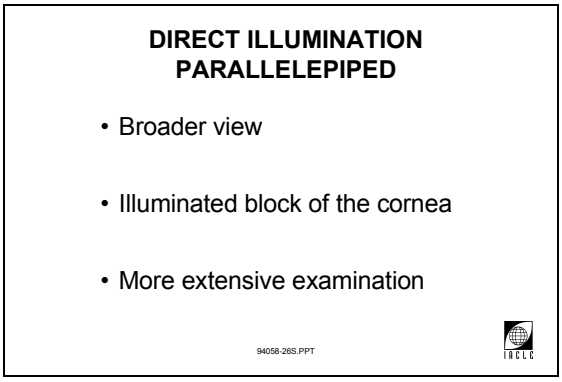
Thickness of the Optic Section

AB is the apparent thickness of the cornea in optic section. It is ***not*** the true corneal thickness because of the obliquity of the slit beam. The true corneal thickness is found by calculation based on the obliquity, the curvature and the refractive index of the cornea. It cannot be found by dividing the apparent thickness by *Cos* θ where θ is the angle between the slit and the normal to the surface at A or B.

I.V.B.2 Parallelepiped

38



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Direct Illumination

Parallelepiped:

- Allows a wider field of view for observation.
- A three-dimensional block of the cornea can be observed.
- Allows a more extensive examination of the corneal layers.

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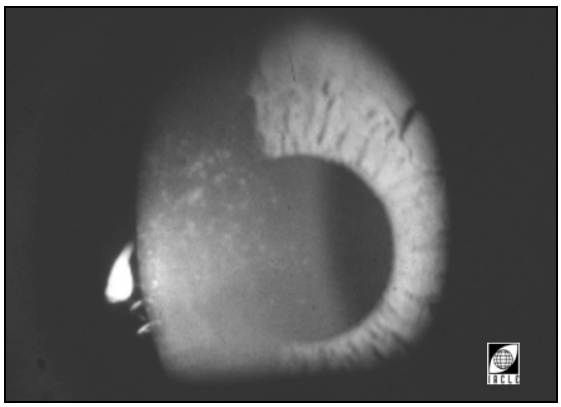

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Punctate Keratitis

Punctate keratitis seen with a parallelepiped using medium magnification.

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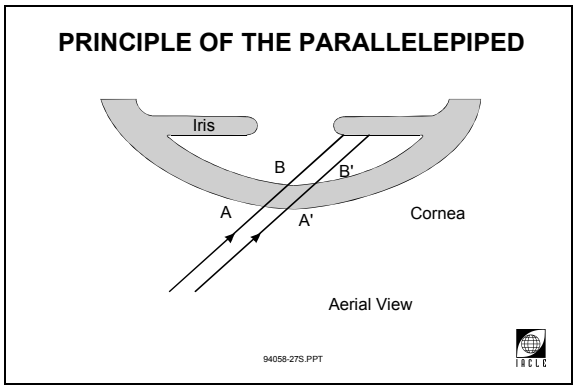
Corneal Nerve Fibres

Nerve fibres in the corneal stroma observed with a narrow parallelepiped and high magnification.

41

Principle of the Parallelepiped



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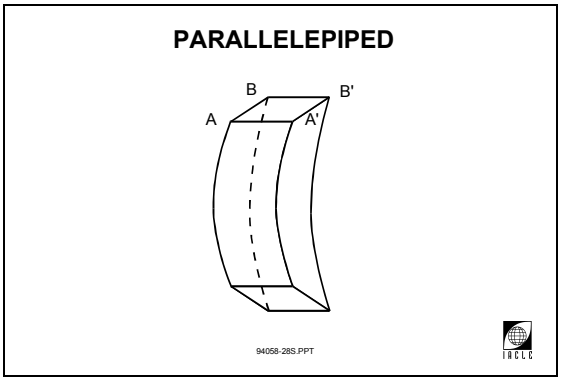
Thickness of the Parallelepiped

As stated in slide 37, AB or A´B´ are only apparent corneal thicknesses in optic section and ***not*** the true corneal thicknesses.



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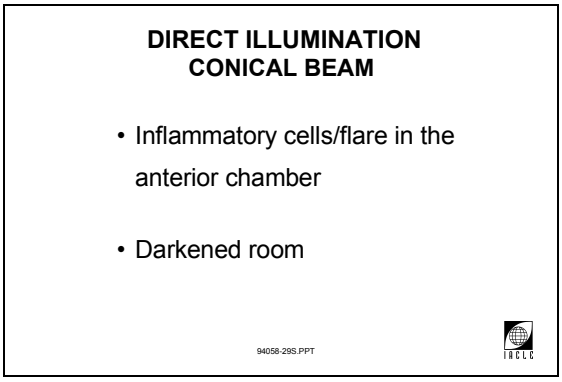
IV.B.3 Conical Beam

43



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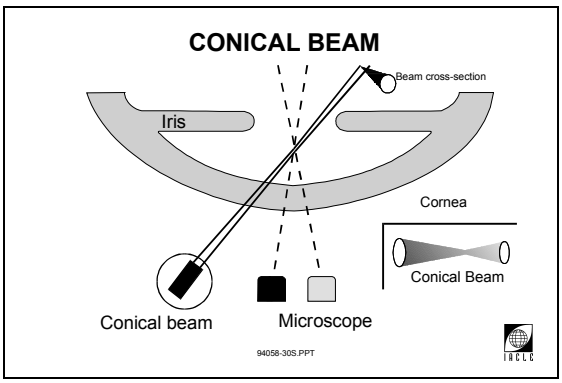
Direct Illumination - Conical Beam

- Used to view the anterior chamber for flare, pigmentation or cell debris.
- Best used in a completely darkened room.

44



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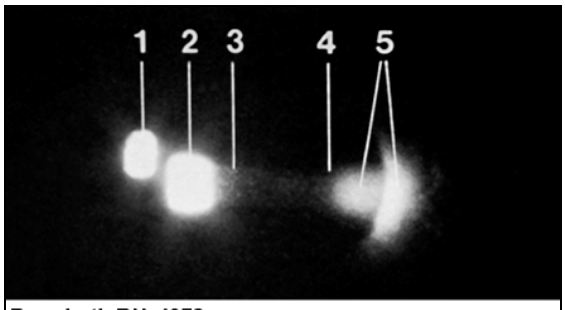

Brandreth RH, 1978
Clinical Slit-Lamp Biomicroscopy
Fig. 3-16
Published by Roy H Brandreth

1L40958-96

Aqueous Flare

Aqueous flare seen with direct illumination, using a conical beam and high magnification.

Key to illustration:

- 1: Specular reflection of flash.
- 2: Conical beam traversing the cornea.
- 3 & 4: Conical beam revealing some aqueous flare.
- 5 left: Conical beam striking the anterior crystalline lens.
- 5 right: Conical beam striking the iris at the pupil margin.

IV.C Indirect Illumination

46

INDIRECT ILLUMINATION

Observation and illumination systems
are not focused at the same point

94058-31S.PPT

1L494058-31

Indirect Illumination

- Observation and illumination systems *are not* focused at the same point.
- Focal light beam is directed adjacent to the area of observation.

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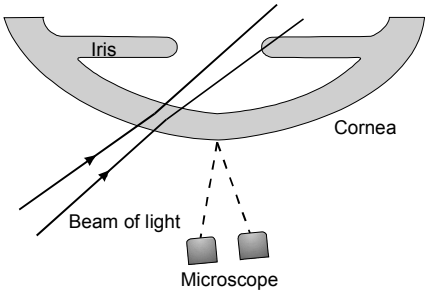
INDIRECT ILLUMINATION



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48

INDIRECT ILLUMINATION

- Vary angle of illumination
- Slit beam is offset
- Vary beam width
- Low to high magnification

94058-33S.PPT

1L494058-33

Indirect Illumination

- Varying the angle of illumination relative to the observation system is achieved by rotating the illumination system only.
- The slit beam is offset by rotating the prism or mirror at the ‘head’ of the illumination system.
- Variation in the width of the slit beam can be made with the slit width control.
- Low to high magnifications allow general to detailed observations.

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INDIRECT ILLUMINATION

Valuable for observing:

- epithelial vesicles
- epithelial erosions
- iris pathology
- iris sphincter

94058-34S.PPT

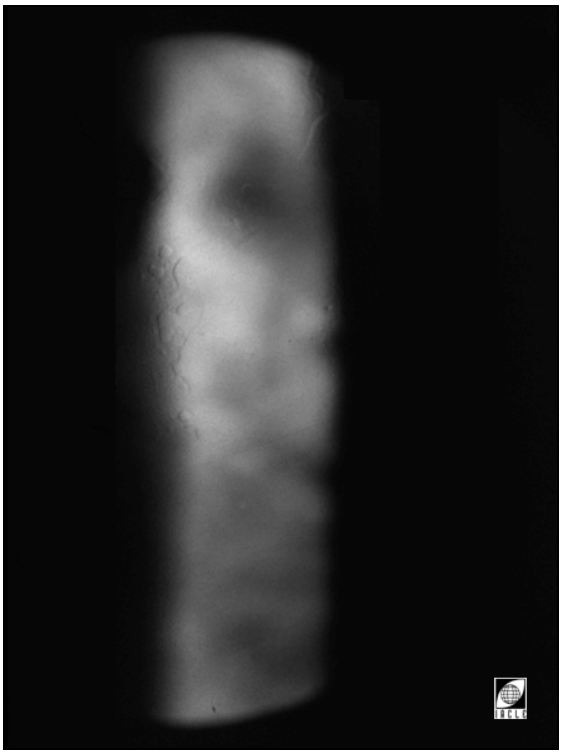
1L494058-34

Indirect Illumination

Valuable for observing:

- Iris pathology.
- Epithelial vesicles.
- Epithelial erosions.
- Iris sphincter.

50

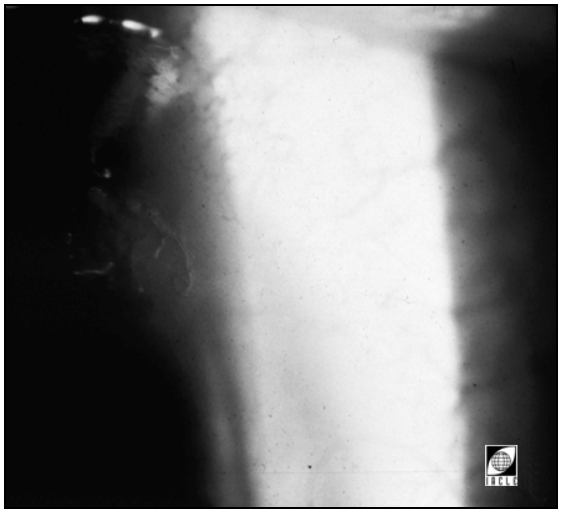


1L41798-92

Epithelial Dystrophy

Epithelial vesicles observed with indirect illumination and high magnification.

51



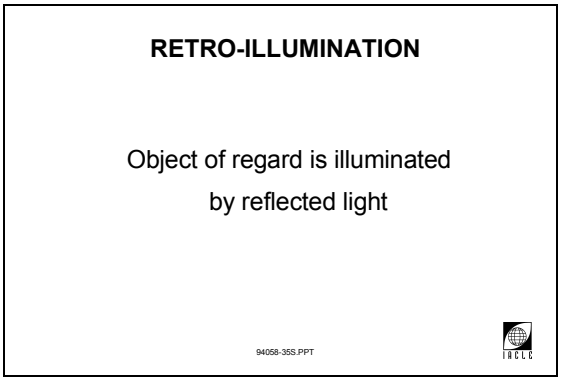
521L40666-92

Epithelial Erosion

Peripheral corneal erosion observed with indirect illumination and high magnification.

IV.D Retro Illumination

52

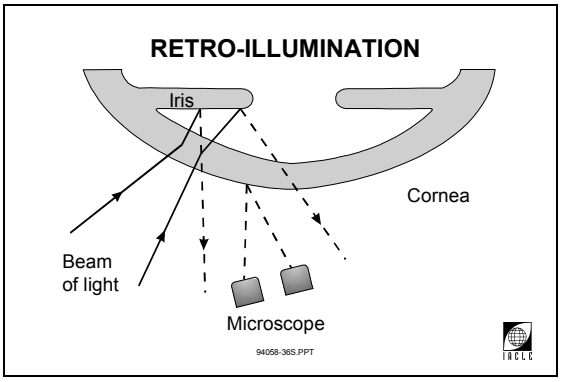


1L494058-35

Retro-illumination

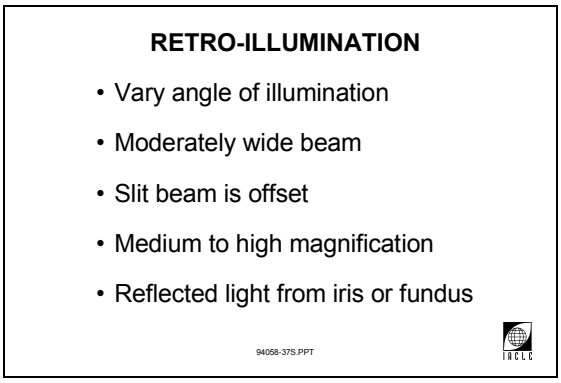
Object of interest is illuminated by light reflected from the structures behind it.

53



1L494058-36

54

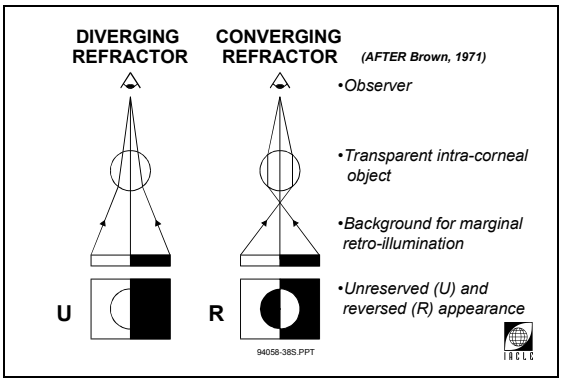


1L494058-37

Retro-illumination

- Varying the angle of illumination relative to the observation system is achieved by rotating the body of the illumination system.
- Moderately wide beam is used.
- Slit beam is offset by rotation of the prism at the ‘head’ of the illumination system.
- Observation is made with medium to high magnification.
- The cornea is illuminated by light reflected from the iris, crystalline lens or fundus.

55



1L494058-38

Principle of Retro-Illumination with Diverging and Converging Refractors

56

RETRO-ILLUMINATION
Alignment of reflected beam with area under observation

TYPE	ALIGNMENT
Direct	Direct and full view
Indirect	Adjacent
Marginal	Margin or edge

94058-39S.PPT

1L494058-39

Retro-Illumination

There are three types of retro-illumination that are differentiated by the alignment of the reflected light beam with the area under observation:

- Direct
  - the prism or mirror is moved so that the light reflected from the iris or crystalline lens is directly aligned (and widened for a full view) with the area under observation.
- Indirect
  - the prism or mirror is offset so that the area under observation is viewed between the focal light beam and the light reflected from the iris or crystalline lens.
- Marginal
  - the prism or mirror is offset so that the light reflected from both the iris and crystalline lens at the pupil margin, is aligned with the area under observation.

57

RETRO-ILLUMINATION

Valuable for observing:
- vascularisation
- epithelial oedema
- microcysts
- vacuoles
- dystrophies
- crystalline lens opacities
- contact lens deposits

94058-40S.PPT

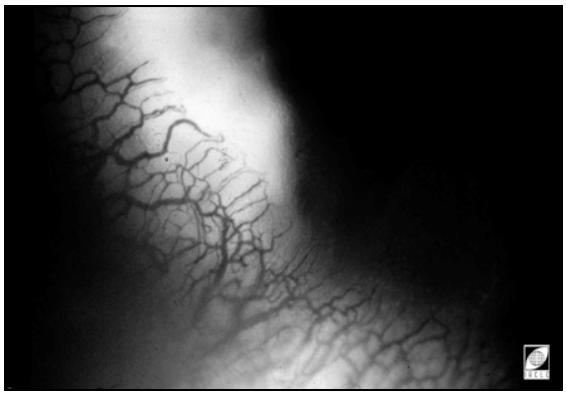
1L494058-40

Retro-illumination

Valuable for observing:

- Vascularization.
- Epithelial oedema.
- Microcysts.
- Vacuoles.
- Dystrophies.
- Crystalline lens opacities.
- Contact lens deposits.

58

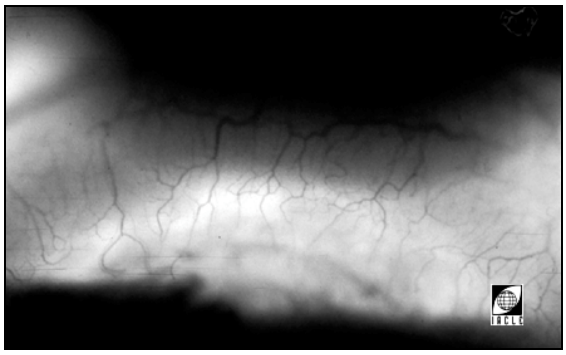


1L41238-92

Limbal Injection

Limbal vessel engorgement seen with retro-illumination and very high magnification. This may be a prelude to vascularization.

59

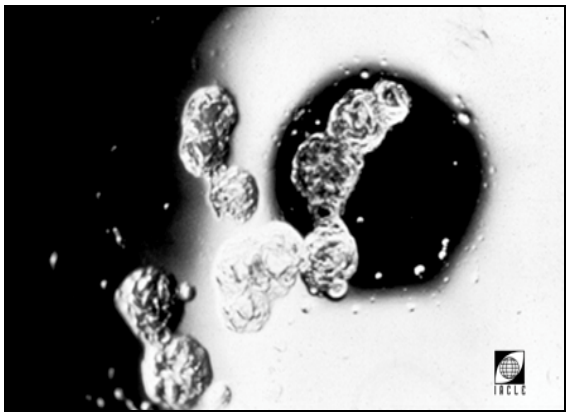


1L41331-93

Vascularization

- Vascular ingrowth into the cornea arising from a vaso-proliferative stimulus.
- Observe the looping and branching limbal vessels seen against the illuminated background of the clear cornea.

60



1L41576-93

Jelly Bumps

Gelatinous deposition on the lens surface, common with high water content lenses.

IV.E Specular Reflection

61

SPECULAR REFLECTION

Angle of incidence equals angle of reflection

94058-41S.PPT

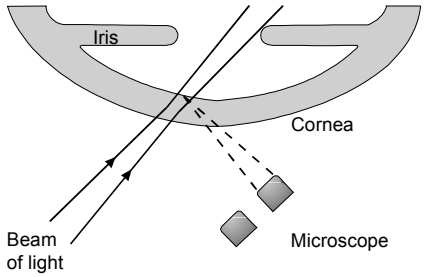
1L494058-41

Specular Reflection

- The angle of incident light is equal to the angle of reflected light.
- The conditions for specular reflection are such, that the physical and angular separation of the binocular microscope's light paths preclude the simultaneous observation of the specular reflex through both eyepieces. Specular reflection therefore is a *monocular* phenomenon. Should a specular reflex be seen through both eyepieces then two separate areas of the reflecting surface are involved.

62

SPECULAR REFLECTION



94058-42S.PPT

1L494058-42

63

SPECULAR REFLECTION

Valuable for observing:

- endothelial cell layer
- tear film debris
- tear film lipid layer thickness

94058-43S.PPT

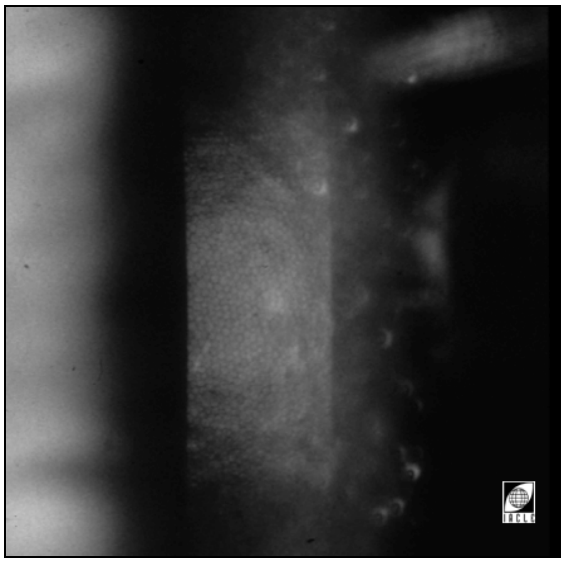
1L294058-43

Specular Reflection

Valuable for observing:

- Endothelial cells.
- Tear film debris.
- Tear film lipid layer.

64

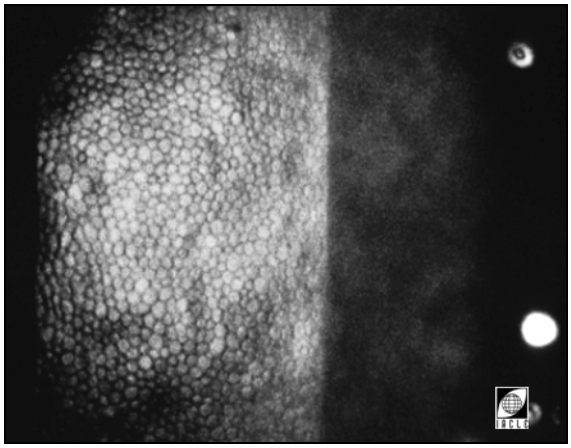


1L40115-93

Endothelium

Observation of the endothelium using specular reflection and 35x magnification. At this magnification, a judicious selection of the illumination angle makes it possible to locate the specular reflection from the tear film *outside* the microscope's field of view. In slide 64 the tear film specular reflection is to the right of the field of view.

65

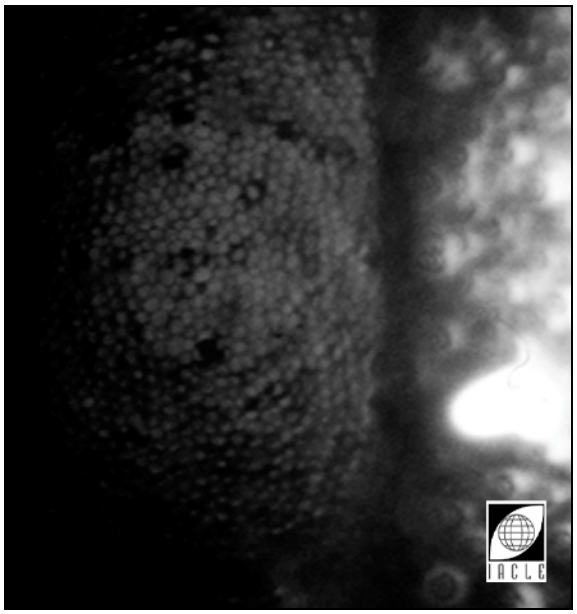


1L40943-91

Endothelial Mosaic

Observation is made with specular reflection and very high magnification.

66

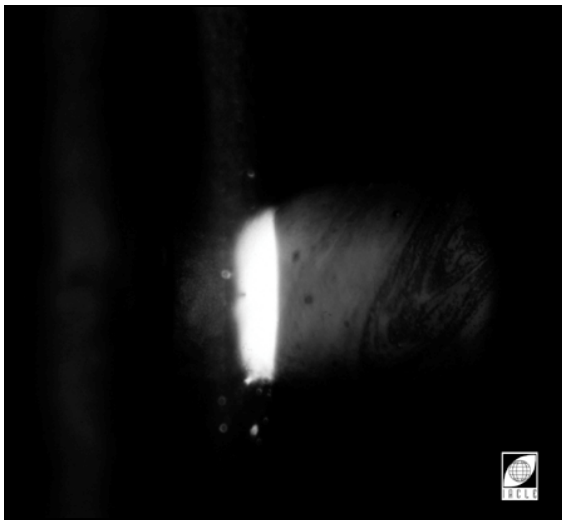


1L41565-96

Endothelial Blebs

- Cellular oedema manifests itself as dark pockets due to irregularities it induces in the endothelial cell layer of the cornea. This transient condition can be observed within minutes of lens insertion and the response peaks between 20 and 30 minutes depending on the severity of the stimulus and individual variation.
- Studies by Holden et al. (1985) and Bonnano and Polse (1987) suggest that pH change is a possible cause of the endothelial bleb response.
- Observed with specular reflection and high magnification.

67



1L40382-92

Tear Film Lipid Layer

Observed flow pattern of the coloured fringes of the lipid layer of the tear film.

IV.F Sclerotic Scatter

68

SCLEROTIC SCATTER

Valuable for observing:

- localised epithelial oedema (CCC)
- corneal scars
- foreign bodies in the cornea

94058-44S.PPT

1L494058-44

Sclerotic Scatter

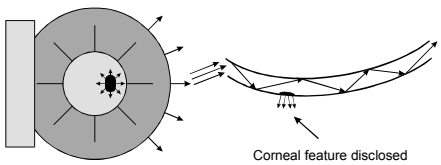
- Illumination of the cornea by total internal reflection of a wide angle light source.
- The light beam is directed at the limbal region while observing the cornea.

Valuable for observing:

- Localized epithelial oedema.
- Corneal scars.
- Foreign bodies in the cornea.

69

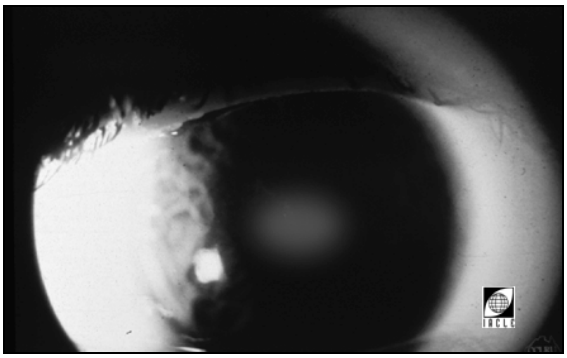
SCLEROTIC SCATTER



94058-45S.PPT

1L494058-45

70



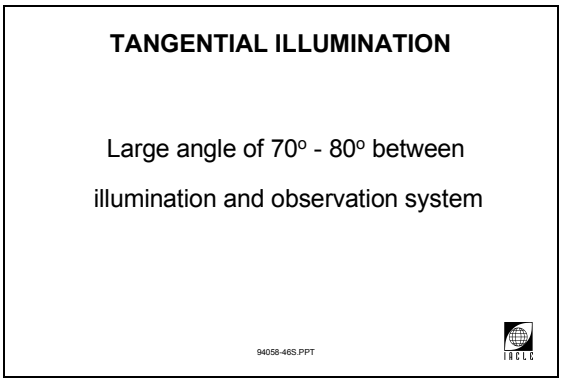
1L40019-94

Central Corneal Clouding

Central corneal clouding results from corneal oedema caused by hypoxia. This is most likely to be observed in a patient who has been wearing PMMA corneal lenses.

IV.G Tangential Illumination

71

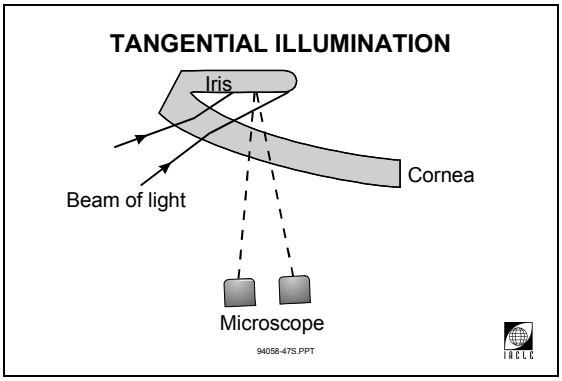


1L494058-46

Tangential Illumination

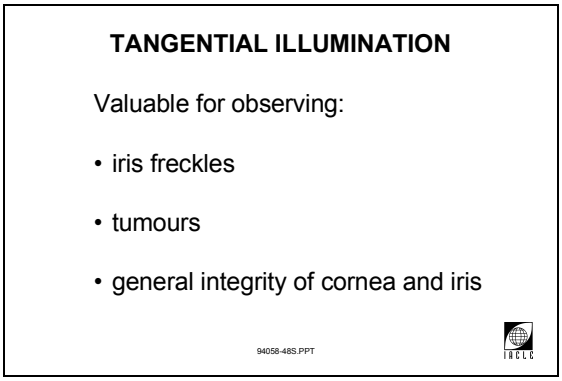
This technique allows examination of the iris appearance and condition by extreme oblique illumination with the observation system directly in front of the eye being examined. This creates a large angle (70 - 80 degrees) between the two systems.

72



1L494058-47

73



1L494058-48

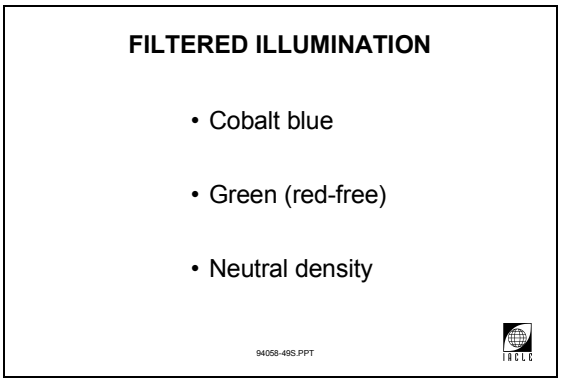
Tangential Illumination

Valuable for observing:

- Iris freckles.
- Tumours.
- General integrity of the cornea and iris.

V. Filters and Accessories

74

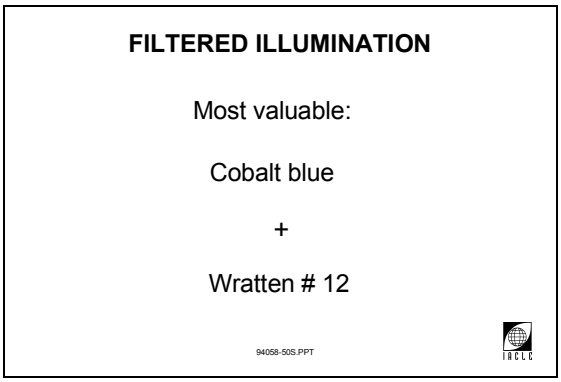


1L494058-49

Filtered Illumination

- Cobalt blue.
- Red-free (green).
- Neutral density.

75

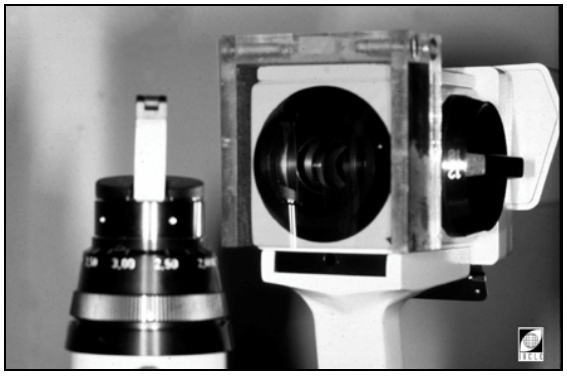


1L494058-50

Filtered Illumination

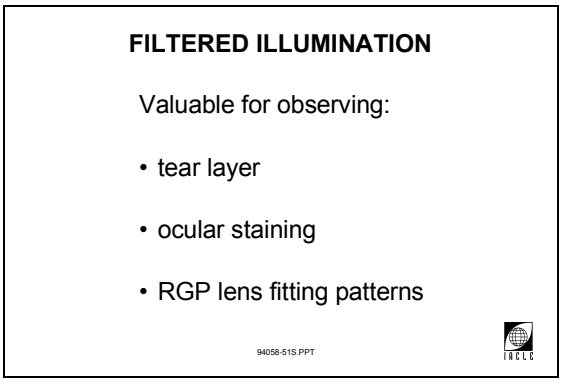
The most valuable filtered illumination technique has proved to be the use of cobalt blue (e.g. Wratten 47A) combined with a Wratten #12 (yellow barrier) filter. This enhances fluorescein observations of the cornea and contact lens fitting. A disadvantage of this filter technique is the high levels of illumination required because of the significant light losses in the filters and the relatively low level of ‘fluorescence’ being imaged.

76



1L40135-92

77



1L494058-51

Filtered Illumination

Valuable for observing:

- Tear film.
- Ocular staining.
- RGP lens fitting patterns.

78

1L41578-96

Corneal Erosion With White Light and With and Without a Wratten #12 Barrier Filter

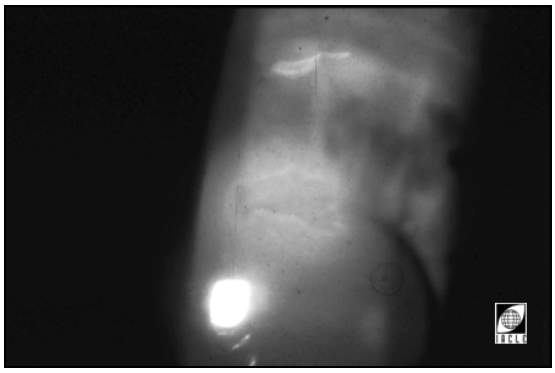
Corneal erosion seen under high magnification showing epithelial damage and stromal glow.

Slide 78 was taken with white light only.

Slide 79 was taken with a cobalt-blue 'exciter' filter in the illumination system but ***without*** a 'barrier' filter in place in the observation system.

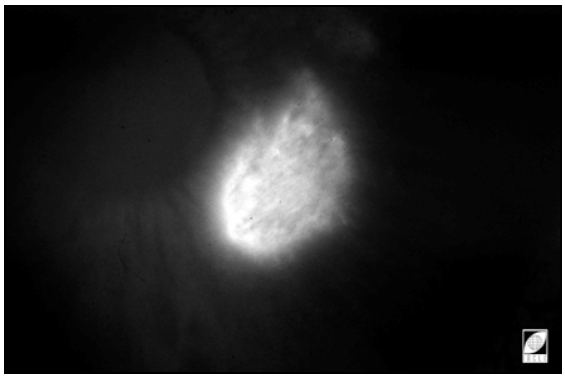
Slide 80 was taken ***with*** a barrier filter in place. The subject matter of slide 80 is unrelated to slides 78 and 79.

79



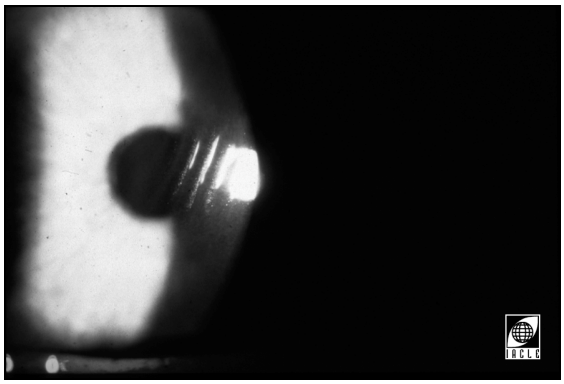
1L41577-96

80



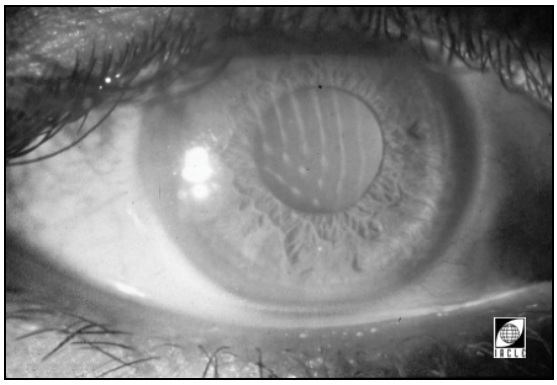
1L4719-95

81



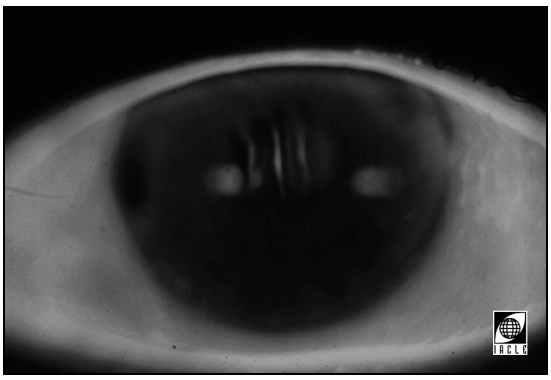
1L41576-96

82



1L4IC13

83



1L41575-96

Corneal Wrinkling With White Light and With and Without Wratten #12 Barrier Filter

- Epithelial wrinkling caused by mechanical trauma.
- Can be seen in high myopes wearing low water content soft contact lenses.
- Wratten #12 yellow filter enhances observation of staining and surface irregularities (see slide 83).

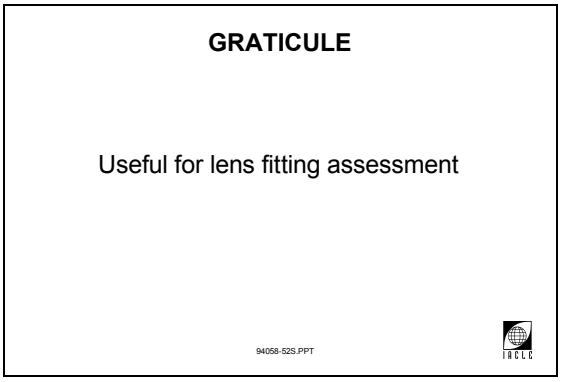
Slide 81 was taken in white light.

Slide 82 was taken with a cobalt-blue filter only.

Slide 83 was taken with both cobalt-blue and yellow barrier filters in place.

Different subjects appear in slides 81 to 83.

84

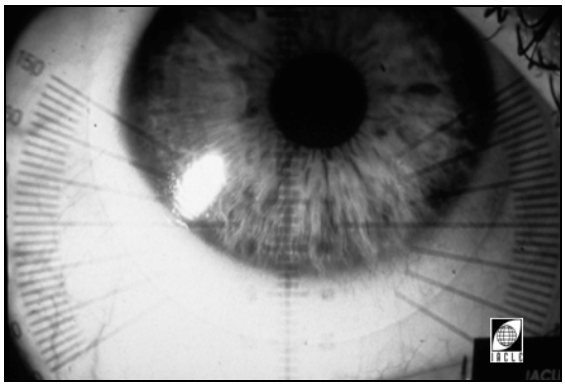


1L494058-52

Graticule

- Useful for making quantitative lens fitting assessments.
- Used for precise measurement of ocular parameters.

85



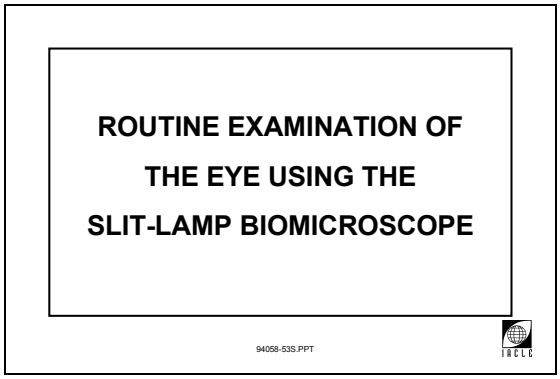
1L41707-94

Viewing the Eye with the Graticule

The graticule is part of the microscope eyepiece of the slit-lamp.

VI. Routine Examination

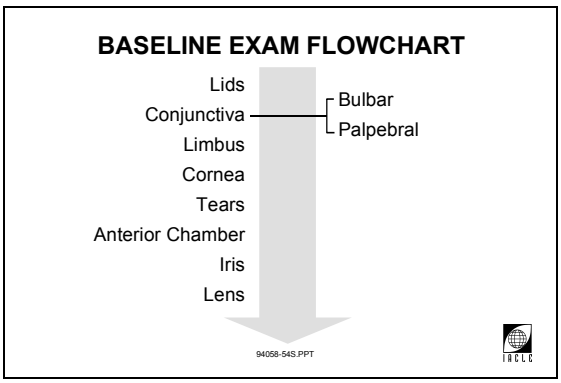
86



1L494058-53

Routine Examination of the Eye Using the Slit-lamp Biomicroscope (*title slide*)

87

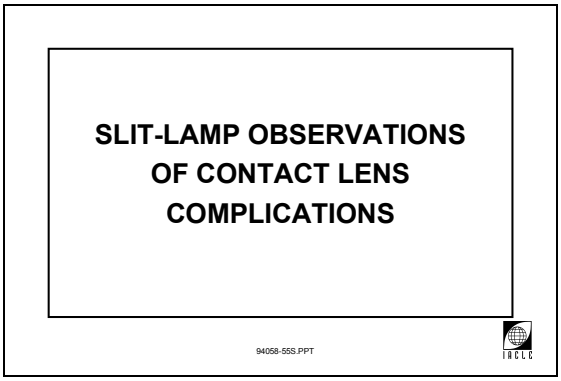


1L494058-54

Baseline Examination Flowchart

- Examination should proceed from the most anterior to the deepest structures utilizing various illumination techniques and magnifications.
- A minimally invasive routine should be employed.

88



1L494058-55

Slit-Lamp Observations of Contact Lens Complications (*title slide*)

VI.A Lids

89

LID EXAMINATION

- Lids
  - redness, swelling, defects, growths, discolouration
- Puncta
  - clear, functioning
- Caruncle
  - swollen, inflamed

94058-56S.PPT

1L494058-56

Lid Examination

The following structures should be observed during an examination of the lids:

- Lids
  - redness
    e.g. blepharitis
  - swelling
    e.g. chalazion, meibomianitis
  - defects/malformation
    e.g. ectropion, entropion, dermatochalasis
  - growths
    e.g. basal cell carcinoma, hordeolum
  - discolouration
    e.g. acne rosacea, herpes simplex, haemangioma.
- Puncta
  - clear/occlusions
    e.g. canaliculitis, presence of punctal occlusions for treatment of keratoconjunctivitis sicca
  - function
    e.g. dacryocystitis
  - assessed using Jones Tests I and II.
- Caruncle
  - swelling and inflammation
    e.g. crushing injuries of the medial canthus or the adjacent orbit, blepharitis.

90

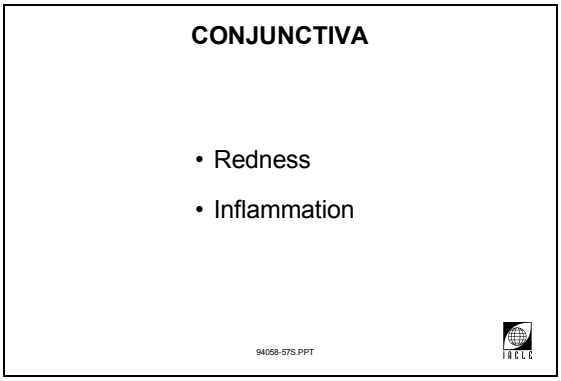
1L41702-94

Blepharitis

- Chronic inflammation of the lid margins.
- May be ulcerative or non-ulcerative.
- Symptoms of irritation, burning and itching of the lid margins.

VI.B Conjunctiva

91



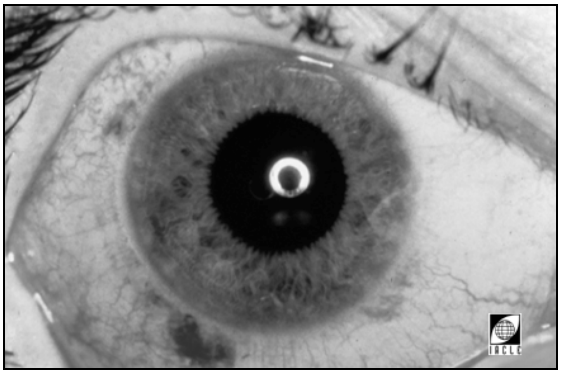
1L494058-57

Conjunctiva

The best indicators of contact lens intolerance are:

- Redness
  - conjunctival capillary dilation
  - engorgement of the conjunctival blood vessels which may be brought about by corneal hypoxia.
- Inflammation
  - conjunctival inflammation may be associated with corneal inflammation
  - tissue damage involving leukocytic invasion from the limbal vasculature
  - response brought about by mechanical, chemical or thermal trauma
  - response brought about by microbiological infections.

92



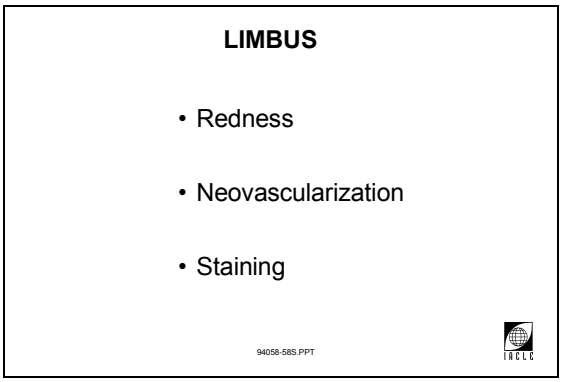
1L41703-94

Conjunctival Haemorrhage

Rupture of conjunctival vessels, observed with low magnification and diffuse illumination.

VI.C Limbus

93



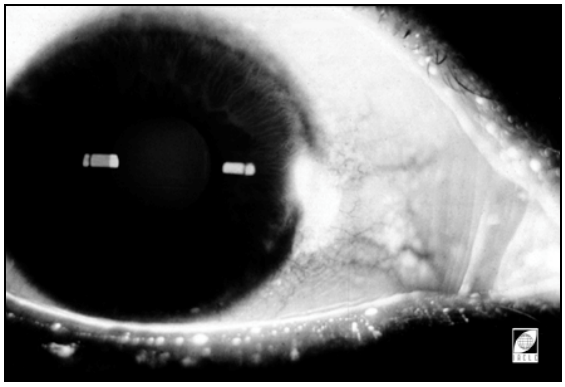
1L494058-58

Limbus

- Redness
  - limbal capillary dilation.
- Neovascularization
  - vessel ingrowth radiating from the limbal vasculature
  - found adjacent to the area of tissue damage, accompanied by limbal engorgement of blood vessels.
- Staining
  - desiccation of epithelial tissue caused by dehydration, trauma or hypoxia.

The above signs are most commonly found with extended use of thick daily wear lenses and long term extended wear with no follow-up care.

94



1L40066-93

Dellen

Peripheral corneal thinning and erosion brought about by wearing an RGP contact lens with too much edge lift and limited movement. The fluorescein staining is observed with low magnification and use of a Wratten #12 filter to highlight the erosion.

VI.D Cornea

95

CORNEA

- Transparency
- Tissue damage/insult

94058-59S.PPT

1L494058-59

Cornea

Loss of corneal transparency may be brought about by:

- Oedema.
- Deposition.
- Opacification.
- Vascularization.

Tissue damage/insult may cause the following pathologic reactions:

- Keratinization.
- Cicatrization.
- Erosions.
- Inflammation.
- Vascularization.
- Scarring.

96

DETECTION OF OEDEMA

- Corneal clarity
- Striae/folds
- Corneal thickness measurement

94058-60S.PPT

1L494058-60

Cornea: Transparency

Detection of Oedema

- Corneal clarity
  - Increased hydration disrupts the arrangement of the collagen fibrils in the stroma. This causes light scattering which is observed as a loss in transparency.
- Striae/folds
  - corneal response to excessive oedema can result in striae in the posterior stroma and folds observed against the endothelial mosaic.
- Corneal thickness measurement
  - pachometry measurements for pre- and post-lens wear provide evidence of oedema.

97

STRAIE

- Refractile effect
- Fluid separation of collagen fibrils
- Minimum 5% corneal swelling
- Refit with higher Dk/*t*

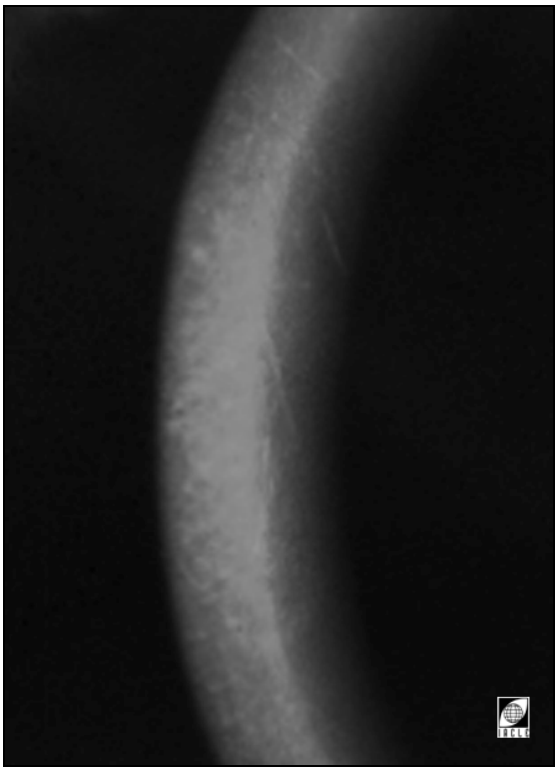
94058-61S.PPT

1L494058-61

Striae

- Refractile effect.
- Fluid separation of collagen fibrils.
- 5% corneal swelling or more.
- Refit the patient with higher Dk/*t* lenses.

98

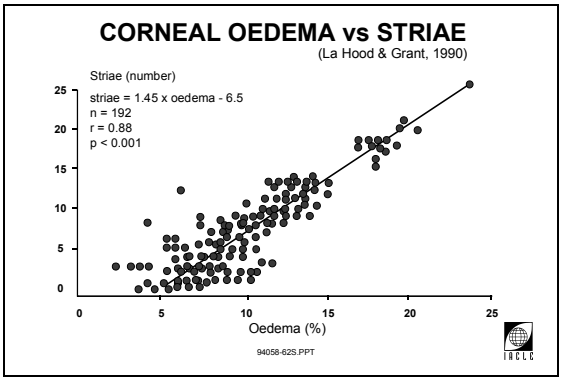


1L42015A-95

Striae

High magnification view of vertical corneal striae seen with a parallelepiped.

99



1L493005-62

Corneal Oedema *versus* Striae

La Hood and Grant (1990) demonstrated a direct relationship between the level of corneal oedema and the number of striae.

100

FOLDS

- Physical buckling of Descemet's membrane and the endothelium
- Minimum 8% corneal swelling
- Severely compromised cornea
- Immediate refit with higher Dk/*t*

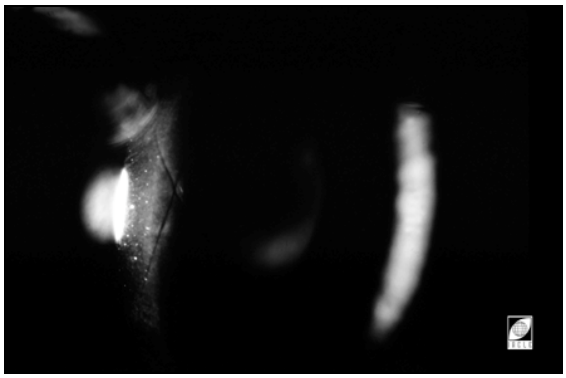
94058-63S.PPT

1L494058-63

Folds

- Physical buckling of Descemet's membrane and the endothelium.
- Requires 8% corneal swelling or more.
- Long-term corneal compromise.
- Immediately refit the patient with higher Dk/*t* lenses.

101

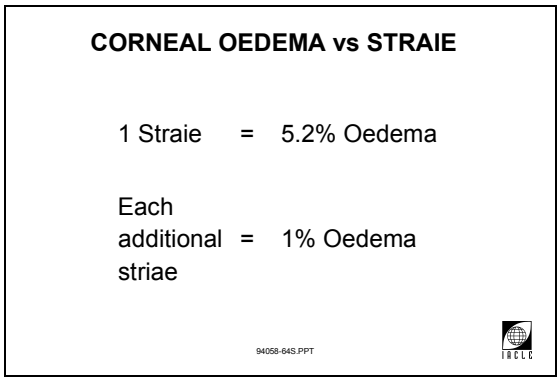


1L40291-91

Folds

Corneal folds seen with a narrow parallelepiped and high magnification.

102

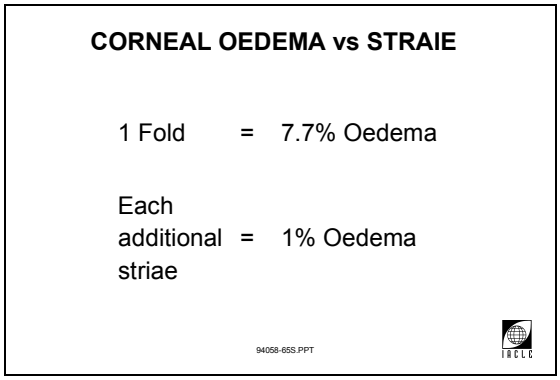


1L494058-64

Corneal Oedema *versus* Striae

- 1 striae = 5.2% corneal swelling.
- Each additional striae = 1% corneal swelling.

103

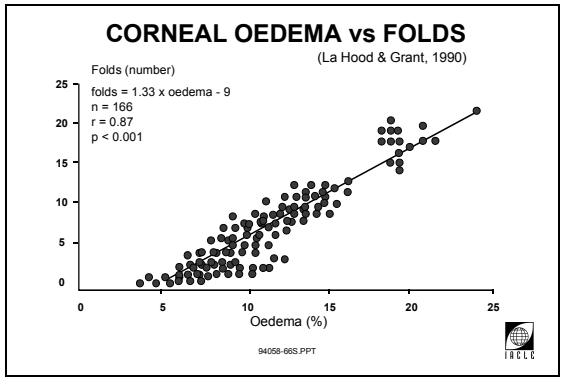


1L494058-65

Corneal Oedema *versus* Folds

- 1 fold = 7.7% corneal swelling.
- Each additional fold = 1% corneal swelling.

104

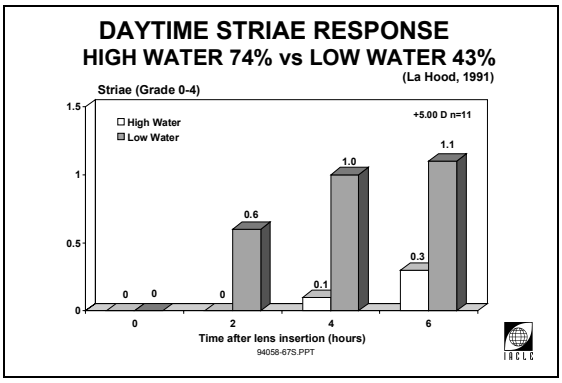


1L493005-66

Corneal Oedema *versus* Folds

La Hood and Grant (1990) demonstrated that the number of folds seen is directly proportional to the percentage of corneal oedema.

105

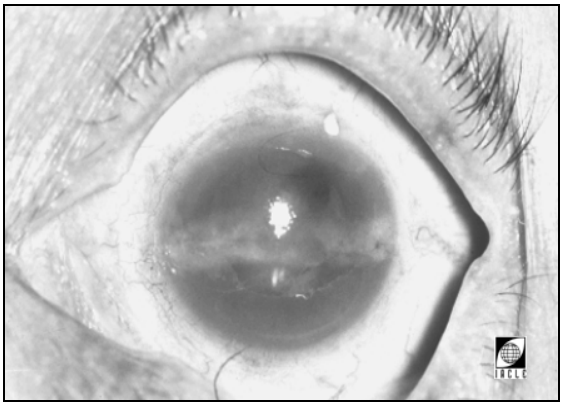


1L493005-67

Daytime Striae Response

La Hood (1991) demonstrated that low water content lenses (43%) worn for eight hours under open-eye conditions cause more striae, folds and corneal oedema than high water content lenses (74%).

106



1L41441-92

Cornea: Tissue Damage/Insult

Calcific Band Keratopathy

- Deposits of calcium salts in the anterior cornea, which may extend into the stroma.
- Present in some cases of rheumatoid arthritis and other long-standing degenerative inflammatory diseases of the eye.
- The location is inter-palpebral.

107

MICROCYSTS

- Small, irregular shape (15-50 μm)
- Reversed illumination
- Slow onset
- Cyclic phenomenon
- Asymptomatic

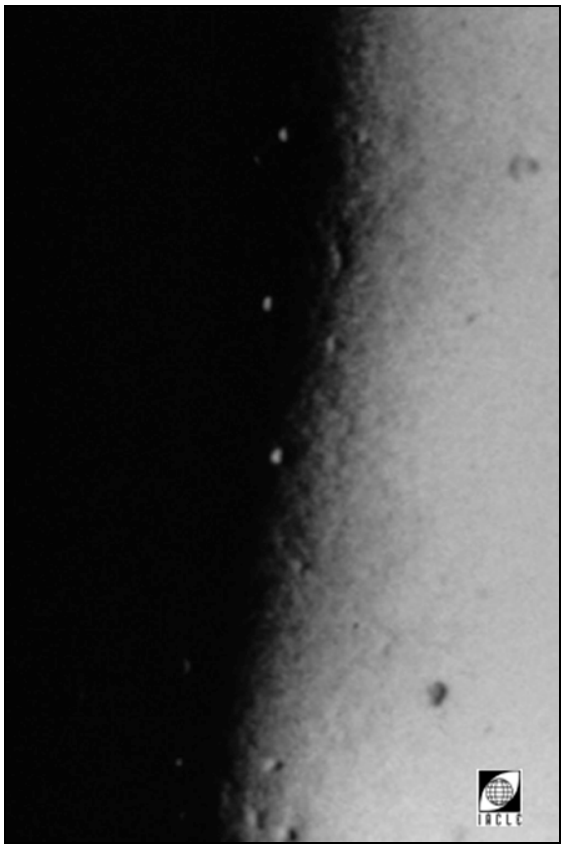
94058-68S.PPT

1L494058-68

Microcysts

- Small and irregularly shaped (15 - 50 μm).
- Display reversed illumination because of their higher refractive index.
- They have a slow onset, appearing after several months of wear.
- Cyclic phenomenon.
- Asymptomatic.

108

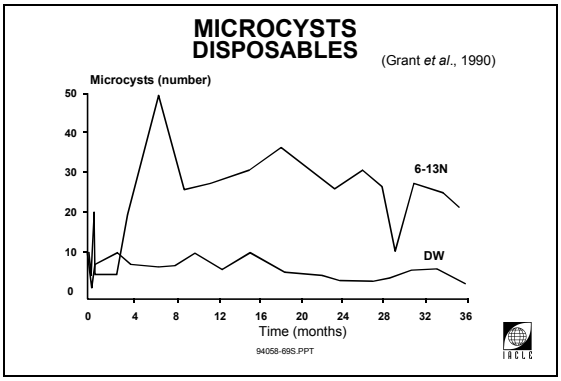


1L40919-91

Microcysts

Microcysts seen under high magnification with *marginal* retro-illumination.

109

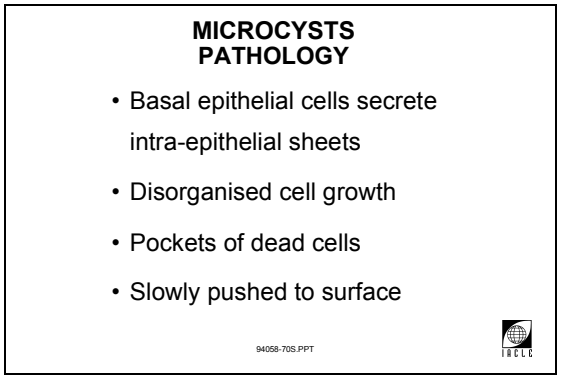


1L493005-69

Microcysts: Disposables

- Grant et al. (1990) revealed that disposable lenses worn on an extended wear basis resulted in a greater number of microcysts than disposable lenses worn on a daily wear basis.

110



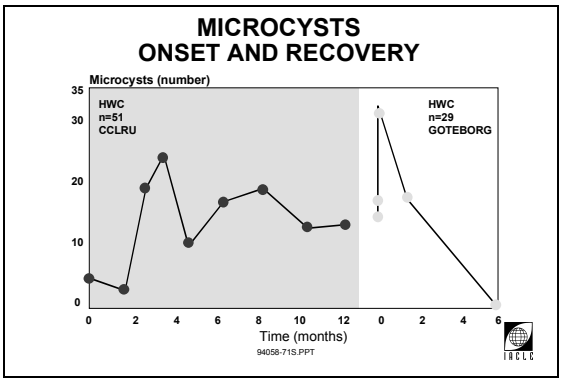
1L494058-70

Microcysts

Pathology:

- Basal epithelial cells secrete intra-epithelial sheets.
- Disorganised cell growth.
- Pockets of dead cells.
- Dead cells are slowly pushed to the surface.

111

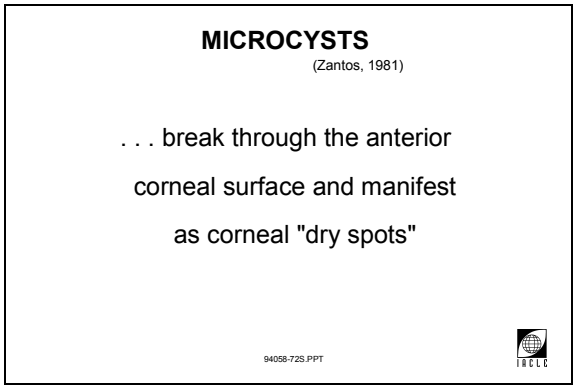


1L493005-71

Microcysts: Onset and Recovery

- Onset: A CCLRU study of wearers of high water content lenses monitored the occurrence of microcysts over a 12 month period. The occurrence shows a cyclic response with a peak between three and four months.
- Recovery: A study in Göteborg showed that the condition was completely resolved within six months of the cessation of lens wear and that the majority had disappeared by two to three months. The *increase* in the number of microcysts immediately after lens wear ceased, has also been reported by others.

112

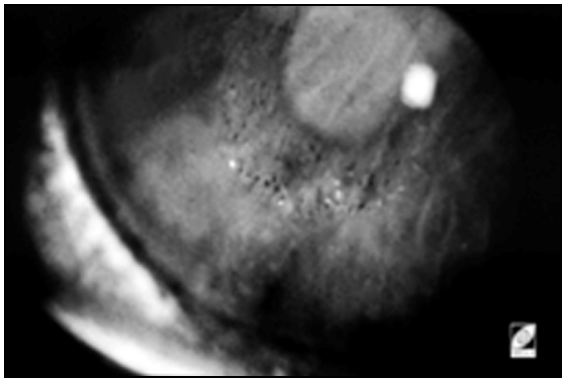


1L494058-72

Microcysts

Zantos (1981) showed that microcysts can break through the anterior corneal surface and are manifested as corneal ‘dry spots’.

113



1L40292-91

Microcysts

Fluorescein instillation shows microcysts appearing as minute ‘dry spot’ formations on the anterior corneal surface.

114

ENDOTHELIUM

Detection with slit-lamp:

- high magnification (30x - 40x)
- high illumination
- specular reflection

94058-73S.PPT

1L494058-73

Endothelium

Detection with slit-lamp:

- High magnification (30x - 40x).
- High illumination.
- Specular reflection.

115

POLYMEGETHISM SIGNS

- Increasing variation in endothelial cell size
- Increased ratio of large/small cells

94058-74S.PPT

1L494058-74

Polymegethism

Signs:

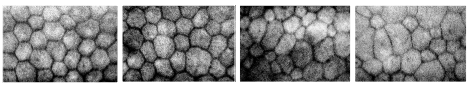
- Increasing variation in endothelial cell size.
- Increased numbers of large and small cells. However, the actual cell density may remain unaltered despite significant apparent polymegethism.

116

CCLRU POLYMEGETHISM SCALE

GRADE

1 2 3 4



94058-75S.PPT

1L494058-75

Increasing Degrees of Polymegethism

A grading scale can be used as a comparator to broadly categorize the level of polymegethism apparent during observation of the endothelial mosaic. This example uses four levels to grade polymegethism.

117

CLINICAL SIGNIFICANCE OF POLYMEGETHISM

94058-76S.PPT

1L494058-76

Clinical Significance of Polymegethism
(*title slide*)

118

POLYMEGETHISM CAUSES

- Age
- Diseases (diabetes, etc)
- Trauma
- Contact lenses

94058-77S.PPT

1L494058-77

Polymegethism

The development of polymegethism may be caused by:

- Age
  - A decrease in endothelial cell density has been confirmed as an age-related change.
- Diseases (diabetes, etc.)
  - Systemic pathological conditions can compromise corneal functions. Long-standing (chronic) diseases may lead to corneal oedema and polymegethism.
- Trauma
  - Trauma to the cornea can alter its metabolic processes.
- Contact lenses
  - Adaptation to contact lenses and lens wear may also mean alterations in corneal metabolism. Significant alterations can initiate pathological reactions.

VI.E Tears

119

TEAR EXAMINATION

- Quality
- Lipid layer
- Debris

94058-78S.PPT

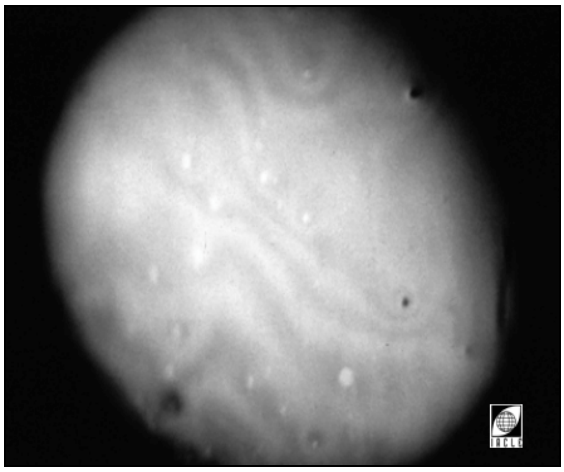
1L494058-78

Tear Examination

Successful contact lens wear depends on adequate tear function which can be evaluated by assessing the following:

- Quality
  - non-lens wear
  - with lens wear:
    - pre-lens tear film
    - post-lens tear film.
- Lipid layer
  - controls the rate of evaporation of the deeper aqueous layer
  - described as:
    - marmoreal
      - open meshwork
      - closed meshwork.
    - flow
    - amorphous
    - coloured fringes
- Debris
  - quantity
  - pre- and post-lens debris.

120



1L41705-94

121

TEAR EXAMINATION

Quality

- BUT (fluorescein)
- Tear prism height
- Movement of debris
- Rose Bengal staining

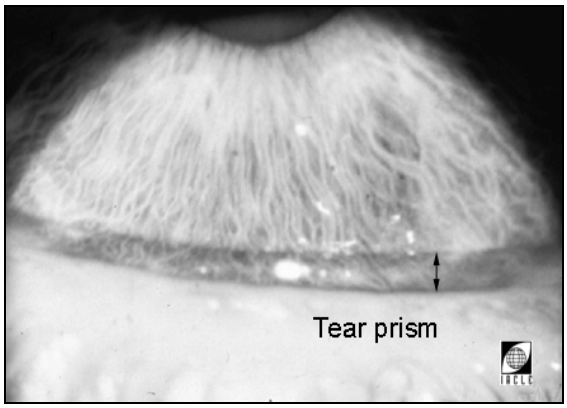
94058-79S.PPT

1L494058-79

Tear Examination

- BUT (fluorescein)
  - invasive examination of tear film stability
  - detection of ‘dry spots’ indicative of tear thinning and exposure of the underlying corneal epithelium.
- Observed with cobalt blue light and Wratten #12 filter
- Tear prism height
  - invasive (with fluorescein) or non-invasive examination of the basal tear volume
  - tear film along the lower lid margin is observed by using a narrow slit beam.
- Movement of debris
  - observed using moderate magnification and diffuse illumination.
- Rose bengal staining
  - used to determine the presence of dead epithelial and conjunctival cells as these are the cells which take up the stain
  - technique is diagnostic of

122



1L43057-93L

keratoconjunctivitis sicca.

VI.F Anterior Chamber

123

ANTERIOR CHAMBER

Transparency

- Cells and flare

- Persistent pupillary membrane

94058-80S.PPT

1L494058-80

Anterior Chamber

Transparency

- Anterior chamber should be free of flare or cells as these are indicative of ocular pathology.
- Non-pathologic tissue debris or pigmentation may be remnants of ocular tissue development during the eye's embryological formation.

124

IRIS EXAMINATION

Architecture

- Inflammation
- Pigmentation
- Naevi
- Iridectomy
- Colobomas

94058-81S.PPT

1L494058-81

Iris Examination

Architecture

The following characteristics may be observed with medium to high magnification with diffuse illumination:

- Inflammation

e.g. iritis.

- Pigmentation: indicative of ocular pathology.

e.g. uveitis, glaucoma.

- Naevi: pigmented lesions in the stroma.

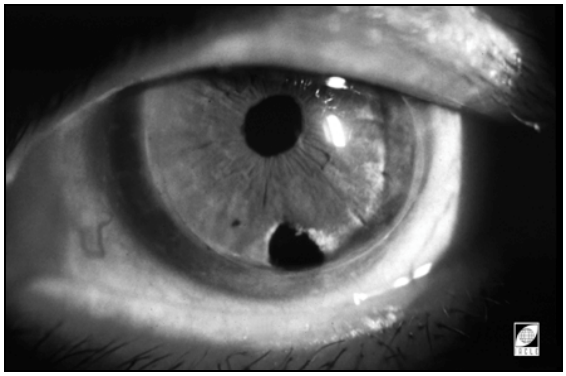
e.g. iris ‘freckles’.

- Iridectomy

e.g. caused by cataract or glaucoma surgery.

- Colobomas: incomplete development of the iris.

125



1L41706-94

Iridectomy

Surgical removal of part of the iris tissue during cataract surgery or as a therapeutic procedure for angle-closure glaucoma.

126

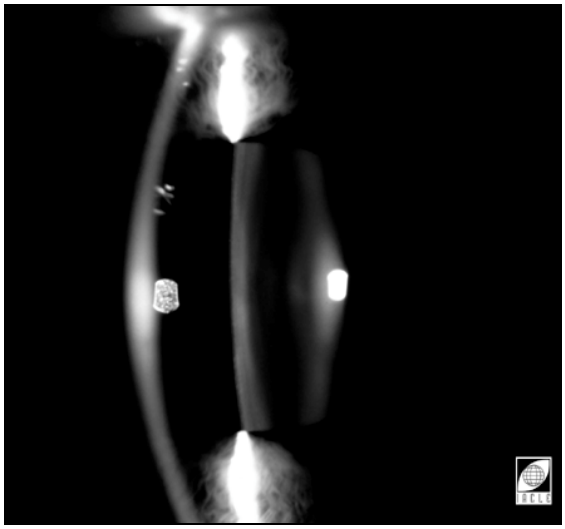
CRYSTALLINE LENS EXAMINATION

- "Orange Peel"
- Opacities
- Pigment on capsule
- Centration
- Iris attachments

94058-82S.PPT

1L494058-82

127



1L41117-95

Crystalline Lens Examination

The following may be observed using direct illumination or specular reflection and medium to high magnification:

- ‘Orange peel’ effect
  - the surface texture of the lens capsule.
- Opacities
  - e.g. radiation, diabetic or other cataracts.
- Pigment on capsule
  - could be evidence of a history of posterior synechiae resulting from anterior uveitis or a simple benign congenital anomaly.
- Cataracts
  - lens opacity brought on by alteration of protein composition, lens fibre structure or lenticular oedema.
- Centration
  - e.g. Marfan's syndrome - a familial disease accompanied by subluxation of the lens.
- Iris attachments
  - posterior synechiae accompanying uveitis.

Practical 1.4.1

(2 Hours)

Slit-Lamp Biomicroscopy: Illumination Techniques

Schedule of Practice Sessions

Preliminary

Video Presentation: An Introduction to Slit-lamp Biomicroscopy

Practical Session: Slit-Lamp Biomicroscopy: Illumination Techniques

Instructions: Students are to be divided according to the number of slit-lamps available. Familiarisation with the following features will be assessed:

Features: Use and purposes of the knobs, lighting, microscopes, magnification, optics, filters.

Set-up: Turning on the instrument, focusing the eyepieces and adjusting the instrument.

Instructions: The same grouping will be used for examination of a spectacle lens to gain familiarisation with the following illumination techniques:

- Diffuse.
- Direct
  - optic section
  - parallelepiped
  - conical beam.
- Indirect.
- Retro-illumination
  - direct
  - indirect
  - marginal.
- Tangential.

Practical 1.4.2

(4 Hours)

Slit-Lamp Biomicroscopy: Examination of the Eye

Schedule of Practical Session

Preliminary

Video Presentation: Introduction to Biomicroscopy (Part II: Examining external eye).

Practical Session: Examining the Eye

Instructions: Students are to work in pairs to examine each other using the slit-lamp.

1. Observe anterior eye structures with different illuminations.
2. Routine examination of the eye using the slit-lamp. Record the following information on the record form provided:

- Eyelid skin appearance.
- Lid position in primary gaze.
- Lid margin appearance.
- Eyelash hygiene and direction of growth.
- Bulbar conjunctival redness and appearance.
- Palpebral conjunctival redness and roughness (lid eversion).
- Corneal condition (light reflection).
- Blink frequency and completeness.
- Iris colour and pigmentation.
- Pupil reflexes.
- Anterior chamber.
- Crystalline lens.

Demonstration of Additional Techniques:

1. Specular reflection (endothelial examination).
2. Conical beam.
3. Sclerotic scatter.

Instructions: Students work in pairs performing the additional techniques.

Practical Session

RECORD FORM

Name:_____ Date:_____

Partner:_____ Group:_____

RIGHT	**LEFT**
Eyelid Skin Appearance: (describe)	
Lid Position in Primary Gaze: (illustrate)	
Lid Margin Appearance: (describe)	
Upper lid margin_____ Lower lid margin_____	Upper lid margin_____ Lower lid margin_____
Eyelash Hygiene and Direction of Growth: (illustrate)	
Bulbar Conjunctival Redness and Appearance: (describe and illustrate)	
Palpebral Conjunctival Redness and Roughness: (lid eversion)	

RIGHT	**LEFT**
Upper lid Lower lid	Upper lid Lower lid
Corneal Condition:	
Blink Frequency and Completeness:	
Number of blinks per minute_____ Partial ☐ Full ☐	Number of blinks per minute_____ Partial ☐ Full ☐
Iris Colour and Pigmentation:	
Pupil Reflexes	
Direct Consensual Near Pupils Regular Y/N Pupil Size	Direct Consensual Near Pupils Regular Y/N Pupil Size
Anterior Chamber (flare, cells, etc.)	
Angle (van Herick)	Angle (van Herick)
Crystalline Lens (pigments, deposits, opacities)	

Tutorial 1.4

(1 Hour)

Review of Slit-Lamp Illumination Techniques

Slide Series Presentation

Group Number:_____ **Date:**_____

Instructions: Divide the class into four to six students for discussion. A slide series will be presented allowing one minute to observe the slit-lamp illumination and condition being presented. Group assessment is recorded on the space provided corresponding to the number of the slide.

Slide 1: Illumination used:_____ Set-up:_____

Condition:_____

Slide 2: Illumination used:_____ Set-up:_____

Condition:_____

Slide 3: Illumination used:_____ Set-up:_____

Condition:_____

Slide 4: Illumination used:_____ Set-up:_____

Condition:_____

Slide 5: Illumination used:_____ Set-up:_____

Condition:_____

Slide 6: Illumination used:_____ Set-up:_____

Condition:_____

Slide 7: Illumination used:_____ Set-up:_____

Condition:_____

Slide 8: Illumination used:_____ Set-up:_____

Condition:_____

Slide 9: Illumination used:_____ Set-up:_____

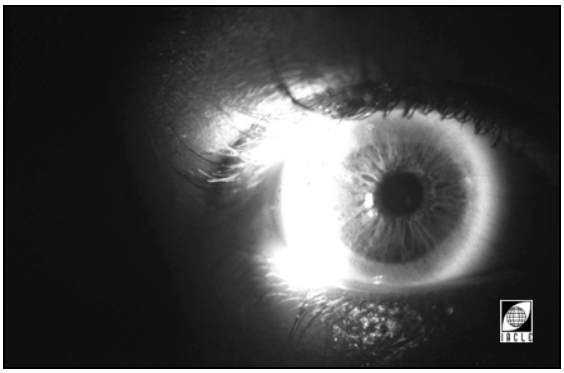
Condition:_____

Slide 10: Illumination used:_____ Set-up:_____

Condition:_____

Slide Series Presentation

128 **Slide 1**



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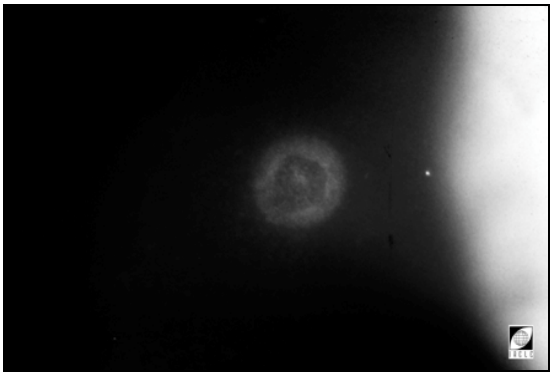
129 **Slide 2**



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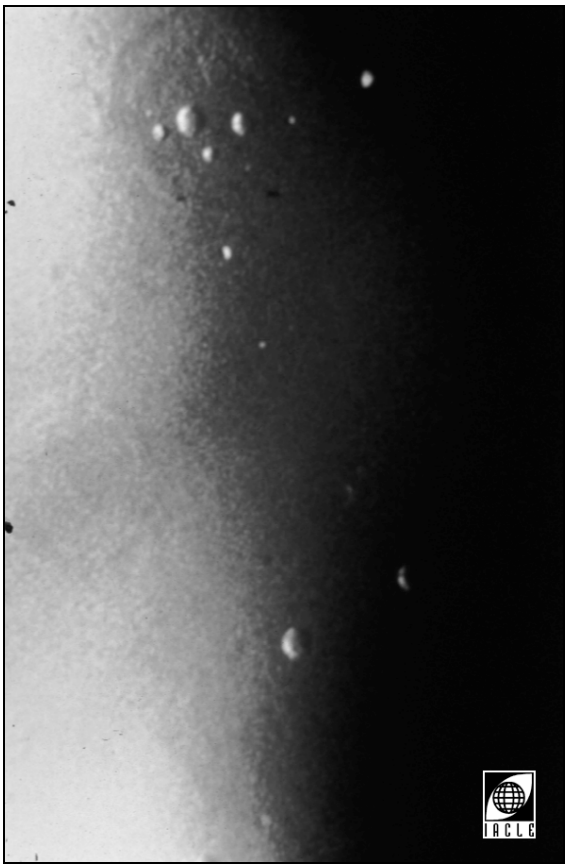
130 **Slide 3**



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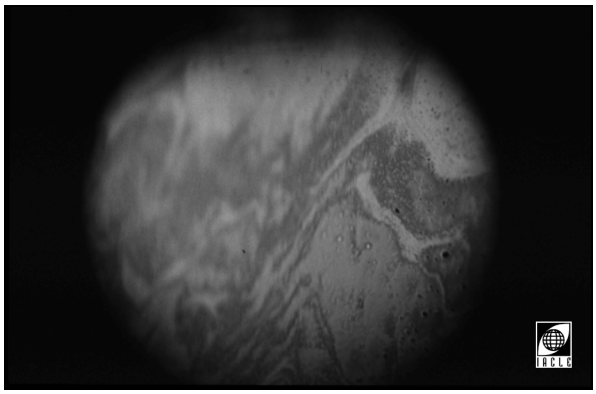
131 **Slide 4**

111T41436-96

132 **Slide 5**



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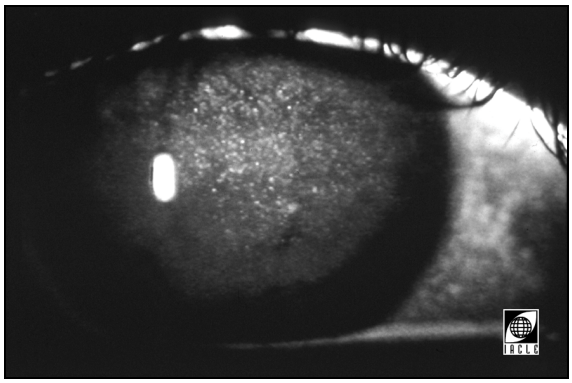
133 **Slide 6**



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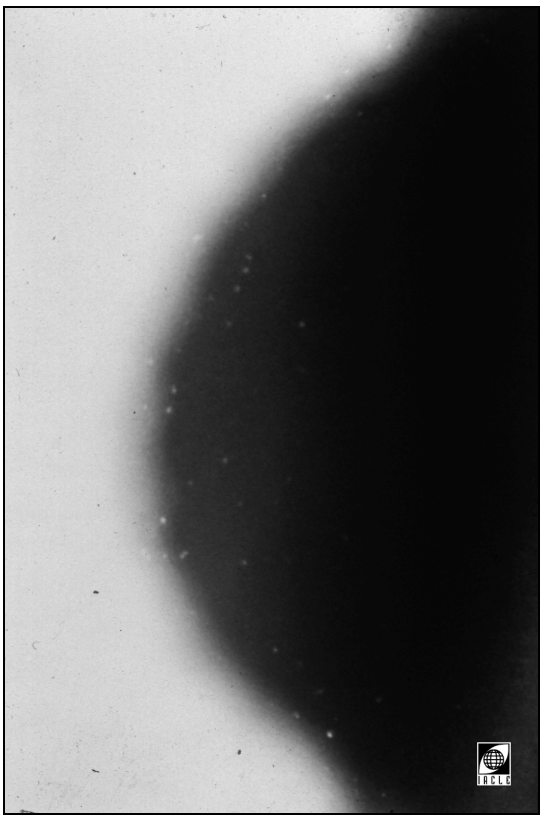
134 **Slide 7**



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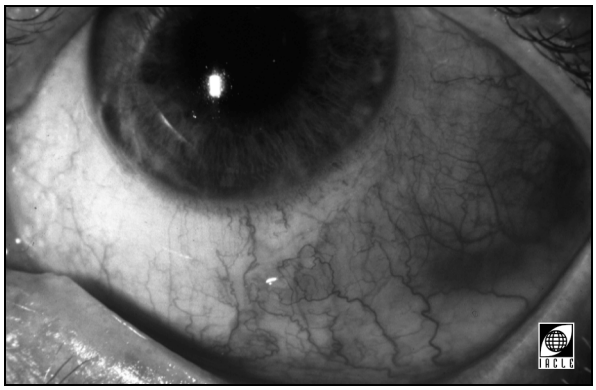
135 **Slide 8**

11T41567-96

136 **Slide 9**



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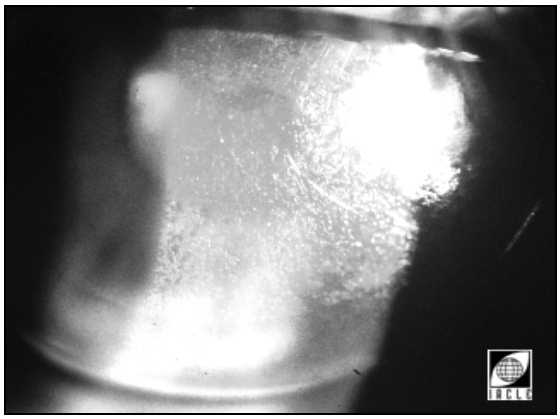
137 **Slide 10**



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