

## Valutazione del segmento oculare anteriore nella pratica optometrica moderna

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Dipartimento di Scienza dei Materiali, Università degli Studi di Milano-Bicocca  
Optics and Optometry Research Center (COMB), Università degli Studi di Milano-Bicocca

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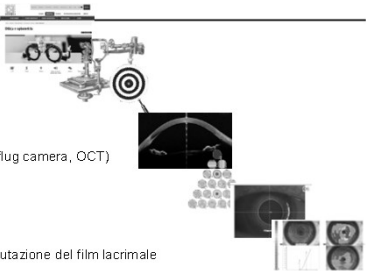
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### Key points

- Intro CdL e Comib
- Biomicroscopia
- Topografia Corneale
- Tomografia (Scheimpflug camera, OCT)
- Aberrometria
- Pupillografia
- Sistemi integrati di valutazione del film lacrimale



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**Università degli Studi di Milano-Bicocca**

**AREE DISCIPLINARI**

Economico statistica | Giuridica | Scientifica | Medica | Sociologica | Psicologica | Pedagogica

**14 Dipartimenti**

**33 Corsi di Laurea Triennale (di cui 11 di area scientifica)**

**40 Corsi di Laurea Magistrale (di cui 17 di area scientifica)**

**OTTICA E OPTOMETRIA**  
 SCIENZE MEDICHE  
 SCIENZE PSICOLOGICHE  
 SCIENZE PEDAGOGICHE  
 SCIENZE PEDAGOGICHE DEL TERRITORIO

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**1° anno**

Anatomia e Istologia Umana e Oculare  
 Chimica  
 Fisica I  
 Fisiologia Generale ed Oculare  
 Istruzioni di Matematica I  
 Ottica Geometrica e Oftalmica con Laboratorio  
 Sistemi Ottici e Oftalmici con Laboratorio

**2° anno**

Fisica II  
 Istruzioni di Matematica II  
 Laboratorio Ottico della Constatologia  
 Laboratorio Tecniche Fisiche per l'Optometria  
 Ottica della Constatologia Generale  
 Percettione Visiva  
 Tecniche Fisiche per l'Optometria Generale

**3° anno**

Interazione Luce-Materia  
 Optometria Avanzata con Laboratorio  
 Principi di Psicologia Oculare  
 Storia della Fisica Moderna e degli Strumenti Ottici

+ TIROCINIO  
 + PROVA FINALE

**OTTICA E OPTOMETRIA**

Didattica  
 e-mail: didattica.ottica@unimib.it  
 tel. 02 6448 6556

Sito del Dipartimento di Scienza dei Materiali

E-learning

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**Ricerca**

**comib**  
 OPTICS AND OPTOMETRY RESEARCH CENTER  
 UNIVERSITY OF MILANO BICOCCA

**Alessandro Borghesi**

**Alessandro Duse**

**Aziza Obaid**

**Erika Ponzini**

**Giulia C. Rizzo**

**Riccardo Rolandi**

**Silvia Tavazzi**

**Fabrizio Zerl**

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**comib**  
OPTICS AND OPTOMETRY  
RESEARCH CENTER  
UNIVERSITY OF MILANO-BICOCCA

Publicazioni peer-review  
COMIB (2014-oggi)

**Centro universitario di ricerca in ottica e optometria Milano - Bicocca (COMIB)**

Costituito nel 2015 presso il Dipartimento di Scienza dei Materiali dell'Università di Milano-Bicocca per creare un collegamento tra il mondo accademico e le attività produttive su tutto il territorio nazionale. In sinergia con ricercatori esterni di altri dipartimento quali Scienze Sociali, Psicologia, Medicina e Statistica.



<https://comib.unimib.it/>

**Ambiti d'azione:**

- ✓ Ricerca (Optica, optometria, lenti a contatto, percezione visiva, scienza dei materiali) anche in collaborazione con aziende.
- ✓ Screening e analisi visiva (effettuare analisi visive in collaborazione con la Medicina del Lavoro dell'Università, fornire un servizio al territorio [UFYE])
- ✓ Formazione (tirocini studenti, corsi di formazione avanzata e aggiornamento professionale in collaborazione con aziende e/o associazioni di professionisti)

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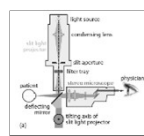
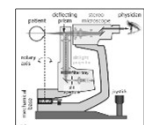


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**Lampada a fessura**

**WHY**

- Valutazione delle strutture oculari (anteriori: cornea, congiuntiva, palpebre, film lacrimale, cristallino)
- Valutazione delle lac (integrità strutturale, bagnabilità, ...)
- Valutazione relazione lente-occhio: posizione, movimento, immagine fluoroscopica (lac RGP, Sclerali).


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### Lampada a fessura: componenti

- Sistema di osservazione (biomicroscopio)
  - stereomicroscopio
  - ingrandimenti da 5x a 40x
- Sistema d'illuminazione: lampada a fessura
  - fascio di luce sezionabile, orientabile e disassabile (tilting)
  - filtri (diffusore, rosso privo, cobalto...)
- Sistema meccanico
  - coassialità tra i due sistemi
  - movimento sincrono
  - favorisce un preciso dislocamento del paziente



**Nikon** **comib** **25** **ITTECI**

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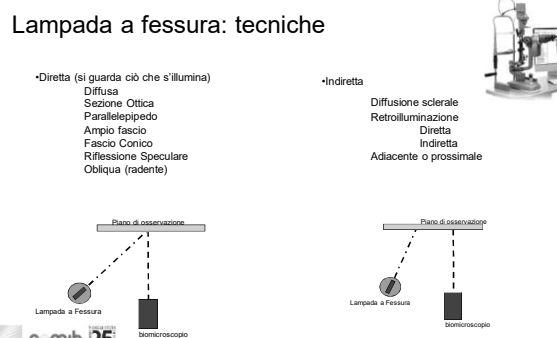
### Lampada a fessura: tecniche

•Diretta (si guarda ciò che s'illumina)

- Diffusa
- Sezione Ottica
- Parallelepipedo
- Angio fascio
- Fascio Conico
- Riflessione Speculare
- Obliqua (radente)

•Indiretta

- Diffusione sclerale
- Retroilluminazione
- Diretta
- Indiretta
- Adiacente o prossimale



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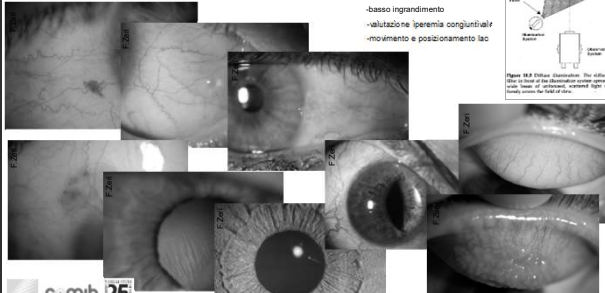
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### Lampada a fessura: tecniche

•Dirette

- Diffusa
  - veduta d'insieme delle strutture oculari esterne
  - basso ingrandimento
  - valutazione iperemia congiuntivale
  - movimento e posizionamento lac



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**Lampada a fessura: tecniche**

- Diffusa
- veduta d'insieme delle strutture
- oculi esterni
- basso ingrandimento
- ventilazione (peremia congiuntivale)
- movimento e posizionamento lac

**Figure 18-3 Clinical illustration:** The diffusing fibers in front of the illumination system spreads a wide beam of uniform, softened light uniformly across the field of view.

**comib 25**  
Nikon

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**Lampada a fessura: tecniche**

- Ampio fascio
- fascio ampio (1-5 mm)
- ridurre la luminosità restato
- ampie opacità cornea, pteriglio, detriti sotto le lac, pattern fluoresceinico...

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Nikon

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**Lampada a fessura: tecniche**

**il filtro giallo**

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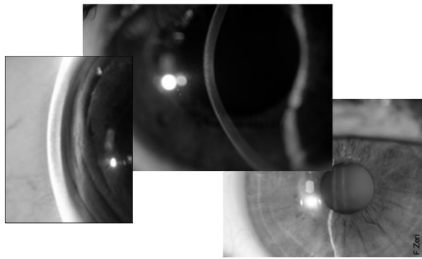
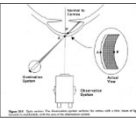
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•Dirette

### Lampada a fessura: tecniche

•Sezione Ottica  
 -fascio sottile (0,02-0,1mm)  
 -angolo tra i 2 sistemi 30-60°  
 -corpi estranei, haze stromale, strie solchi etc...

Nikon combi 25 iitcci

BIOSECCA

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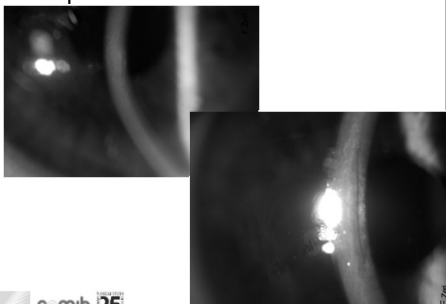
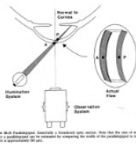
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•Dirette

### Lampada a fessura: tecniche

•Parallelepipedo  
 -fascio sottile  
 -angolo tra i 2 sistemi 30-60°  
 -corpi estranei, haze stromale, strie solchi, staining, vascolarizzazione...

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•Dirette

### Lampada a fessura: tecniche




•Fascio Conico  
 -sezione molto piccola (1-2mm)  
 -focalizzazione in camera anteriore  
 -corpi in camera anteriore

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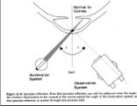
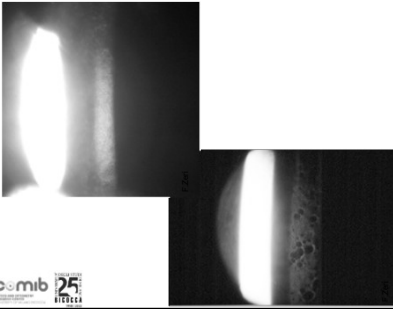
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Lampada a fessura: tecniche

•Riflessione Speculare  
 -uguale angolo tra i due sistemi rispetto alla bisettrice  
 -superficie strutturate  
 -endotelio, film lacrimale (interferenza)  
 - Alto ingrandimento (40X)

•Dirette

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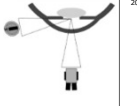
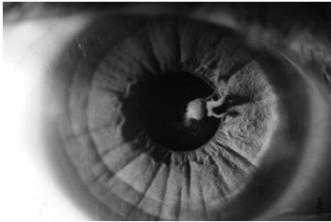
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Lampada a fessura: tecniche

•Obliqua o radente  
 -ampio fascio  
 -angolo a 90°  
 -visibili rilievi di una superficie  
 -irama iridea, depositi su di una lac

•Dirette

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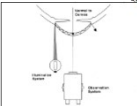
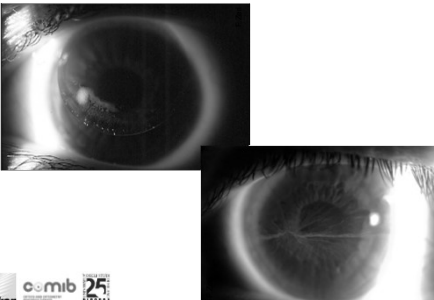
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Lampada a fessura: tecniche

•Diffusione Sclerale  
 -fascio di luce diretto al limbus  
 -riflessione totale all'interno della lamina corneale  
 -opacità corneali (edema, CCC, haze...)

•Indirette

Nikon combi 25

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Lampada a fessura: tecniche

•Indirette

•Retrolluminazione diretta  
 -fascio diretto sull'iride, la retina o il cristallino che lo riflettono e consentono alla cornea di essere illuminata da dietro  
 -l'oggetto appare su uno sfondo illuminato (nero su sfondo chiaro)  
 -microcisti, vacuoli, mucin balls, infiltrati....

Nikon COMIB 25 YEARS

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Lampada a fessura: tecniche

•Indirette

•Retrolluminazione indiretta  
 -fascio diretto sull'iride, la retina o il cristallino che lo riflettono e consentono alla cornea di essere illuminata da dietro  
 -l'oggetto appare su uno sfondo scuro  
 -microcisti, vacuoli, mucin balls, infiltrati....

Nikon COMIB 25 YEARS

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- Pupillografia
- Sistemi integrati di valutazione del film lacrimale

Nikon COMIB 25 YEARS

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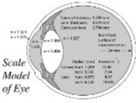
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## Topografia Corneale

WHY



- La struttura oculare con il più alto potere refrattivo.  $F_{\text{cornea}} = 2/3 F_{\text{total eye}}$
- Le astigmatismo e le aberrazioni della superficie anteriore corneale prevalgono sull'astigmatismo e sulle aberrazioni delle altre strutture oculari interne.



Scale Model of Eye

BUT

- È estremamente complessa
- È caratterizzata da un'ampia differenza inter-personale

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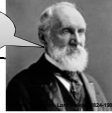
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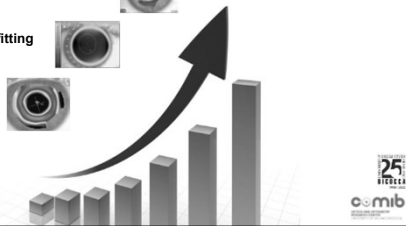
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## Topografia Corneale





"If you can't measure it, you can't know it."

- Knowledge about normal cornea and corneal disease
- Develop Contact Lenses fitting
- Develop Corneal surgery



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## Topografia Corneale: un po' di storia

### Spheres

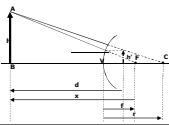

**Father Christoph Scheiner (1619)**  
First measure of shape.  
He compared reflection of objects on the cornea and on glass spheres with known curvature






### Keratometer

**von Helmholtz (1854)** first keratometer for clinical use (ophthalmometer)

**Javal and Schiotz' keratometer (1881)**

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### Topografia Corneale: un po' di storia

#### Keratoscope


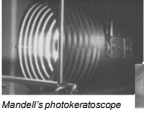
- Cuignet (1820)
- Henry Goode (1847)
- Antonio Placido (1880)




Klein keratroscope

#### Photokeratroscope



Quantitative analysis of keratometry  
(1896) Alvar Gullstrand

Mandell's photokeratroscope



Rowsey e coll 1981  
CorneaScope (Kera Corporation)


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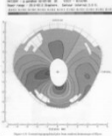
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### Topografia Corneale: un po' di storia

#### Computerized Videokeratroscope (CVK)

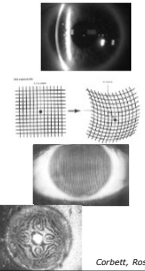


Doss (1981)  
algorithm to calculate corneal shape from a photokeratography.


Klyce (1984)  
computerized procedure to build and plot corneal shape.

Maguire et al (1987)  
colour-coded contour map



#### Projection-based System



Slit Photography  
Scheimpflug Camera  
Rasterstereophotography  
Moire' Interference  
Laser Interferometry



Corbett, Rosen O'Brat, 1999


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### Topografia Corneale: un po' di storia

#### Reflection based systems: the most prevalent option

**Stephen Klyce**  
*Corneal Topography. In Efron The Cornea. (2001)*

Manufacturer	Model(s)	Method
Alcon Surgical	EyeMap EPI-200	Placido
Alliance Medical Mds	Keratam CT Scout	Placido
B & L Surgical	Oculus II	Scanned slit and Placido
B & L Surgical	Orbus1	Placido
Chaco	CT-200	Placido
Heald Systems	ET-400	Fluorescein profilometry
Hardy/Tronair	Emery 2000; Vista	Placido
Iyema	CT-2000	Placido
Humphrey Instruments	Atlas 991, 992	Placido
Kera Ictinia	CLAS 1000	Laser topography
Medmont	E300	Placido
Oculus	Keratograph	Placido
PAR Vision Systems	CTS, Avicent	Fluorescein profilometry
PAR Vision Systems	Linnix, CTS	Fluorescein profilometry
Sea Coast Lens Co.	SE-2001	Placido
TekniskMed Technology	CSCAN	Placido
Tomey Technology	AutoTopographer	Placido
Topcon America Corp.	CM-1000	Placido


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Topografia Corneale: un po' di storia

**Integrated systems:**  
Placido-based CVK + scanning slit beam technology (Orbscan, B&L)



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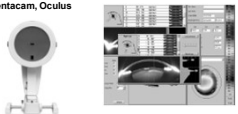
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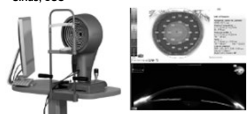
Topografia Corneale: un po' di storia

**Integrated systems:**  
Pure rotating Scheimpflug camera system + Pupillography  
Integrated systems: Placido-based CVK + Scheimpflug Camera + Pupillography + Dry Eye Assessment

Pentacam, Oculus



Sirius, CSO



Tomographic representation  
Thickness (map)  
Anterior chamber depth  
Anterior chamber angle

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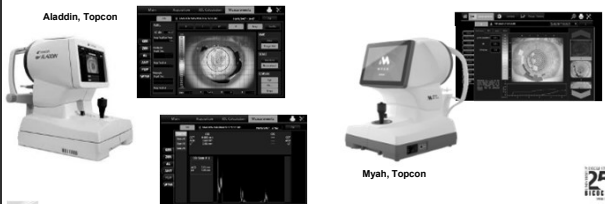
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Topografia Corneale: un po' di storia

**Integrated systems:**  
Placido-based CVK + Optical biometer + Pupillography + Tear film assessment

Aladdin, Topcon



Myah, Topcon

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**Topografia Corneale: caratteristiche**

**Keratometer**

2.5mm  
0.7mm

**Computerized Videokeratoscope (CVK)**

**versus**

**Computerized Videokeratoscope (CVK)**

- Up to 95% of coverage of corneal surface (up to 11 mm of diameter)
- Up to 38 rings
- Over 6000 points of measurement (can reach more than 1000)

**versus**

**Integrated systems: Placido-based CVK + Scheimpflug Camera**

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**Topografia Corneale: funzionamento**

**Keratoscope**

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**Digital video-camera acquires keratoscopic image**

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**Specific software analyses digital image**

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**Output on monitor**

1 **Capturing**

2 **Processing**

3 **Visualization**

**Nikon** **c:mib**

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**Topografia Corneale: caratteristiche**

**Keratoscope**

**Large-diameter Placido disc**  
(long working distance, less sensitive to misalignment, eclipse problems)

**Small-diameter Placido disc**  
(short working distance, automatic alignment and focusing, no problem of eclipse or shadow)

1 **Capturing**

**Nikon** **c:mib**

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Topografia Corneale: caratteristiche 2 Processing

**Height or elevation**

Reference surface

**Slope**

**Curvature**

- Axial radius
- Tangential radius
- Gaussian

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Topografia Corneale: caratteristiche 2 Processing

**Power**

Snell Law

Radius of curvature can be converted in Diopters

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

**Wave-front**

Corneal Surface

Perfect spherical wave-front generated by Cartesian oval

Wave Front generated by the corneal surface

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Topografia Corneale: caratteristiche 3 Visualization

- Keratoscopic image (raw)
- Color-coded map
- Cross Sections
- Numeric and statistical displays

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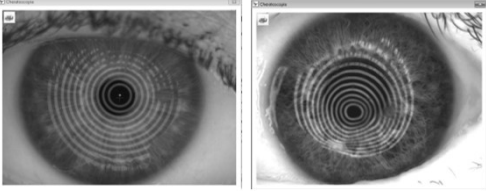
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Topografia Corneale: caratteristiche 3 Visualization

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**Keratoscopic image (raw)**



Analisi qualitativa



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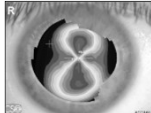
Topografia Corneale: caratteristiche 3 Visualization

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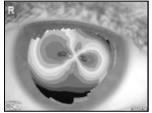
**Color-coded maps**  
They provide a rapid method for clinical diagnosis

Regular Astigmatism

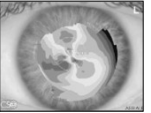
With-the-rule





Against-the-rule



Oblique





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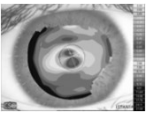
Topografia Corneale: caratteristiche 3 Visualization

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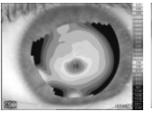
**Color-coded maps**  
They provide a rapid method for clinical diagnosis

Keratoconus

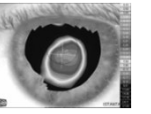
Nipple, central





Nipple, inferiorly decentered



Oval





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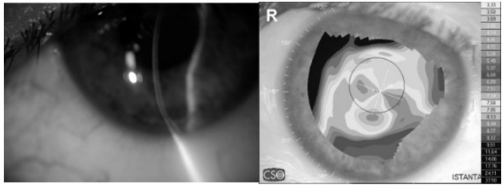
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Topografia Corneale: caratteristiche 3 Visualization

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**Color-coded maps**  
They provide a rapid method for clinical diagnosis

Pellucid marginal degeneration



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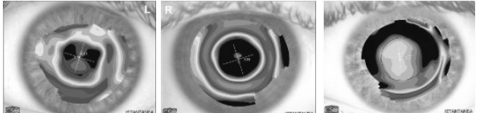
Topografia Corneale: caratteristiche 3 Visualization

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**Color-coded maps**  
They provide a rapid method for clinical diagnosis

Post Refractive Surgery

- PRK
- Lasik High Myopia
- PRK Hyperopia



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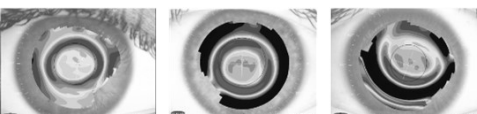
Topografia Corneale: caratteristiche 3 Visualization

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**Color-coded maps**  
They provide a rapid method for clinical diagnosis

Orthokeratology

- Well centred
- Slightly decentred
- Extremely decentred



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Topografia Corneale: caratteristiche 3 Visualization

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Color-coded map: 3D

Nikon c·mib

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Topografia Corneale: caratteristiche 3 Visualization

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Color-coded map: algorithm

Nikon c·mib

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Topografia Corneale: caratteristiche 3 Visualization

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Color-coded map: scale

**Absolute  
(standardised)**

Fixed colour-coding system.  
Absolute scales can be different among manufacturers.

\*Hoye-Wilson scale (1.50D step).  
26 steps of 1.50D between 35.5 and 50.5D  
and 5.00 D above and below from 9.0 to 101.50D

Power	Color
20.00	Blue
21.50	Blue
23.00	Blue
24.50	Blue
26.00	Blue
27.50	Blue
29.00	Blue
30.50	Blue
32.00	Blue
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56.00	Blue
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65.00	Blue
66.50	Blue
68.00	Blue
69.50	Blue
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72.50	Blue
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783.50	Blue
785.00	Blue
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813.50	Blue
815.00	Blue
816.50	Blue

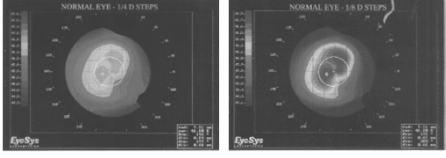




Topografia Corneale: caratteristiche 3 Visualization

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Color-coded map: scale

Adjustable scale



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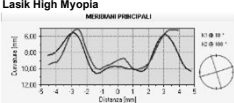
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Topografia Corneale: caratteristiche 3 Visualization

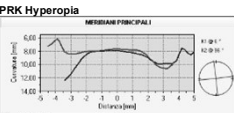
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**Cross Sections**

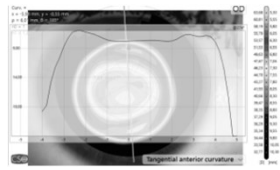
**Lasik High Myopia**



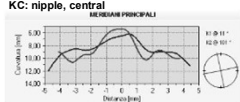
**PRK Hyperopia**





**Ortho-K Myopia**



**KC: nipple, central**



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Topografia Corneale: caratteristiche 3 Visualization


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**Numeric and statistical displays**


Cursor box




Numerical  $m_{ap}$




Basic Topographic Indexes  
(SimK, Asphericity, LSA, Average corneal power)





Indexes for Corneal Optical Quality  
(SRI, SAI, RMS, MTF)



Keratoconus Indexes (AK, AGC, I-S value, KPI)



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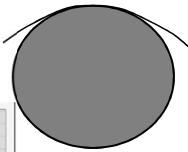
Topografia Corneale: caratteristiche 3 Visualization



Centrally, Normal Cornea has a slightly prolate asphericity that increases towards periphery.



Normal Corneal Asphericity

4.5mm	p=0.86 (0.47/1.21)
8.0mm	p=0.72 (0.14/1.05)




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Topografia Corneale: caratteristiche 3 Visualization

Basic topographic indexes: LSA (longitudinal spherical aberration)

**K-INDICES**

Stigmatism  
3mm  
-0.67D @ 128°  
0.66D @ 146°

Avg Pupilat Pos.  
P = 41.48 D

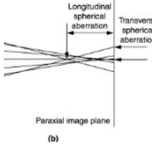
Asphericity  
p = 0.87

Spherical Aberr.  
LSA = 0.75 D

Curvature Irreg.  
CI = 0.82 D

Asymmetry  
A1 = 0.19 D  
A2 = 0.19 D  
SAI = 0.19 D

p	e	LSA (3mm)	LSA (5mm)	LSA (7mm)
0,8	0,45	+0,30	+0,84	+1,70





Analisi refrattiva

Q = -4.5 mm

Cyl = -0.85 D Ax = 184°

Potere Pupillare Medio = 46.19 D

LSA 0.88 D


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Topografia Corneale: caratteristiche 3 Visualization

Basic topographic indexes: SRI

**K-INDICES**

Stigmatism  
3mm  
-0.67D @ 128°  
0.66D @ 146°

Avg Pupilat Pos.  
P = 41.48 D

Asphericity  
p = 0.87

Spherical Aberr.  
LSA = 0.75 D

Curvature Irreg.  
CI = 0.82 D

Asymmetry  
A1 = 0.19 D  
A2 = 0.19 D  
SAI = 0.19 D

**SRI= Surface Regularity Index**

Index of central corneal optical quality.

RMS of curvature with respect to a best fit aspherical surface

SRI=0 indicates a perfect smooth surface

High correlation between SRI and BCVA (Wilson and Klyce, 1991)

INDICE CURVATURE/REGOLATIVI

Asfericità

3mm C/I = -0.94 D @ 90°



7mm C/I = -4.90 D @ 90°

Pot. Pup. Medio = 46.83 D

p = 0.87

LSA = 0.75 D

Imp. Curv(ED) = 1.22 D


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Topografia Corneale: caratteristiche 3 Visualization

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**Keratoconus Indexes**

**KPI= Keratoconus Prediction Index**  
It provides an estimation of possibility to have keratoconus.

KPI is not a good index to distinguish between moderate and severe keratoconus (Smolek and Klyce, 1997)

KERATOCONUS

AK 46.92 D

AGG 1.33 D/mm

PKR 0.25

Topography not compatible with keratoconus

SCHEFFING DEL CHERATOCONO

Ceratometria attuale (AK)

AK = 6.77 mm

Ceratometria di controllo (AKC)

AKC = 5.19 D/mm

Indice di Scheffing

SI = 6.88 D

Probabilità di cheratoconus

KPI = 100 %

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Area del Cheratocono

A = 0.82 mm<sup>2</sup>

Circonferenza del Cheratocono

D = 5.35 mm

Circonferenza PKR

Radius (mm) = (0.73-2.25)

Apex (mm) = (1.81-2.6)

Pattern di Ciconekari

RBC = 1.35

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Topografia Corneale: caratteristiche 3 Visualization

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**Keratoconus Indexes**

**Integrated systems: Placido-based CVK + Scheimpflug Camera**

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Topografia Corneale: caratteristiche 3 Visualization

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**Aberrazioni corneali**

**Wave-front**

Wave-front

Corneal Surface

Perfect spherical wave-front generated by Cartesian oval

Wave Front generated by the corneal surface

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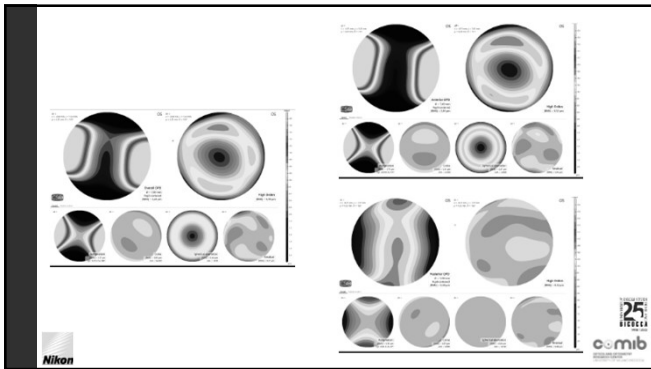
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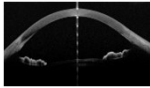
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**Key points**

- Intro CdL e COMIB
- Biomicroscopia
- Topografia Corneale
- Tomografia (Scheimpflug camera, OCT)
- Aberrometria
- Pupillografia
- Sistemi integrati di valutazione del film lacrimale




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**Sistemi a riflessione vs sistemi a scansione**

- Sistemi a riflessione (es topografo): presentano una miglior accuratezza nella rappresentazione della cornea anteriore
- Sistemi a scansione (es Scheimpflug): ampia copertura, mappe curvatura e elevazione posteriori, pachimetria etc

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Sistemi combinati

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**Tomografia:** tomos = taglio + grapho = scrivere/registrare (greco)

**WHAT?** Tecnica di imaging che consente di ottenere immagini dettagliate di una sezione specifica del corpo o di un oggetto tridimensionale. Questa tecnica è ampiamente utilizzata per visualizzare gli strati interni in modo non invasivo.

**Scheimpflug tomography**

(a)

**Optical Coherence Tomography**

(a) (b) (c)

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**Scheimpflug camera**

Theodor Scheimpflug (1865-1911): Capitano dell'esercito austriaco che mise a punto uno strumento per correggere le distorsioni dovute alla prospettiva nella fotografia aerea.

optical sectioning of lens and cornea

(a)

detector surface

(b)

**Depth of Field:** The range of distances that pass extending before and beyond the point of focus is the depth of field. It depends on focusing distance and aperture (f-number) (see next slide).

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**Scheimpflug camera**

WHY

(a)

(b)

(c)

Normally, the lens principal plane and the image plane of a camera are parallel (a). If the object plane is not parallel to the lens, the image will be sharp only along a line where the image intersects the plane of the detector (b)

**Scheimpflug condition:** The detector plane and the lens plane meet at a line through which also the object plane passes. With this condition, the image of a planar object that is not parallel to the detector plane can be completely sharp.

\* a) b) c) Not in scale

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### Scheimpflug Tomographer + Reflection Topography

**Summary Index**

Parameter	Value
Max. $\mu$	0.001 - 0.003 mm
Min. $\mu$	0.001 - 0.003 mm
Max. $\mu$ (at 10.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 15.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 20.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 25.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 30.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 35.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 40.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 45.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 50.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 55.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 60.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 65.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 70.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 75.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 80.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 85.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 90.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 95.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 100.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 105.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 110.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 115.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 120.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 125.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 130.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 135.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 140.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 145.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 150.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 155.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 160.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 165.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 170.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 175.00°)	0.001 - 0.003 mm
Max. $\mu$ (at 180.00°)	0.001 - 0.003 mm

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### Optical Coherence Tomography

Year	Milestone
1991	Demonstration of OCT in vitro
1993	First in vivo images of the retina
1994	Carl Zeiss (Humphrey Instruments) acquired OCT technology
1995	Clinical studies with first prototypes
1996	First commercial TD-OCT system introduced (ZEISS OCT 1)
1999	Approximately 200 units sold
2000	Improved commercial system ZEISS OCT 2
2001	Approximately 400 units sold
2002	Second generation TD-OCT system introduced (ZEISS Stratus OCT™)
2005	OCT becomes a standard of care
2006	Approximately 6000 units of ZEISS Stratus OCT sold
2006	Multiple companies enter ophthalmic market with FD-OCT devices
2009	Worldwide OCT revenues exceed US\$ 250 million
2010	US Medicare reimbursed OCT procedures exceed \$ million
2010	Worldwide reimbursement payments exceed US\$ 1 billion
2012	ZEISS Cirrus™ HD-OCT reaches 10000 installations
2012	Inventors of OCT receive Antonio Champalimaud Vision Award

La tomografia a coerenza ottica (Optical Coherence Tomography, OCT) applicata all'occhio è una tecnica diagnostica non invasiva nata negli **anni Novanta** del Novecento.

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### Optical Coherence Tomography

- L'OCT fornisce immagini trasversali (x,y), ma anche sezioni tomografiche ((x,z) e (y,z)) della retina o del segmento anteriore dell'occhio.
- La tecnica OCT misura l'intensità della luce retro-diffusa o riflessa e il ritardo dell'eco. La misura del tempo di ritardo permette di misurare le distanze.
- L'OCT impiega radiazione elettromagnetica (tipicamente nel vicino IR) con cui è possibile ottenere una risoluzione spaziale tipicamente pari a 3-5  $\mu\text{m}$  in direzione assiale (z) e 15-20  $\mu\text{m}$  trasversalmente (x,y).

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### Optical Coherence Tomography

Reference mirror

Light source

Beam splitter

Eye

Photo-detector

Schema generico basato su interferometro di Michelson

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### Optical Coherence Tomography

I primi OCT erano di tipo **Time Domain** (Specchio mobile).

Gli strumenti moderni sono di tipo **Fourier Domain**:

- Spectral Domain OCT (SD-OCT):** lo specchio di riferimento è **fisso** (riduzione della probabilità di artefatti) e il rivelatore è uno spettrometro (es CCD) che rivela **radiazioni di frequenza diversa**. E più sensibile di un TD OCT. I tempi di acquisizione sono inferiori.
- Swept Source OCT (SS-OCT):** l'informazione in frequenza si ottiene impiegando una **sorgente che emette radiazione di lunghezza d'onda variabile**. Esistono SS OCT che impiegano intervalli di lunghezza d'onda tra 1000 e 1300 nm; ciò permette la visualizzazione di strutture **più profonde** rispetto al caso delle lunghezze d'onda più corte.

Figure 2.16 Overview of various OCT techniques.

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### Optical Coherence Tomography

I risultati si rappresentano nelle forme:

- A-scan 1D:** riflettività delle strutture alle varie profondità (z) lungo un singolo raggio luminoso (es. misura della lunghezza oculare)
- B-scan 2D:** insieme di A-scan acquisiti muovendosi lungo una linea (x oppure y) trasversale
- C-scan 3D:** insieme di B-scan acquisiti con una scansione completa lungo x e lungo y

Anterior segment

A-scan

B-scan

Volume scan

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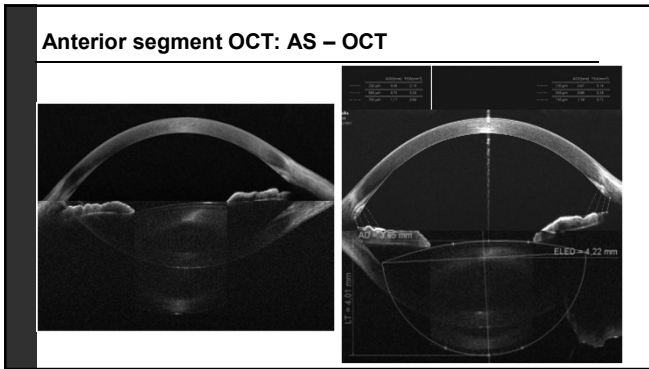
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### Quale impiego dell'AS-OCT in Contattologia?

- Assessment of anterior segment structures (ocular surfaces)**
  - Corneal thickness
  - Volume (TMV), tear meniscus height (HMT) and turbidity
  - Sagittal depth (for a specific chord)
- Assessment of CLs**
  - CL thickness
  - Edge form (shape and thickness)
- In vivo characterization of contact lens fitting and interaction with the ocular surface**
  - Blood vessel compression on the landing zone in Scleral CL
  - Vault thickness and fluid reservoir (FR) turbidity in Scleral CL
  - Epithelial thinning and peripheral thickening in orthokeratology

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### Quale impiego dell'AS-OCT in Contattologia?

- L'AS-OCT nella misura delle strutture oculari**
  - Lo spessore corneale**
  - Tear meniscus height**
  - La stima della sagitta della superficie corneale anteriore**

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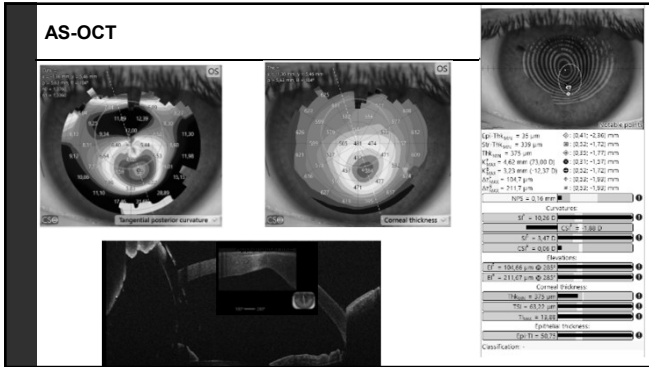
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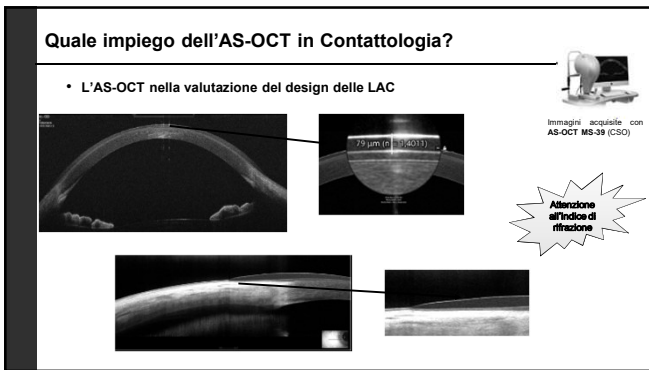
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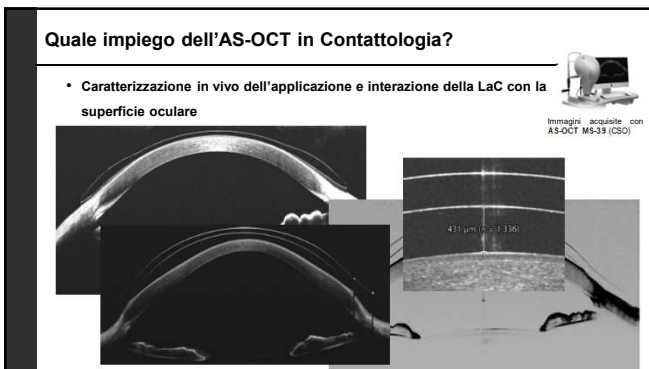
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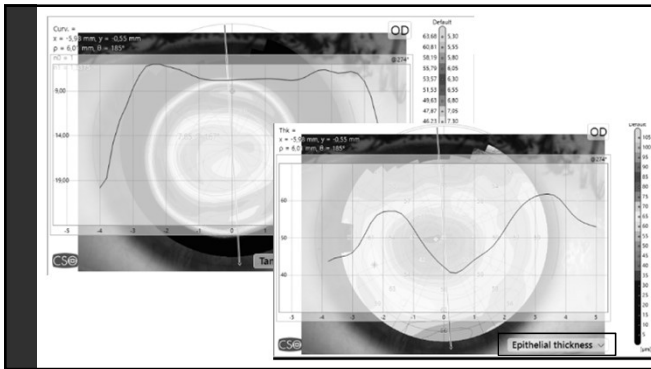
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### Scheimpflug vs AS - OCT

Pro	Cons
<p><b>Scheimpflug Tomography</b></p> <p><b>PRO</b></p> <ul style="list-style-type: none"> <li>• Costi più contenuti</li> <li>• 'Facilità' d'uso?</li> </ul> <p><b>CONTRO</b></p> <ul style="list-style-type: none"> <li>• Minor risoluzione</li> <li>• Deformazione prospettica</li> </ul>	<p><b>AS-OCT</b></p> <p><b>PRO</b></p> <ul style="list-style-type: none"> <li>• Imaging ad alta risoluzione</li> <li>• Maggior 'penetrazione' delle strutture</li> </ul> <p><b>CONTRO</b></p> <ul style="list-style-type: none"> <li>• Costi elevati</li> <li>• Maggior collaborazione del soggetto?</li> </ul>

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### Key points

- Intro CdL e COMIB
- Biomicroscopia
- Topografia Corneale
- Tomografia (Scheimpflug camera, OCT)
- Aberrometria
- Pupillografia
- Sistemi integrati di valutazione del film lacrimale

**Mikon** **c-mib**

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### Aberrometria oculare

Raggi divergenti  
Fronte sferico

Raggi aberrati  
Fronte irregolare

Shack-Hartmann  
Microlens array

Pyramidal sensor

**WHAT?**

**comib** 25th anniversary

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### HSS vs WFP

**Campionamento segnale e risoluzione strumento**

- Nel sistema Hartmann-Shack il fronte d'onda viene campionato da un array di lenti, la risoluzione dipende:
  - dal numero delle lenti (> numero > risoluzione)
  - dalla dimensione (< diametro > diffrazione)
 Risoluzione spaziale media 250-125 micron
- Nel sistema PWS il fronte d'onda non viene mai campionato finche non arriva sul sensore.
  - il numero di campioni di questo sistema è «rappresentato» dal numero di pixel del CCD che vengono illuminati da una delle 4 sub-pupille.
 Risoluzione spaziale media 41 micron

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### Aberrometry: Wavefront refraction

**Definition**  
...wavefront refraction is defined as the process of deriving a conventional spherocylindrical result from wavefront aberration measurements using methods that take into account the amount and type of higher-order aberrations present in an eye to optimize optical quality or vision.

**spherocylindrical refraction**  
according to Zernike  

$$R_0^0 = 1$$

$$R_2^0 = \sqrt{3} \left( \frac{2z^2 - r^2}{2r^2} \right)$$

$$R_2^2 = \sqrt{6} \left( \frac{z^2 - r^2}{r^2} \right)$$

$$R_4^0 = \sqrt{5} \left( \frac{16z^4 - 24z^2r^2 + 8r^4}{16r^4} \right)$$

$$R_4^2 = \sqrt{10} \left( \frac{8z^3 - 6zr^2}{4r^3} \right)$$

$$R_4^4 = \sqrt{35} \left( \frac{8z^2 - 6r^2}{4r^2} \right) \left( \frac{z^2 - r^2}{r^2} \right)$$

$$R_6^0 = \sqrt{7} \left( \frac{32z^6 - 96z^4r^2 + 64z^2r^4 - 16r^6}{32r^6} \right)$$

$$R_6^2 = \sqrt{42} \left( \frac{16z^5 - 20z^3r^2 + 8zr^4}{8r^5} \right)$$

$$R_6^4 = \sqrt{70} \left( \frac{16z^4 - 12z^2r^2 + 3r^4}{4r^4} \right) \left( \frac{z^2 - r^2}{r^2} \right)$$

$$R_6^6 = \sqrt{210} \left( \frac{6z^3 - 6zr^2}{6r^3} \right) \left( \frac{z^2 - r^2}{r^2} \right)$$

**wavefront aberration measurements**

**accommodation**

**comib**

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### Aberrometria metriche: Point Spread Function (PSF)

La PSF è una funzione che ci dice quale sarà l'immagine prodotta da una lente o, più in generale, da un sistema ottico quando l'oggetto è un punto. L'effetto è dovuto a diffrazione, aberrazioni e possibili difetti.

Se la PSF è dovuta solo a diffrazione si ha:

Nikon 25 years of excellence c:mib

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### Aberrometria metriche: Modulation Transfer Function (MTF)

Dalla misura del contrasto (modulation M)...

... alla misura della trasformazione del contrasto da parte di un sistema ottico (modulation transfer MT)...

... alla misura della dipendenza della trasformazione del contrasto dalla frequenza spaziale (modulation transfer function MTF).

Nikon 25 years of excellence c:mib

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### Aberrometria: importanza della pupilla

**Ø = 12 mm**

SpT 0% - SF 0%

VO 0 mm +0.83

VO 12.5 mm +0.82

Total = 0.15 RMS (µm) LDA = 0.16 HCA = 0.25

**Ø = 23 mm**

SpT 0% - SF 0%

VO 0 mm +0.95

VO 12.5 mm +0.94

Total = 0.15 RMS (µm) LDA = 0.14 HCA = 0.25

Nikon 25 years of excellence c:mib

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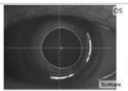


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- Sistemi integrati di valutazione del film lacrimale


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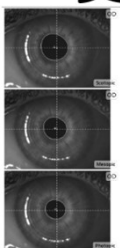


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**Pupillografia**

Valutazione qualitativa e quantitativa (pupillometria) della forma, della posizione e della grandezza della pupilla.

WHAT?

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**Pupillografia: La pupilla**

- Diaframma dell'occhio umano
- Dimensioni determinate dall'azione congiunta di 2 muscoli a controllo vegetativo
- Decentramento nasale di 0,5 mm rispetto all'asse visivo (Westheimer, 1970)
- Il centro pupillare può muoversi con il variare della grandezza della pupilla

WHAT?

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### Pupillografia: La pupilla



Dipende da:

- Livello d'illuminazione
- Visione binoculare e accomodazione
- Età (restringimento e minore reattività con l'invecchiamento)
- Difetto visivo
- Farmaci (miotici: simpaticomimetici o parasimpaticolitici)
- Fattori Psicologici (paura, sorpresa...arousal)


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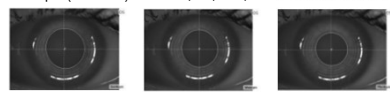
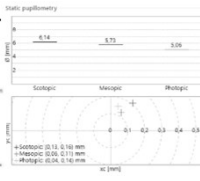
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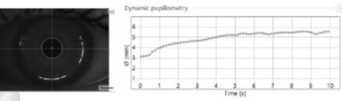
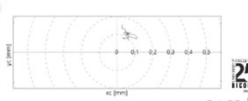
### Pupillografia

Static



- Scotopic (0.04 lux\*)
- Mesopic (4 lux)
- Photopic (50 lux)

Dynamic (500 lux)

\*al piano della pupilla


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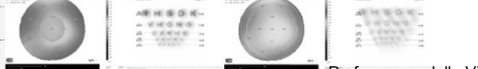
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### Pupillografia

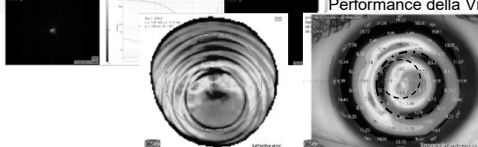
Profondità di fuoco del sistema



Qualità dell'immagine retinica



Performance della Visione




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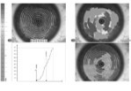


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### Key points

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### Sistemi integrati di valutazione del film lacrimale

#### DED definition

"Dry eye is a multifactorial disease of the tears and ocular surface that results in symptoms of discomfort, visual disturbance, and tear film instability, with potential damage to the ocular surface. It is accompanied by increased osmolarity of the tear film and inflammation of the ocular surface"



The definition and classification of dry eye disease: report of the definition and classification subcommittee of the international dry eye Workshop. *Ocul Surf* 2007;2007(5):356-92.



↓

"Dry eye is a multifactorial disease of the ocular surface characterized by a loss of homeostasis of the tear film, and accompanied by ocular symptoms, in which tear film instability and hyper-osmolarity, ocular surface inflammation and damage, and neuro-sensory abnormalities play etiological roles."

Craig JP, Nichols KK, Nichols JJ, Caffery B, Dua RS, Alpe KE, et al. TFOSDEWS II Definition and Classification Report. *Ocul Surf* 2017;15:278-93.


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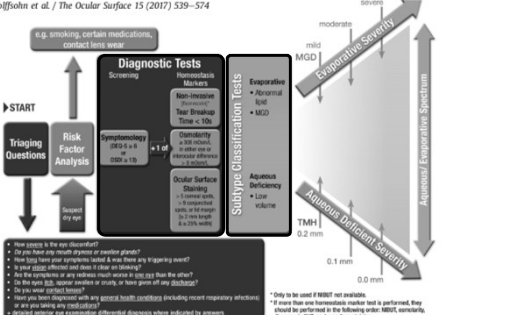
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### DEWS II proposal for a DED diagnostic test battery

J.S. Wolffsohn et al. / *The Ocular Surface* 15 (2017) 539–574



START

Triaging Questions

Risk Factor Analysis

Diagnosis by eye

Diagnostic Tests

Screening

Non-invasive

Invasiveness

Subtype Classification Tests

Evaporative Abnormalities

Aqueous Deficiency

Evaporative Severity

Aqueous Deficient Severity

MGD

TMH

0.0 mm

0.1 mm


0.2 mm

Aqueous Deficient Spectrum

Evaporative Spectrum

How do you feel about your eyes?  
 • Do you have any recent symptoms or episodes present?  
 • How long have you been experiencing them & how often are they occurring now?  
 • Do you experience them more often than the other?  
 • Do you wear contact lenses or have any other eye conditions?  
 • Do you wear contact lenses?  
 • How do you feel about your eyes?  
 • Do you have any other eye conditions?  
 • Do you have any other eye conditions?  
 • Do you have any other eye conditions?

\*Only to be used if NIBST not available.  
 \*If more than one homeostatic marker test is performed, they should be performed in the following order: NIBST, osmolarity, fluorescent dye, and tear film break-up time.




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### Caratteristiche dei test per la valutazione del DED

- Covering different aspects
  - Symptoms
  - Visual Disturbance
  - Tear film stability
  - Tear Volume
  - Tear Composition
  - Damage of Ocular Surface
  - Inflammation of the Ocular surface
  - Eyelids aspects
- Quantitative versus qualitative assessment
  - Non-Invasive
  - Clinically performable
  - Automated assessment

**Nikon** **25** **ITRILLI** **c:mib**

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### Batteria di test diagnostici proposti dal DEWS II per DED

**Nikon** **25** **ITRILLI** **c:mib**

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### OSDI

Ocular Surface Disease Index (OSDI)

	None	Mild	Moderate	Severe
1. Irritation or burning	1	2	3	4
2. Dryness	1	2	3	4
3. Foreign body sensation	1	2	3	4
4. Itching	1	2	3	4
5. Redness	1	2	3	4
6. Blurred vision	1	2	3	4
7. Difficulty seeing at night	1	2	3	4
8. Difficulty wearing contact lenses	1	2	3	4
9. Total score	1	2	3	4

- 12-item questionnaire (Schiffman et al, 2000) that measures:
  - frequency of symptoms
  - impact of symptoms on the vision related functioning
  - environmental triggers
- Strong establishment in the field
- Screening Criteria:
  - Mild 13-22,
  - Moderate 23-32,
  - Severe > 33.

**Nikon** **25** **ITRILLI** **c:mib**

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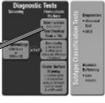
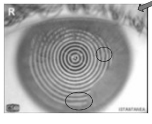
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### NIBUT

- BUT is the interval of time that elapses between a complete blink and the appearance of the first break in the tear film
- NIBUT (with grid pattern or keratoscope) is generally longer than FBUT
- Healthy population  $11.2 \pm 6.8$  sec (Nichols et al, 2002)
- A specific software can automatically assess localized changes in keratoscopic image

NIBUT 13.0sec

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### OSMOLARIMETRIA

L'osmolarità: numero totale di molecole e ioni presenti in un litro di soluzione. È definita come il numero di *osmoli* (Osm) per litro (L) di soluzione, dove l'osmole è l'unità di misura del numero di particelle che contribuiscono alla pressione osmotica della soluzione.

Valori <308 mOsmol/L sono considerati **normali** (Lemp et al., 2011).  
 Valori ≥316 mOsmol/L indicano **occhio secco** clinicamente rilevante (Tomlinson et al., 2006)

Metodo di misura:

- tear fluid collected directly from the eyelid margin
- impedance measurement to provide an indirect assessment of osmolarity (attraverso una curva di calibrazione)

Come viene influenzata durante il porto delle lenti a contatto?

**Ease iniziale:**

- La LAC viene posizionata sull'occhio -> lacrimazione riflessa + eccesso di soluzione -> riduzione dell'osmolarità

**Porto lungo di LAC morbide**

- ridotta sensibilità corneale + riduzione della produzione di lacrima -> aumento dell'osmolarità
- rottura del film lacrimale + stabilità del film lacrimale ridotta -> evaporazione eccessiva -> aumento dell'osmolarità

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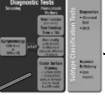
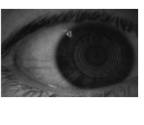
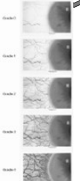
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### Bulbar Redness

- Conjunctival redness is a clinical sign that is suggestive of ocular surface inflammation
- Useful for diagnosis and documentation of treatment.
- A conjunctival digital picture of the eye is acquired and manually graded with the help of a reference grading scale (Efron, 1988).

Ocular redness Grade 2

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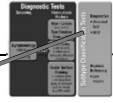
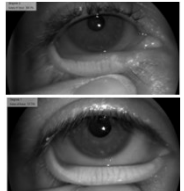
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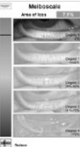

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### Meibography

- Infrared illumination LEDs and IR high-sensitive camera captures a gray-scaled image of Meibomian glands (Mathers et al, 1994)
- Glands marking software tool allows to determine the percentage of glands loss
- Final score is computed automatically and it can be verified by comparing the acquired image with a meiboscale (Puit, 2012)

Meibomian glands 7.5%

**comib**

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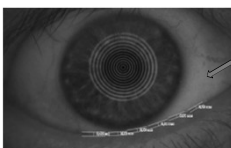
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### Tear meniscus height

- TMH is the most direct approach to study the tear film volume (Wolffshon, 2017)
- Dry eye  $0.15 \pm 0.7$  mm;
- Normal  $0.31 \pm 0.2$  mm

Slit-lamp TMH measurement (Ibrahim et al, 2010)



Tear meniscus 0.30mm

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### Thank you for your attention!



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