Wavefront Sensing Meeting. San Francisco. Feb.2003

Surgically induced aberrations and optical performance

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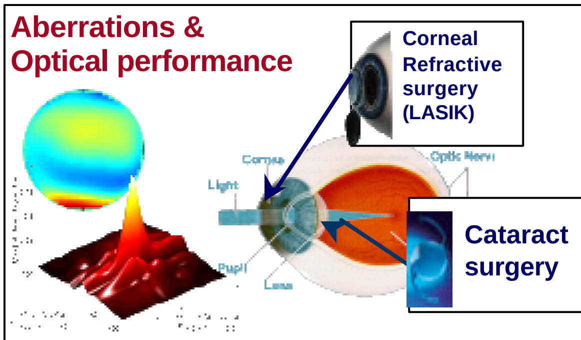
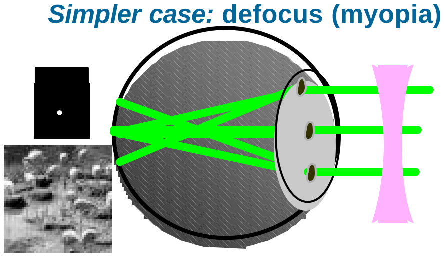
Aberrations & Optical performance



Where does the optical degradation arise from?

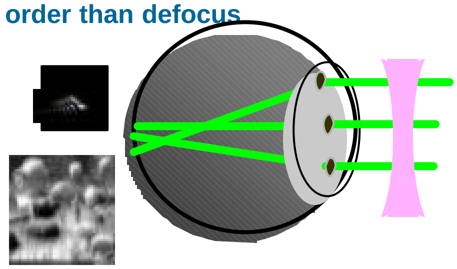
Aberrations

Simpler case: defocus (myopia)

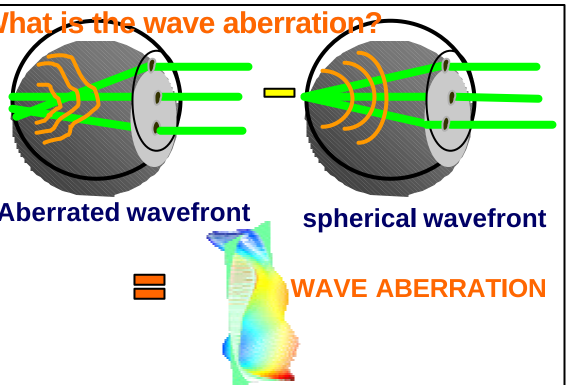


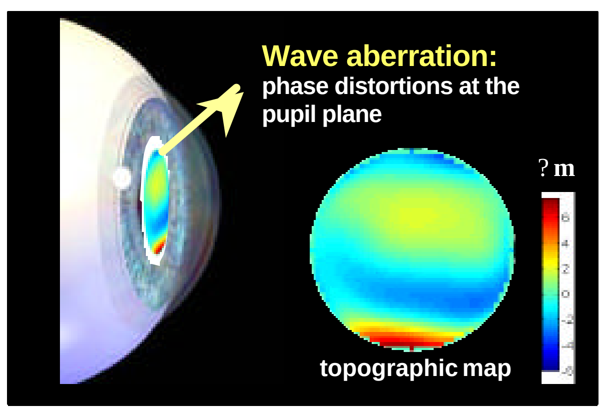
Aberrations

The eye suffers from aberrations of higher order than defocus

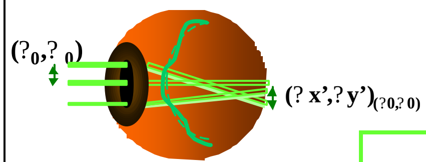


What is the wave aberration?





Mathematical expression

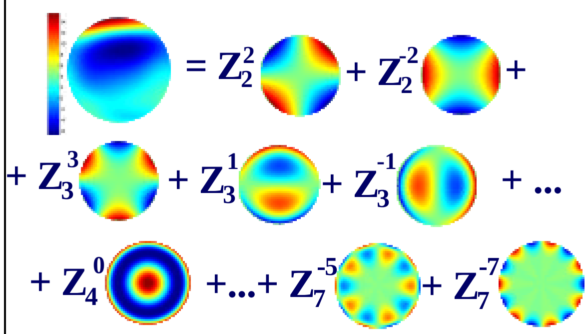


The deviations at the plane of the retina are proportional to the derivatives of the wave aberration

$$?y'?\frac{1}{R_p}\frac{?W(\bar{?},\bar{?})}{??}$$

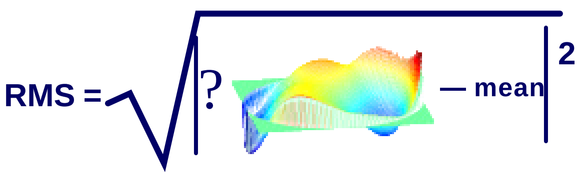
$$?x'?\frac{1}{R_p}\frac{?W(\bar{?},\bar{?})}{??}$$

Zernike Polynomial expansion

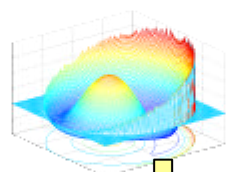


Optical quality metrics

Root mean square wavefront error:



Wavefront aberration



Modulation Transfer (MTF)

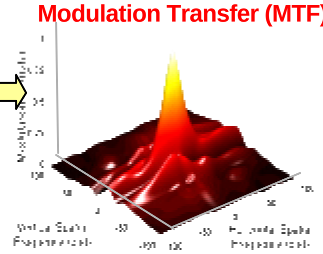
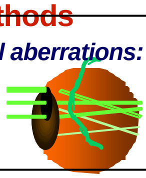


Image of a point (PSF)

Methods

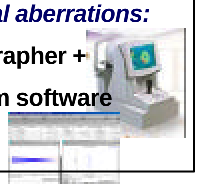
Total aberrations:

LRT



Corneal aberrations:

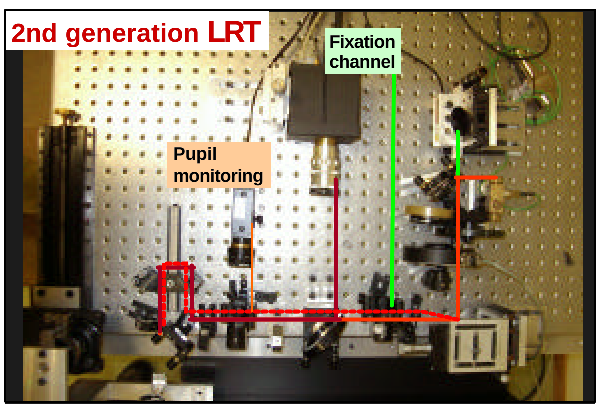
Topographer + Custom software

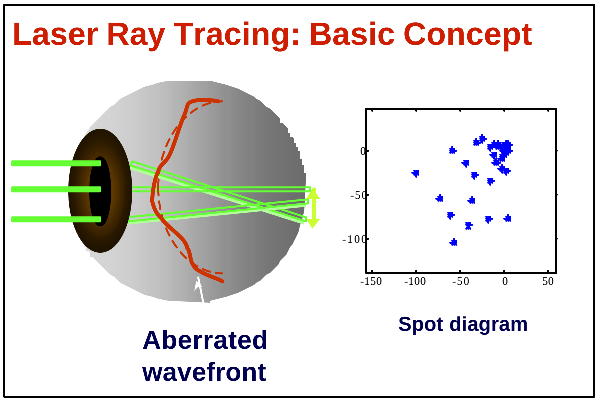


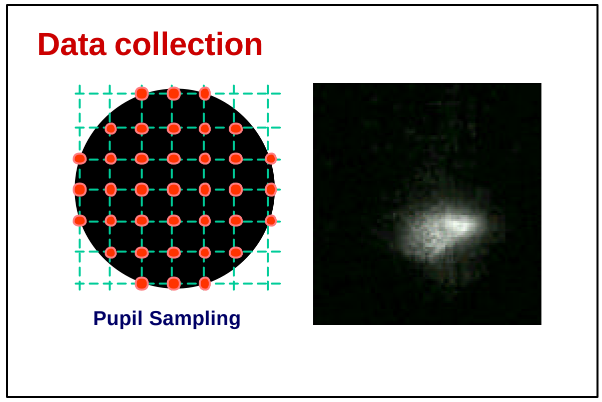
Ocular biometry

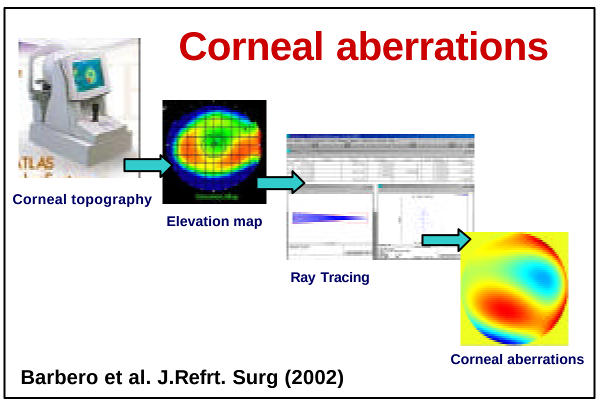
IOL master (OCT + Slit lamp)

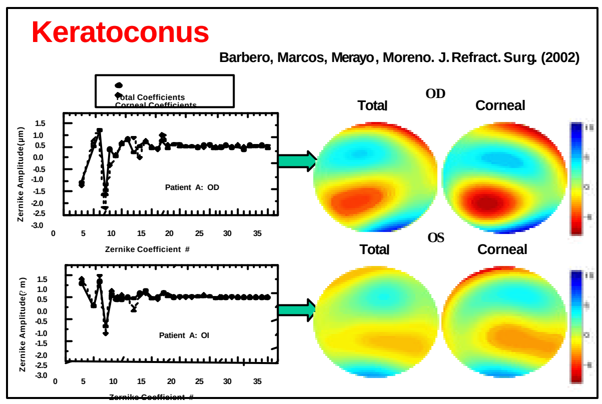
2nd generation LRT

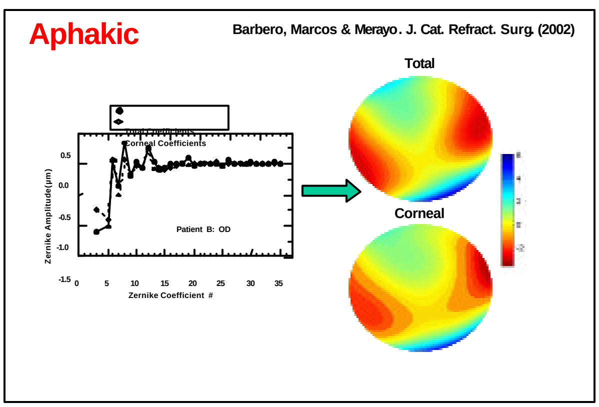


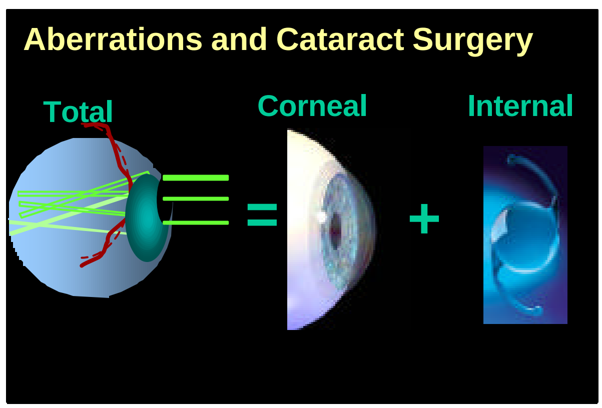

Laser Ray Tracing: Basic Concept
Aberrated wavefront
Spot diagram
0
-50
-100
-150
-100
-50
0
50


Data collection
Pupil Sampling


Corneal aberrations
Corneal topography
Elevation map
Ray Tracing
Corneal aberrations
Barbero et al. J.Refrt. Surg (2002)


Keratoconus
Barbero, Marcos, Merayo, Moreno. J. Refract. Surg. (2002)
OD
Total
Corneal
OS
Total
Corneal
Patient A: OD
Patient A: OI
Zernike Coefficient #


Aphakic
Barbero, Marcos & Merayo. J. Cat. Refract. Surg. (2002)
Total
Corneal
Corneal Coefficients
Patient B: OD
Zernike Amplitude(μm)
Zernike Coefficient #

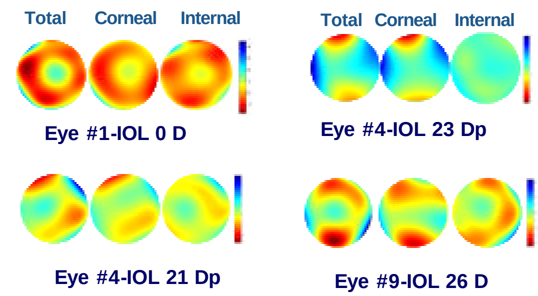

Aberrations and Cataract Surgery
Total
Corneal
Internal
=
+

Patients (cataract surgery)

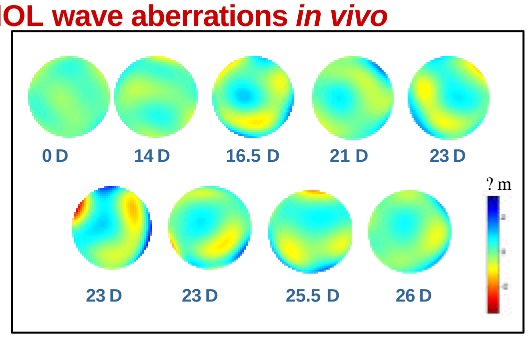
- 9 eyes from 7 subjects
- mean age: 70.58 ± 8.96
- Measurements at least 2 months post-surgery
- 6 eyes also before surgery

- Phacoemulsification: 4.1 mm superior incision (no suture)
- Spherical IOLs
- Powers from 0 to 26 D.

Total, corneal & internal aberrations POST CATARACT surgery

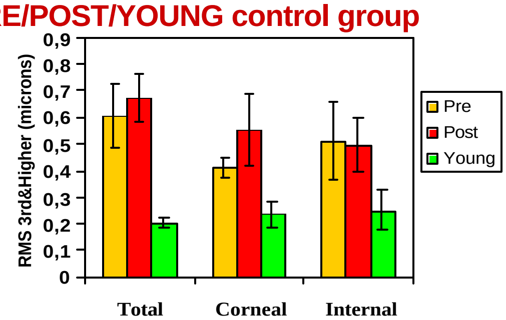


IOL wave aberrations *in vivo*



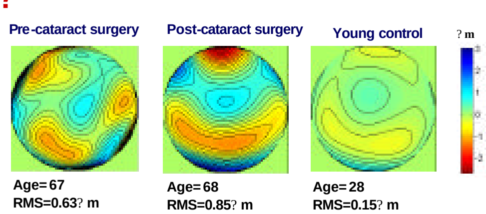
Barbero, Marcos, & Jimenez-Alfaro, JOSA A (2003)

Comparison total aberrations PRE/POST/YOUNG control group



Barbero, Marcos, & Jimenez-Alfaro, JOSA A (2003)

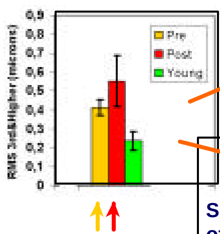
Why the aberrations of pseudophakic patients are higher than those of young eyes?



Various reasons:

- Increase of corneal aberrations with age, and increase of corneal aberrations by incision
- Aberrations of the IOL
- Tilt/decentrations of IOL
- No balance internal/corneal aberrations

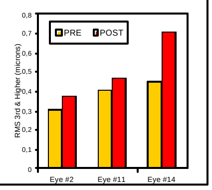
Corneal aberrations



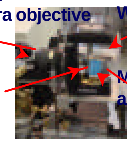
Increase of corneal aberrations with age

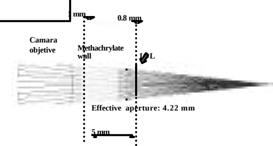
Oshika et al.1999
Guirao et al. 2000

Slight increase of corneal aberrations with surgery

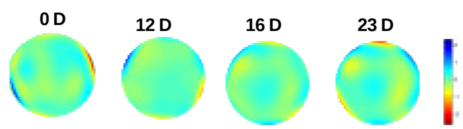


Measuring IOL aberrations *in vitro*





IOL wave aberrations *in vitro*

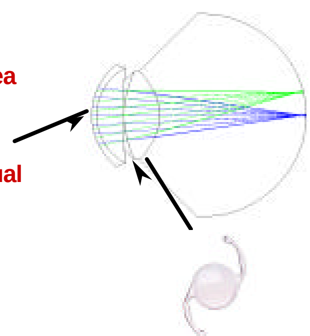


Barbero , Marcos, & Jimenez-Alfaro , JOSA A (2003)

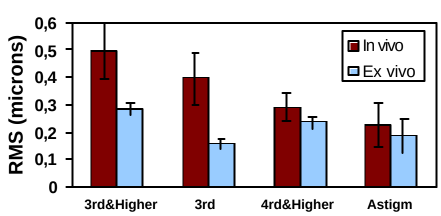
Predicted aberrations of the IOL

Ideal cornea
(for in vitro measurements comparisons)

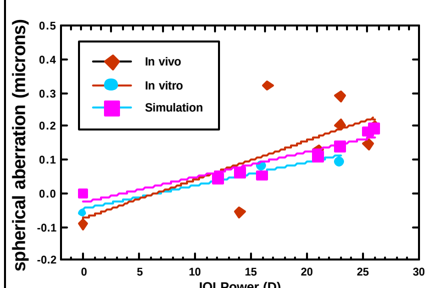
Or individual cornea
(for in vivo measurements comparisons)



IOL Aberrations: in vivo and in vitro

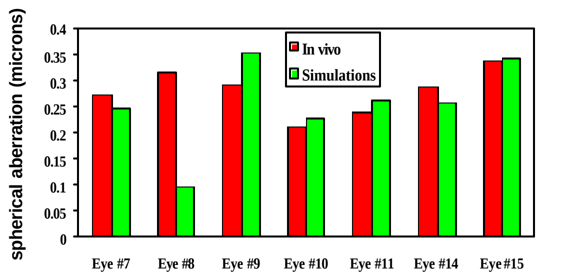


Spherical aberration of the IOL

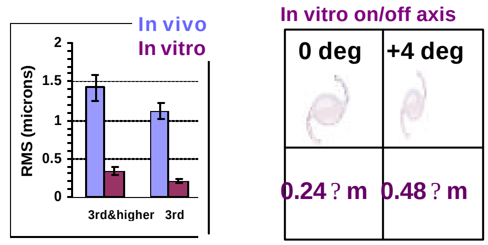


Positive spherical aberration!!

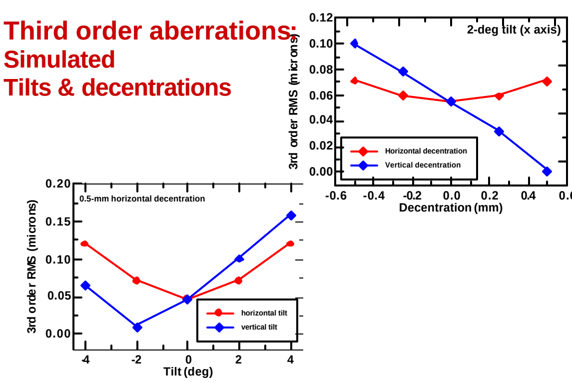
Spherical aberration: in vivo/simulated



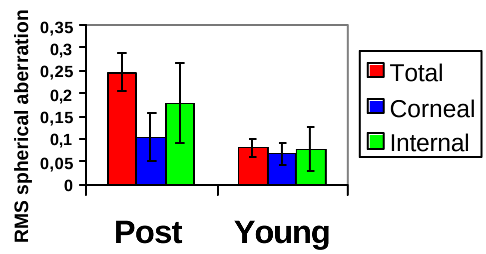
Third order aberrations: Tilts



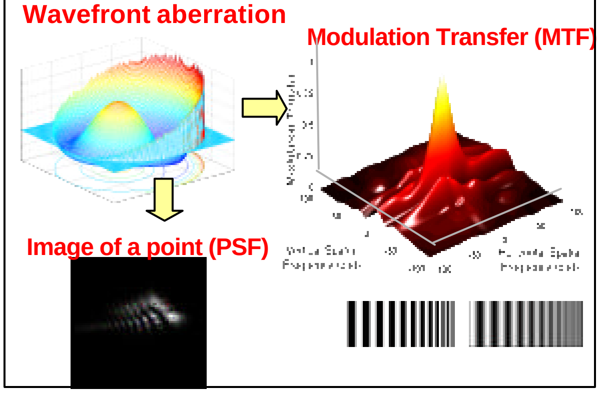
Third order aberrations: Simulated Tilts & decentrations



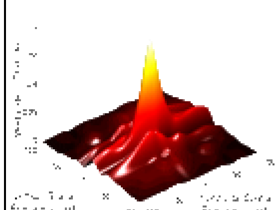
Corneal / Internal aberration balance



Wavefront aberration

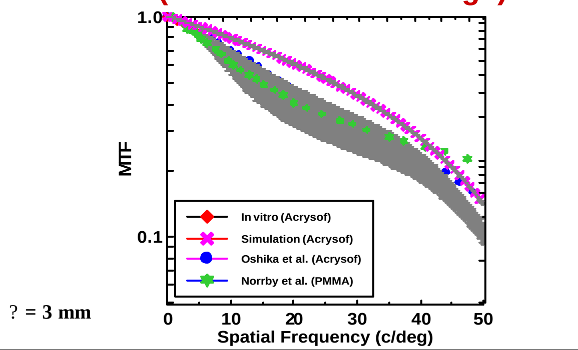


Optical performance in terms of MTF

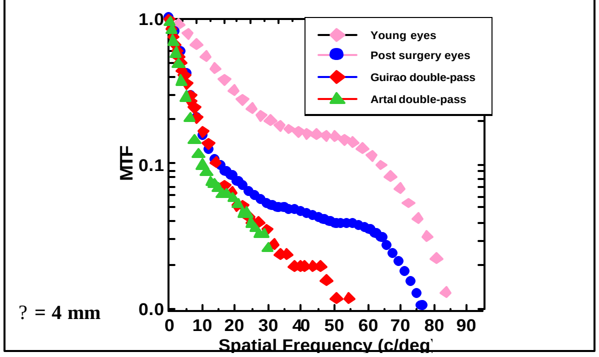


- In vitro MTF measurements
- In vivo double-pass MTF measurements

IOL's MTF (in vitro and from design)



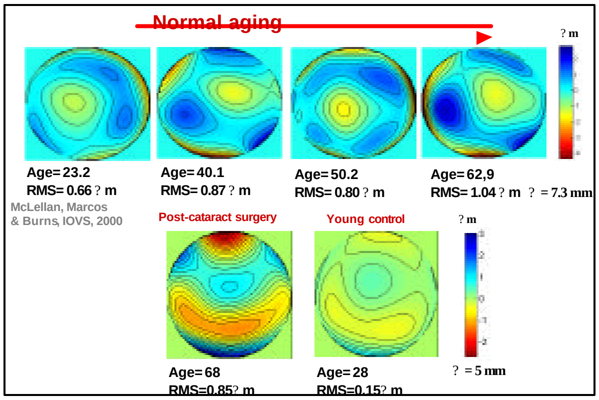
Ocular MTF



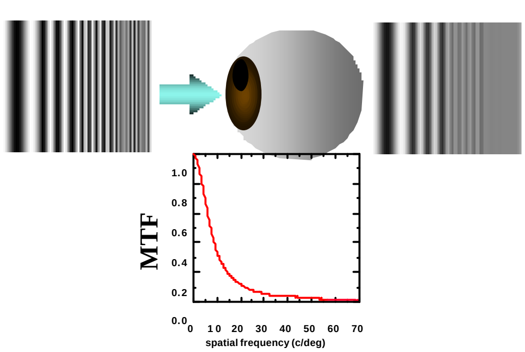
Conclusion

IOLs elliminate the degradation produced by scattering, but do not restore optical quality to young eyes' values....

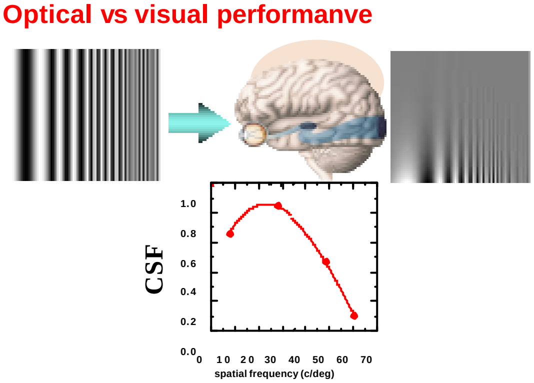
THERE IS ROOM FOR IMPROVEMENT



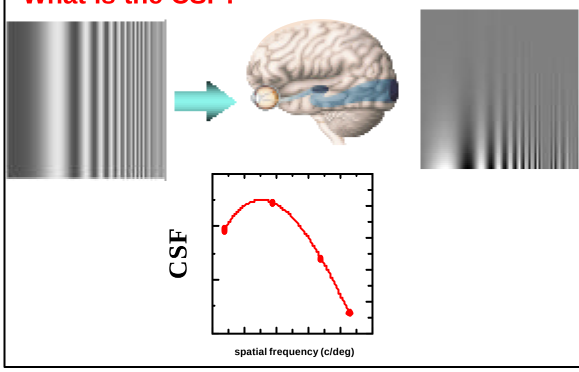
Optical vs visual performanve



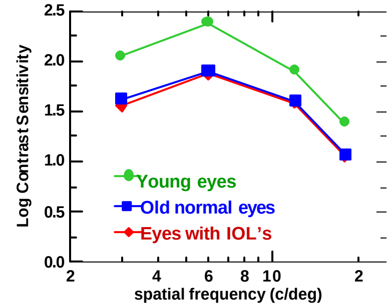
Optical vs visual performanve



What is the CSF?



Visual performance with IOLs



Adapted from Navarro, Ferro, Artal & Miranda, 1993

Potential solution

Aspheric IOLs

With negative spherical aberration, ideally matching the individual cornea

Drawbacks

Tilts and decentrations more detelerious than for spheric IOLs (Atchison, 1989)

Presence of aberrations becomes attenuated by...

Smaller pupils

Increased depth-of-field (i.e. Multifocality)

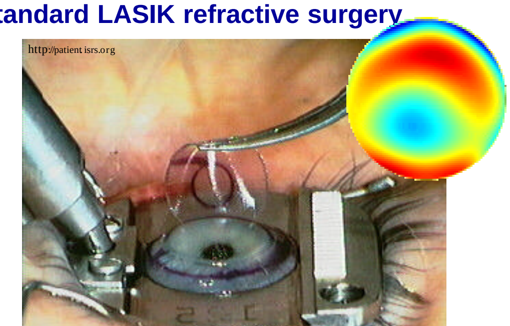
Other questions

Will the benefits of aspheric IOLs exceed their potential drawbacks?

Should we aim toward a customized intraocular (cataract) surgery?

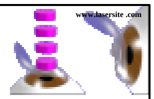
Is an aberration-free eye really needed in an eye without accommodative response?

Optical aberrations and standard LASIK refractive surgery



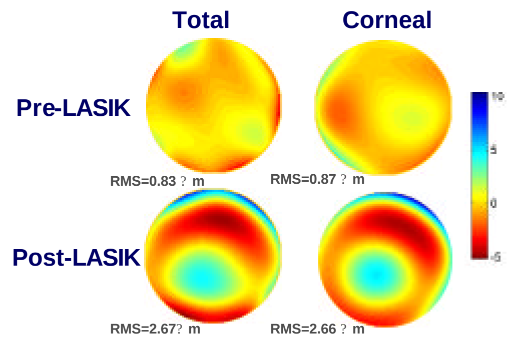
Moreno-Barriuso et al. IOVS; Marcos 2001

Patients (myopic LASIK)



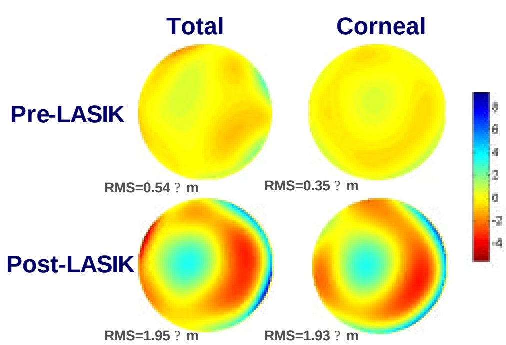
- 22 eyes from 12 subjects
- mean age: 28?5
- Spherical equivalent: -2.5 thru –13 D
- No ocular or retinal condition
- Measurements <1 mo. before and >1 mo. after surgery

- Flying spot Technolas 217-C (B&L surgical)
- Hansatome microkeratome
- Optical zone: 6 mm. Transition zone: 9 mm



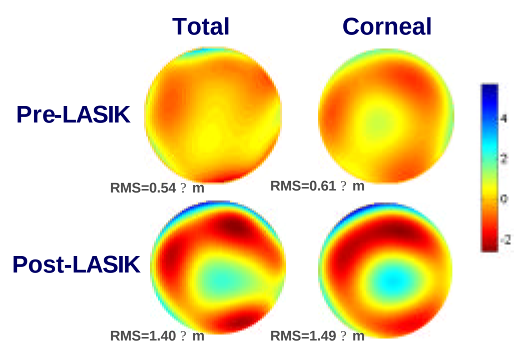
Marcos et al. IOVS (2001)

gacod



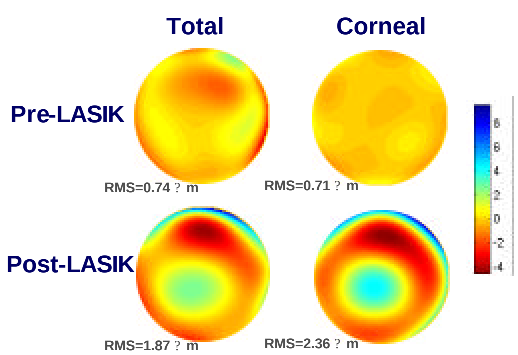
Marcos et al. IOVS (2001)

ahcoi



Marcos et al. IOVS (2001)

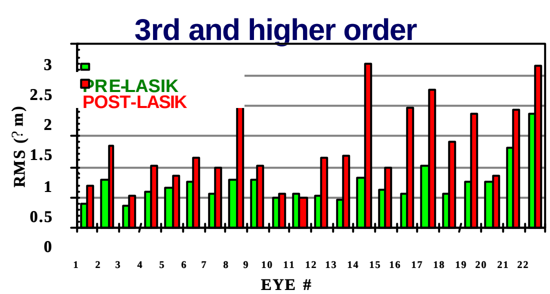
ahcod



Marcos et al. IOVS (2001)

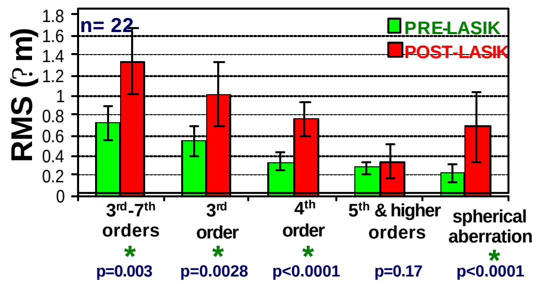
mmaoi

TOTAL aberrations



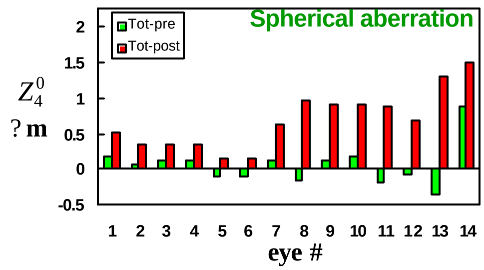
Moreno-Barriuso et al. IOVS (2001)

Average data



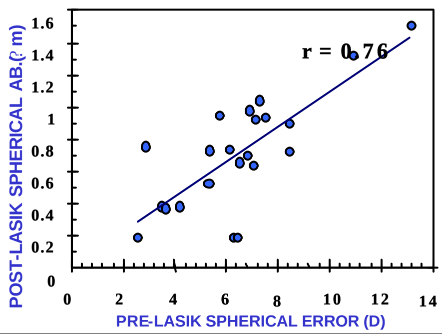
Moreno-Barriuso et al. IOVS (2001)

Increase of TOTAL Spherical Aberration with LASIK

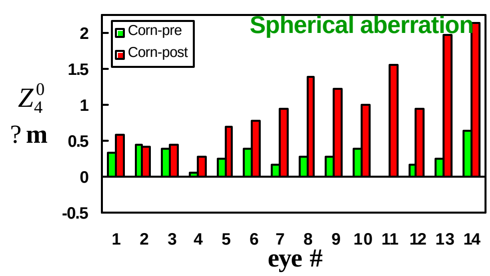


Marcos et al. IOVS (2001)

The higher the pre-op spherical error, the larger spherical aberration is induced

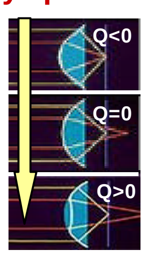


Increase of CORNEAL Spherical Aberration with LASIK



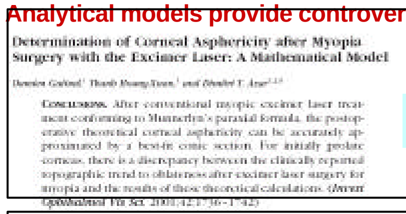
Marcos et al. IOVS (2001)

Why spherical aberration increases?



Because corneal asphericity changes from negative values (prolate cornea) to negative values (oblate cornea). Holladay (1999)

Analytical models provide controversial results:

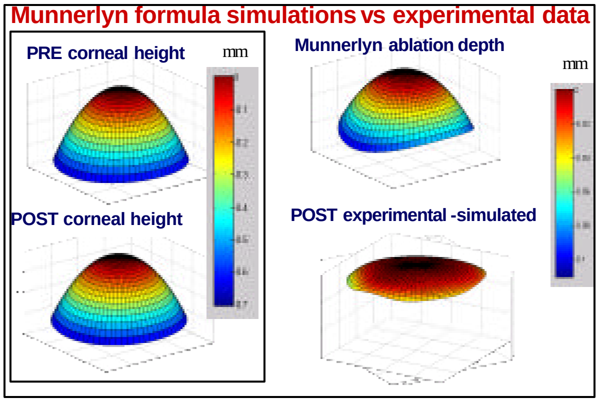

Determination of Corneal Asphericity after Myopia Surgery with the Excimer Laser: A Mathematical Model

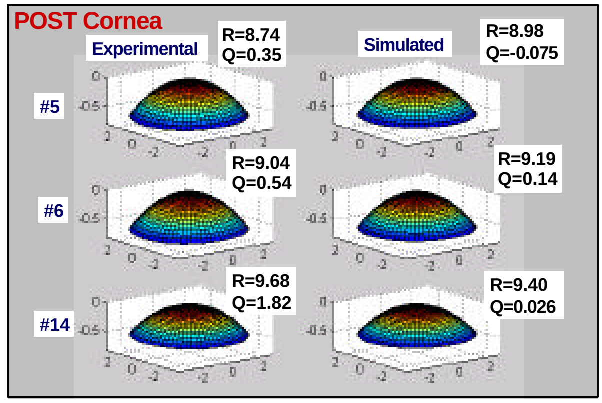
CONCLUSIONS. After conventional myopic excimer laser treatment conforming to Munnerlyn's paraxial formula, the postoperative theoretical corneal asphericity can be accurately approximated by a best-fit conic section. For initially prolate corneas, there is a discrepancy between the clinically reported topographic trend to oblateness after excimer laser surgery for myopia and the results of these theoretical calculations. (Invest Ophthalmol Vis Sci. 2001;42:1736–1742)

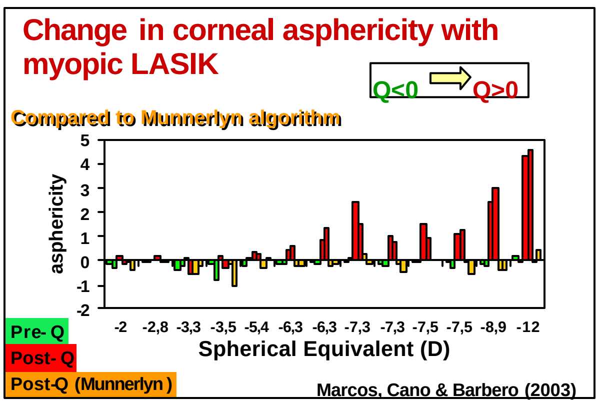
No approximation

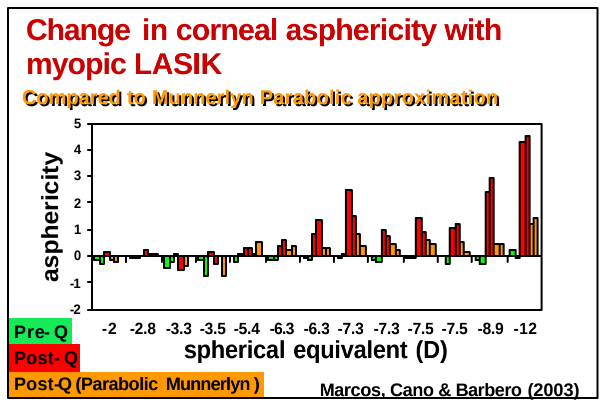
Equation for corneal asphericity after refractive surgery
J.R. Jimenez et al. J. Refract. Surg. In press
CONCLUSIONS: This equation…. Explains the increased spherical aberration after refractive surgery.

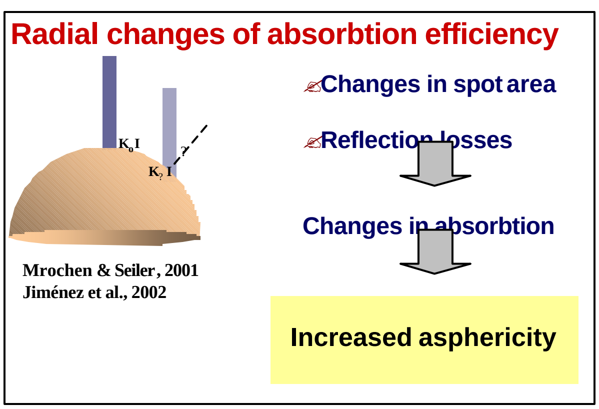
Parabolic approximation











Why corneal asphericity increases?

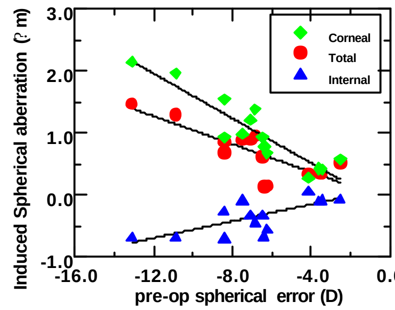
Does the ablation profile really follow the Munnerlyn equation, or an approximation ?

Is the ablation profile properly transferred onto the cornea?

Is the discrepancy due to biomechanical changes?

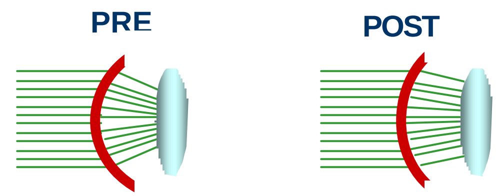
CRITICAL FOR CUSTOMIZED/OPTIMIZED CORRECTION

INDUCED corneal, total & internal aberration



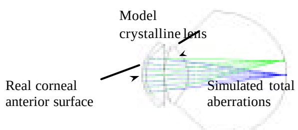
Marcos et al. IOVS (2001)

Explaining the changes in the internal optics

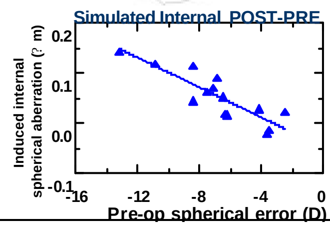


Can the change of ray convergence on the crystalline lens be the cause of the measured change in internal aberrations?

Computer simulation

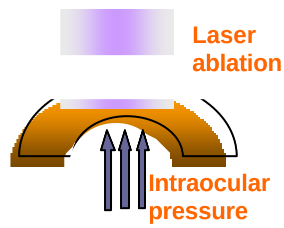


Internal aberration= Total – Corneal



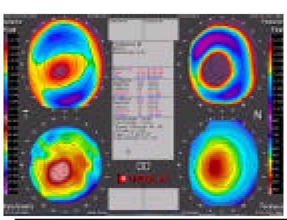
Toward positive values!

Explaining the changes in the internal optics



Can be changes in the posterior corneal surface be the cause of shift of internal aberrations to negative values?

Comparing with scanning slit topography data



Previous studies using Orbscan showed changes in the posterior corneal surface after LASIK

Naroo & Charman (2000)
Baek et al. (2001)
Bruno et al. (2001)
Seitz et al. (2001)

Do those changes in the posterior corneal shape predict our change in posterior spherical aberration?

Spherical aberration of posterior cornea induced by LASIK

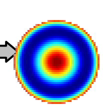
Seitz et al. (2001):

Change in central power:

-6.28 D ⇨ *-6.39 D*

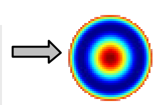
Change in asphericity (P)

0.98 ⇨ *-1.14*

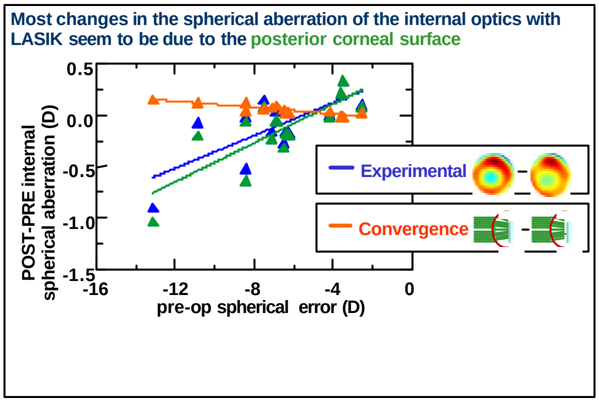


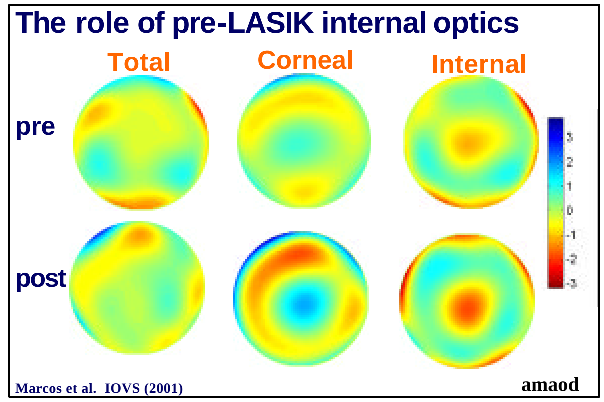
-0.103 ? m

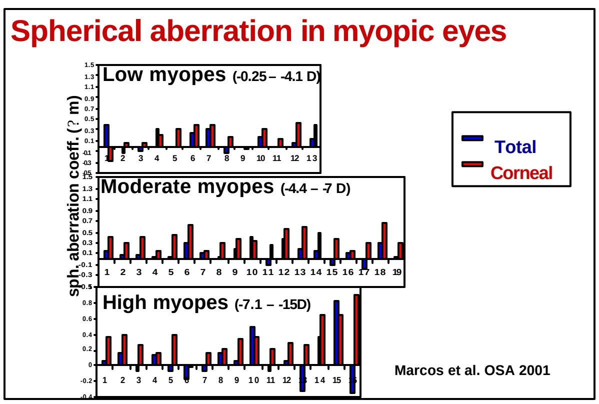
This study. Marcos et al. (2001)

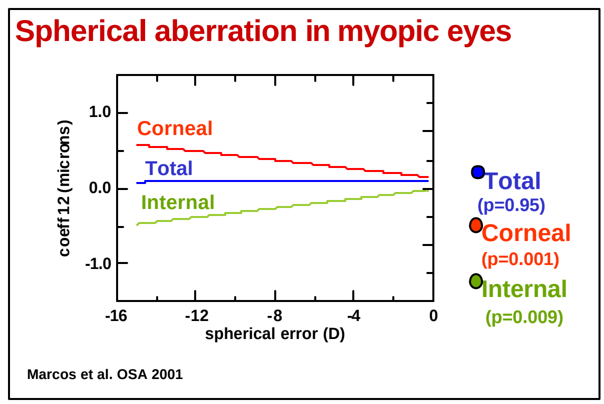


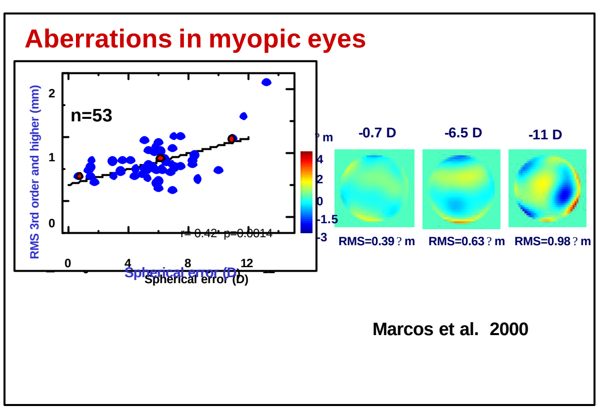
-0.110 ? m


Most changes in the spherical aberration of the internal optics with LASIK seem to be due to the posterior corneal surface
POST-PRE internal spherical aberration (D)
0.5
0.0
-0.5
-1.0
-1.5
-16
-12
-8
-4
0
pre-op spherical error (D)
Experimental
Convergence


The role of pre-LASIK internal optics
Total
Corneal
Internal
pre
post
Marcos et al. IOVS (2001)
amaod


Spherical aberration in myopic eyes
sph. aberration coeff. (? m)
Low myopes (-0.25 – -4.1 D)
Moderate myopes (-4.4 – -7 D)
High myopes (-7.1 – -15D)
Total
Corneal
Marcos et al. OSA 2001


Spherical aberration in myopic eyes
coeff 12 (microns)
1.0
0.0
-1.0
Corneal
Total
Internal
-16
-12
-8
-4
0
spherical error (D)
Total
(p=0.95)
Corneal
(p=0.001)
Internal
(p=0.009)
Marcos et al. OSA 2001

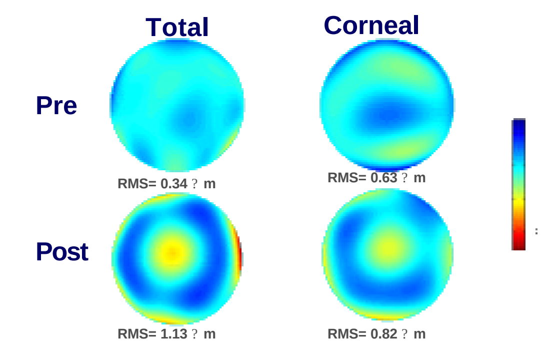

Aberrations in myopic eyes
RMS 3rd order and higher (mm)
n=53
Spherical error (D)
-0.7 D
-6.5 D
-11 D
RMS=0.39 ? m
RMS=0.63 ? m
RMS=0.98 ? m
Marcos et al. 2000


Hyperopic LASIK Refractive Surgery
The central cornea is made steeper than the periphery, by removing tissue around the central area

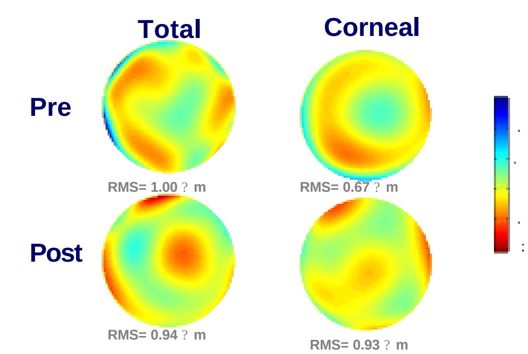
Patients (hyperopic LASIK)

- 13 eyes from 7 subjects
- mean age: 32?11
- Spherical equivalent: +1.25 thru +3.5 D
- No ocular or retinal condition
- Measurements <1 mo. before and >1 mo. after surgery

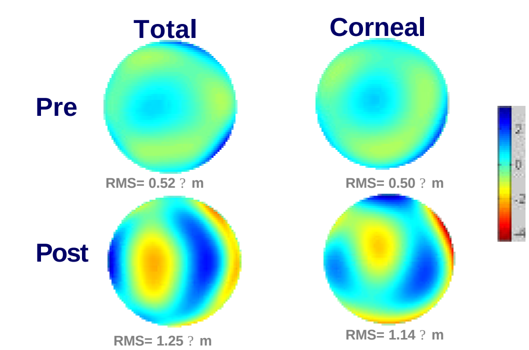
- Flying spot Technolas 217-C (B&L surgical)
- Hansatome microkeratome



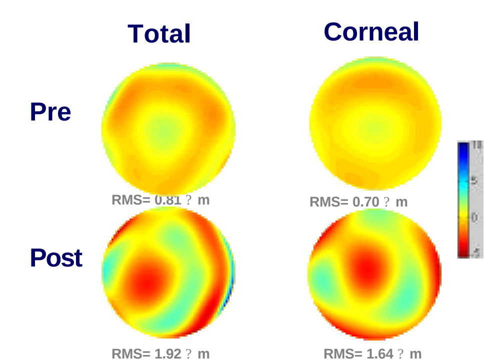
cssoi



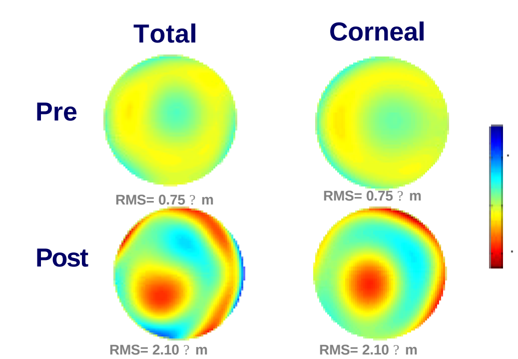
cssod



ifroi

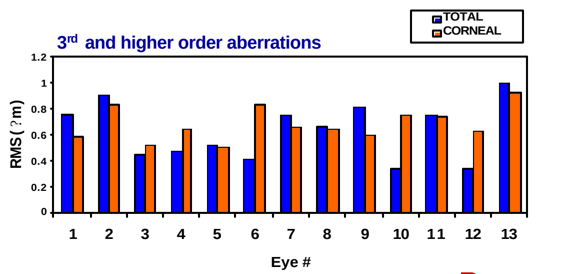


cfaoi



cfaod

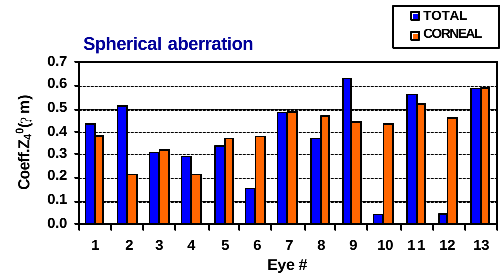
Aberrations in hyperopic eyes



Pre- op

Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

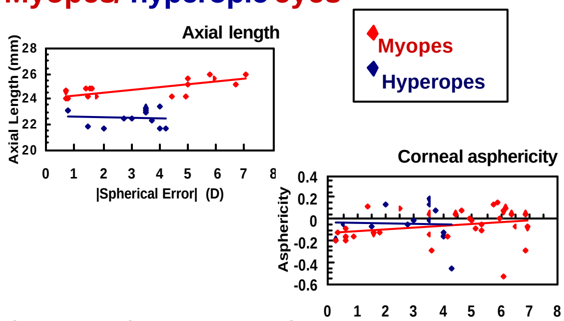
Aberrations in hyperopic eyes



Pre- op

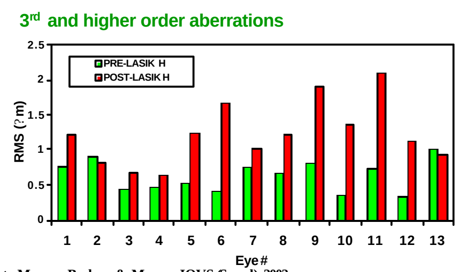
Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

Myopes/ hyperopic eyes



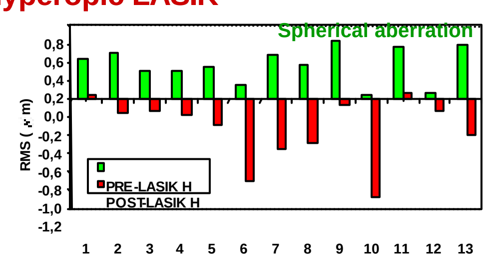
Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

Change of TOTAL aberrations with hyperopic LASIK



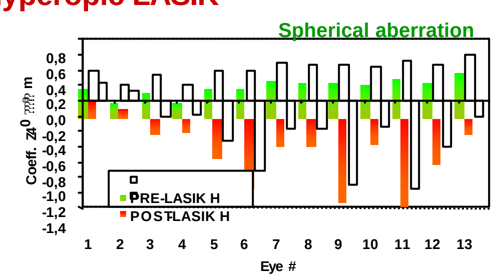
Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

Change of TOTAL aberrations with hyperopic LASIK



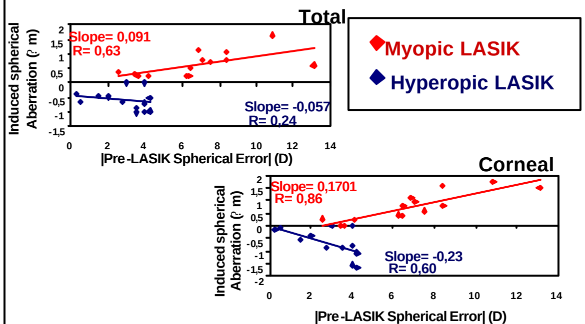
Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

Change of CORNEAL aberrations with hyperopic LASIK



Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

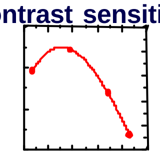
Spherical aberration induced by LASIK



Llorente, Marcos, Barbero & Merayo, IOVS (Suppl), 2002

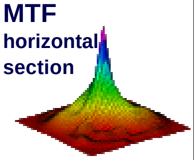
Comparison with visual performance

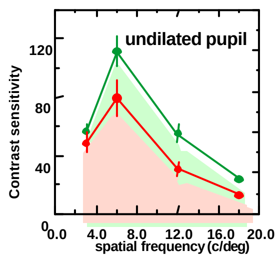
Contrast sensitivity



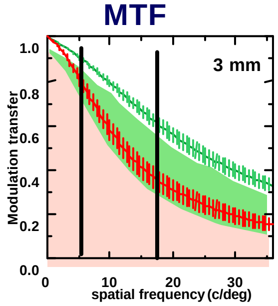
PRE & POST LASIK

MTF horizontal section





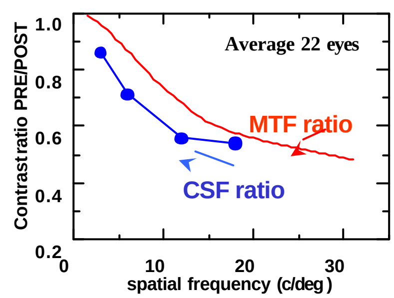
Area $\frac{PRE}{POST}$ = 1.51



Area $\frac{PRE}{POST}$ = 1.38

Marcos. J. Refract. Surg. (2001)

Contrast ratio POST/PRE



Marcos. J. Refract. Surg. (2001)

Total and corneal aberrometry provide:

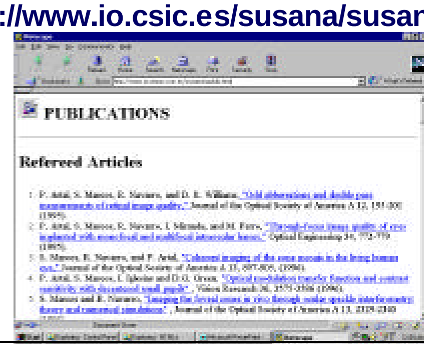
- Detailed evaluation of correction procedures
- Clues for improvent and customization

- IOL lenses design could improve to achieve better corneal/internal balance

- LASIK ablation algorithms should be optimized to avoid aberration induction.

Publications

http://www.io.csic.es/susana/susana.htm



Collaborative Clinical Sites

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(Jesus Merayo)

Fundacion Jimenez Diaz, Madrid
(Ignacio Jimenez-Alfaro)

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