Best fit regression modeling of excimer lasers profiles

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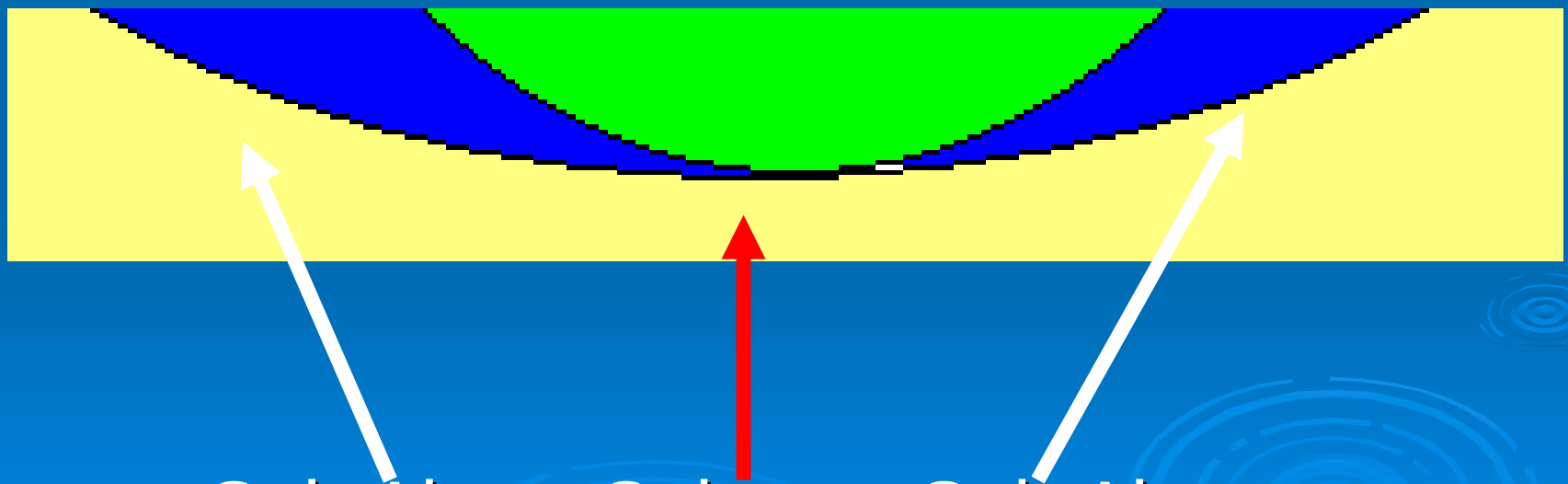
Purpose

- To show that best fit regression formula of postoperative refractive outcomes correlates to excimer laser ablation patterns
- That increased induced spherical aberration is related to the observed overcorrection of sphere
- That increased induced secondary astigmatism is related to overcorrection of cylinder and sphere

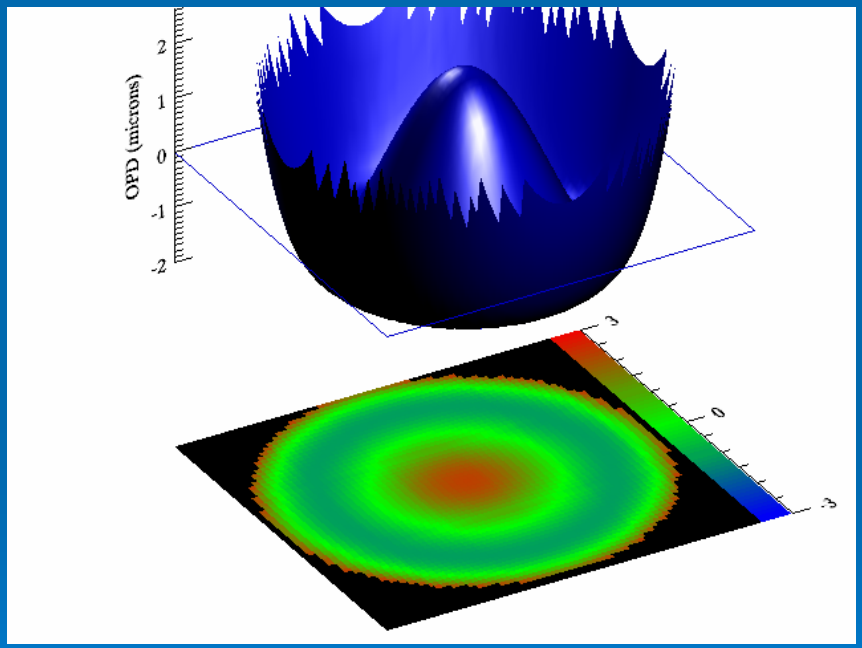
Spherical aberration is directly proportional to the lens power squared.
Expect an exponential increase of overcorrection with increasing sphere treatments

(Secondary cylinder aberration is proportional to the product of the sphere and cylinder)

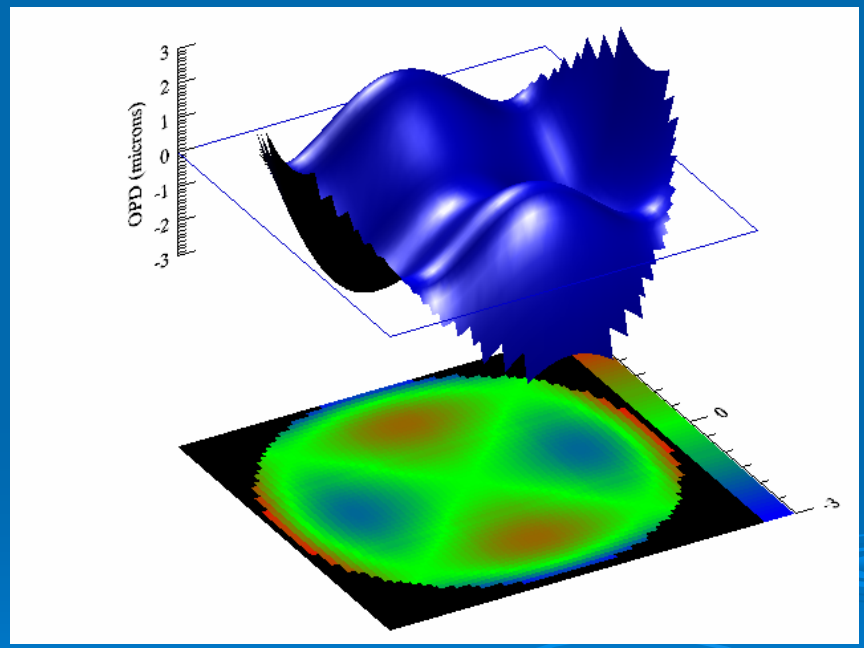


Sph Aber Sphere Sph Aber

Secondary astigmatism is the toric equivalent of spherical aberration



Spherical Aberration



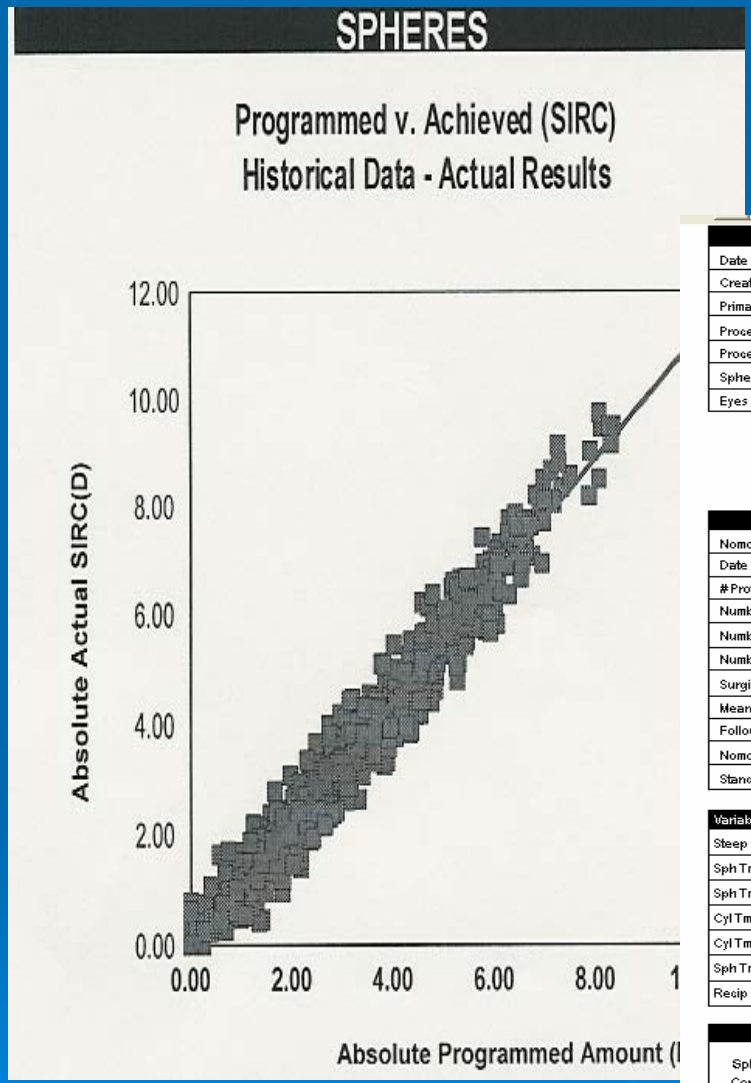
Higher Astigmatism

Methods

- Laser profiles studied were
  - Visx Standard with a peripheral blend (Standard);
  - Visx CustomVue,
    - one to six diopters (Low myopia -Wavefront);
  - Visx CustomVue,
    - six to eleven diopters (High myopia-Wavefront).

Refractive Surgical Consultant ™

uses surgical outcomes to calculate a best fit laser nomograms



Treatment Profile Statistics	
Date Created	10/18/2004
Created By	Jones Eye Clinic Omaha Administrator
Primary or Reoperations	Primary
Procedures to Date	4,043
Procedure Dates	2/8/2002 thru 3/8/2007
Spheres / Spherocylinders	0 / 4,043
Eyes with Postop > 20 Days	2,938

Major Treatment Profile Attributes	
Laser:	Visx Fourier
Laser Software:	Fourier
Hinge Location:	All Locations
Treatment Range:	Myopia
Minor Treatment Profile Attributes	
Hertz Rate:	/ Sec
Optical Zone Diam:	All Diameters
Keratome / Serial:	All Keratomes
Keratome Plate:	All Plates
User Defined:	NA

Sphere Nomogram Statistics	
Nomogram Type	Optimized HK-2
Date Processed	3/12/2007
# Profiles Sharing Nomogram	2
Number of Eyes Evaluated	775
Number of Eyes Eliminated	22
Number of Eyes Used to Create	753
Surgical Dates	3/15/2006 thru 1/19/2007
Mean / SD Follow Up (Days)	106.0 +/- 65.0
Follow Up Range (Days)	30 to 337
Nomogram R Squared Statistic	0.960
Standard Error of Regression	0.38

Cylinder Nomogram Statistics	
Nomogram Type	Optimized HK-2
Date Processed	3/12/2007
# Profiles Sharing Nomogram	2
Number of Eyes Evaluated	775
Number of Eyes Eliminated	26
Number of Eyes Used to Create	749
Surgical Dates	3/15/2006 thru 1/19/2007
Mean / SD Follow Up (Days)	106.0 +/- 64.8
Follow Up Range (Days)	30 to 330
Nomogram R Squared Statistic	0.970
Standard Error of the Regression	0.23

Variable	Coeff	Mean	Std Dev	Min	Max	p
Steep K - Flat K	0.06	1.07	0.75	0.00	6.15	<0.005
Sph Tmt Amount (D)	1.07	-2.78	1.47	-6.92	0.42	<0.005
Sph Tmt Amt Squared	0.02	9.89	9.12	0.00	47.82	<0.005
Cyl Tmt Amount (D)	0.28	-0.81	0.62	-3.21	-0.01	<0.005
Cyl Tmt Amt Squared	0.12	1.04	1.55	0.00	10.32	<0.005
Sph Tmt X Cyl Tmt	0.05	2.23	2.31	-0.34	16.19	<0.005
Recip of Age Squared	-80.20	0.00	0.00	0.00	0.00	<0.005

Variable	Coeff	Mean	Std Dev	Min	Max	p
Sph Tmt Amount (D)	0.02	-2.77	1.48	-8.05	0.42	0.002
Cyl Tmt Amount (D)	0.92	-0.80	0.62	-3.21	-0.01	<0.005
Cyl Tmt Amt Squared	-0.05	1.03	1.58	0.00	10.32	0.001
Sph Tmt X Cyl Tmt	0.02	2.19	2.32	-0.30	18.31	0.001

Sphere Nomogram Equation

Sphere Programmed Amount = + 1.07 X Sphere Correction + 0.02 X Sphere Correction Squared + 0.28 X Cylinder Correction + 0.12 X Cylinder Correction Squared + 0.05 X Sphere X Cylinder Correction + 0.06 X (Steep K - Flat K) + -80.20 X

Cylinder Nomogram Equation

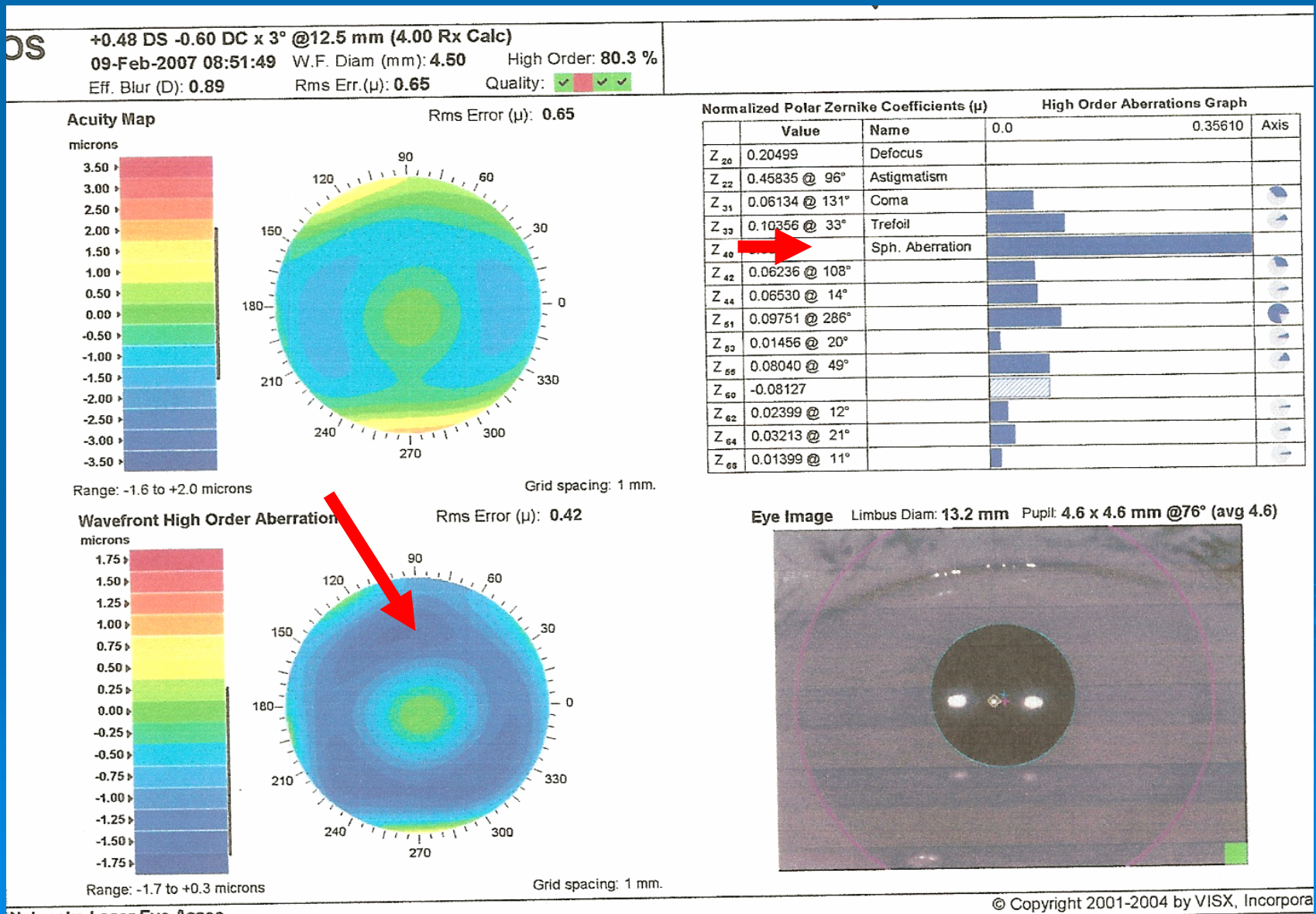
Cylinder Programmed Amount = +0.02 X Sphere Correction + 0.92 X Cylinder Correction + -0.05 X Cylinder Correction Squared + 0.02 X Sphere X Cylinder Correction

Developed by Dr Jack Holladay
and Dr Guy Kezirian

Refractive Surgical Consultant ™ Results

Laser	*Induced spherical aberration	Sphere (s) nomogram	Cyl (c) nomogram	# Eyes s/c	R^2 s	R^2 c
Low Myopia Wavefront	0.11	1.07s +0.01s^2 +0.17c + 0.08 c^2 +0.05sc	+1.02c +0.01sc	1044	0.97	0.85
High Myopia Wavefront	0.26	1.22 s + 0.04s^2	1.32c + 0.06c^2	179	0.98	0.97
High myopia Standard	0.52	1.21s + 0.04s^2 +0.04sc	0.06s +0.01s^2 +1.18c +0.03c^2 +0.05sc	202	0.97	0.97

Positive Spherical aberration is related to relative under-correction of the mid-periphery



OS

+0.48 DS -0.60 DC x 3° @12.5 mm (4.00 Rx Calc)
09-Feb-2007 08:51:49 W.F. Diam (mm): 4.50 High Order: 80.3 %
Eff. Blur (D): 0.89 Rms Err.(μ): 0.65 Quality:

Acuity Map
Rms Error (μ): 0.65
microns
3.50 3.00 2.50 2.00 1.50 1.00 0.50 0.00 -0.50 -1.00 -1.50 -2.00 -2.50 -3.00 -3.50
90 120 60 150 30 180 0 210 330 240 300 270
Range: -1.6 to +2.0 microns
Grid spacing: 1 mm.

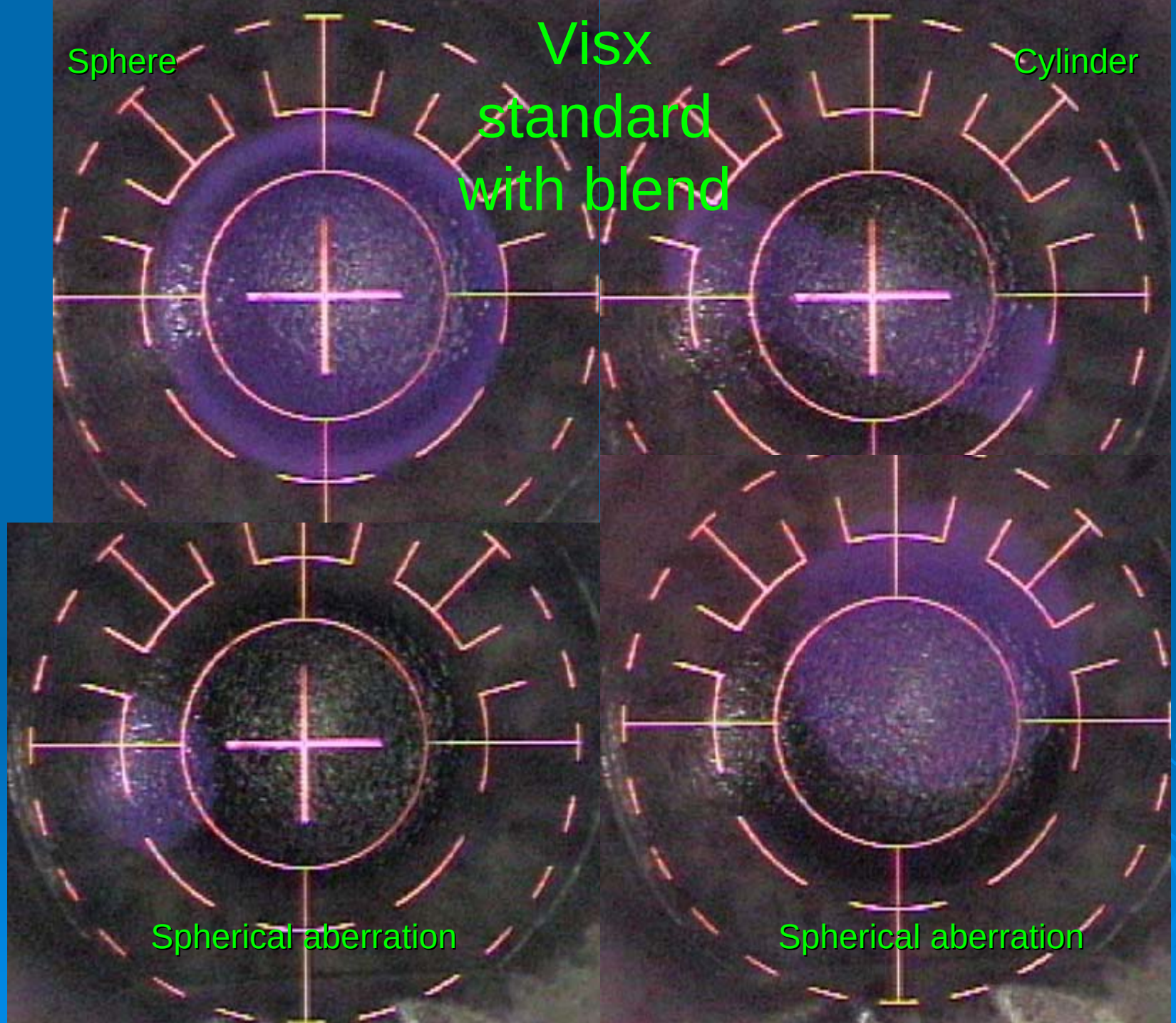
Normalized Polar Zernike Coefficients (μ)

	Value	Name
Z_{20}	0.20499	Defocus
Z_{22}	0.45835 @ 96°	Astigmatism
Z_{31}	0.06134 @ 131°	Coma
Z_{33}	0.10356 @ 33°	Trefoil
Z_{40}		Sph. Aberration
Z_{42}	0.06236 @ 108°	
Z_{44}	0.06530 @ 14°	
Z_{51}	0.09751 @ 286°	
Z_{53}	0.01456 @ 20°	
Z_{55}	0.08040 @ 49°	
Z_{60}	-0.08127	
Z_{62}	0.02399 @ 12°	
Z_{64}	0.03213 @ 21°	
Z_{66}	0.01399 @ 11°	

High Order Aberrations Graph
0.0 0.35610 Axis

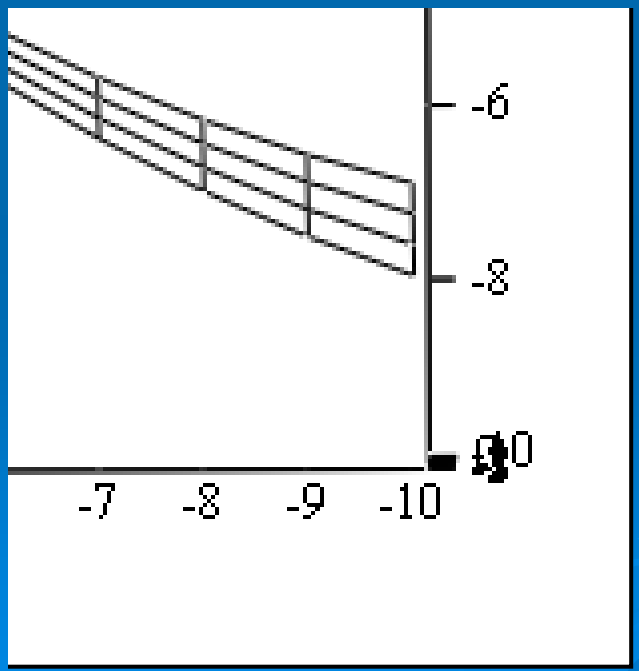
Wavefront High Order Aberration
Rms Error (μ): 0.42
microns
1.75 1.50 1.25 1.00 0.75 0.50 0.25 0.00 -0.25 -0.50 -0.75 -1.00 -1.25 -1.50 -1.75
90 120 60 150 30 180 0 210 330 240 300 270
Range: -1.7 to +0.3 microns
Grid spacing: 1 mm.

Eye Image Limbus Diam: 13.2 mm Pupil: 4.6 x 4.6 mm @76° (avg 4.6)

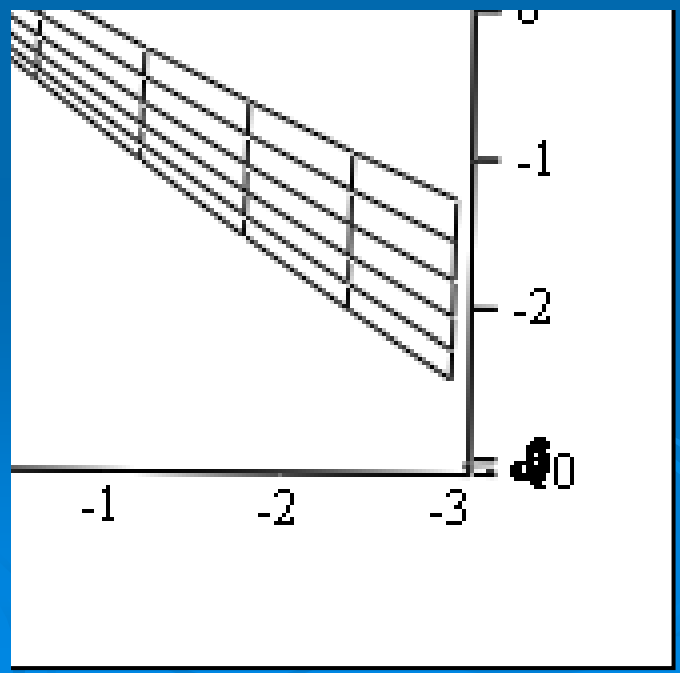

Sphere
Visx
standard
with blend
Cylinder
Spherical aberration
Spherical aberration

Standard High Myopia shows over-correction of both sphere and cylinder with coupling between the sphere and cylinder

Sph=1.21s +0.04s2 +0.04sc (r2 0.97)



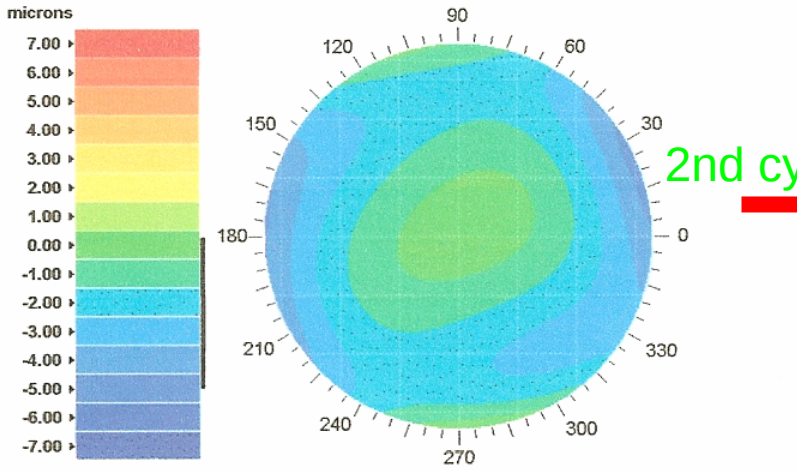
Cyl=0.06s +0.011 s2 +1.18c +0.03c2 +0.05sc



Overcorrection of sphere and cylinder is associated with increased spherical aberration and secondary cylinder

OD +1.21 DS -0.52 DC x 122° @12.5 mm (4.00 Rx Calc)
27-Mar-2007 11:48:06 W.F. Diam (mm): **6.50** High Order: **21.9 %**
Eff. Blur (D): **0.69** Rms Err.(μ): **1.06** Quality: ✓ ✓ ✓ ✓

Acuity Map Rms Error (μ): **1.06**



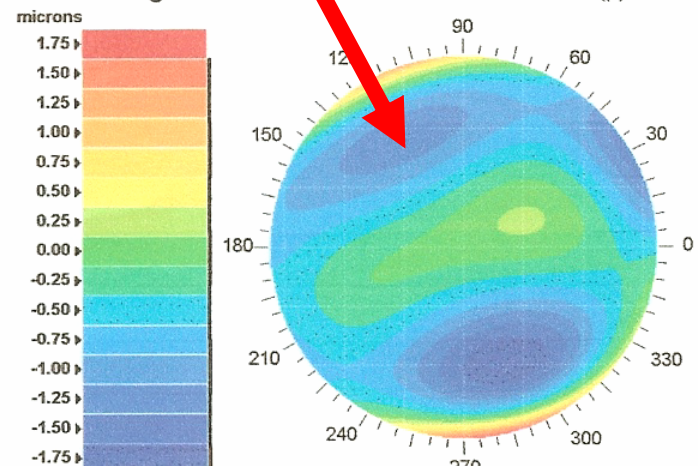
Range: -5.0 to +0.2 microns Grid spacing: 1 mm.

2nd cyl

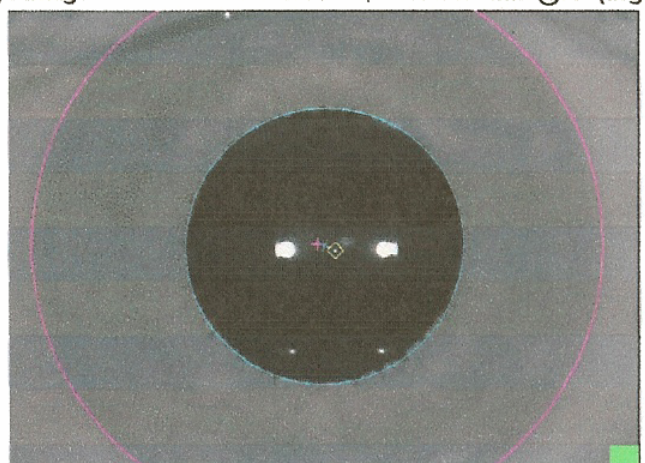
Normalized Polar Zernike Coefficients (μ) **High Order Aberrations Graph**

	Value	Name	0.0 — 0.39571	Axis
Z_{20}	-0.75795	Defocus		
Z_{22}	0.52292 @ 92°	Astigmatism		
Z_{31}	0.13222 @ 260°	Coma		
Z_{33}	0.09369 @ 103°	Trefoil		
Z_{40}	0.27977	Sph. Aberration		
	0.39571 @ 109°			
Z_{44}	0.07735 @ 4°			
Z_{51}	0.01588 @ 9°			
Z_{53}	0.03175 @ 43°			
Z_{55}	0.06263 @ 55°			
Z_{60}	0.01139			
Z_{62}	0.01386 @ 33°			
Z_{64}	0.01906 @ 19°			
Z_{66}	0.01304 @ 56°			

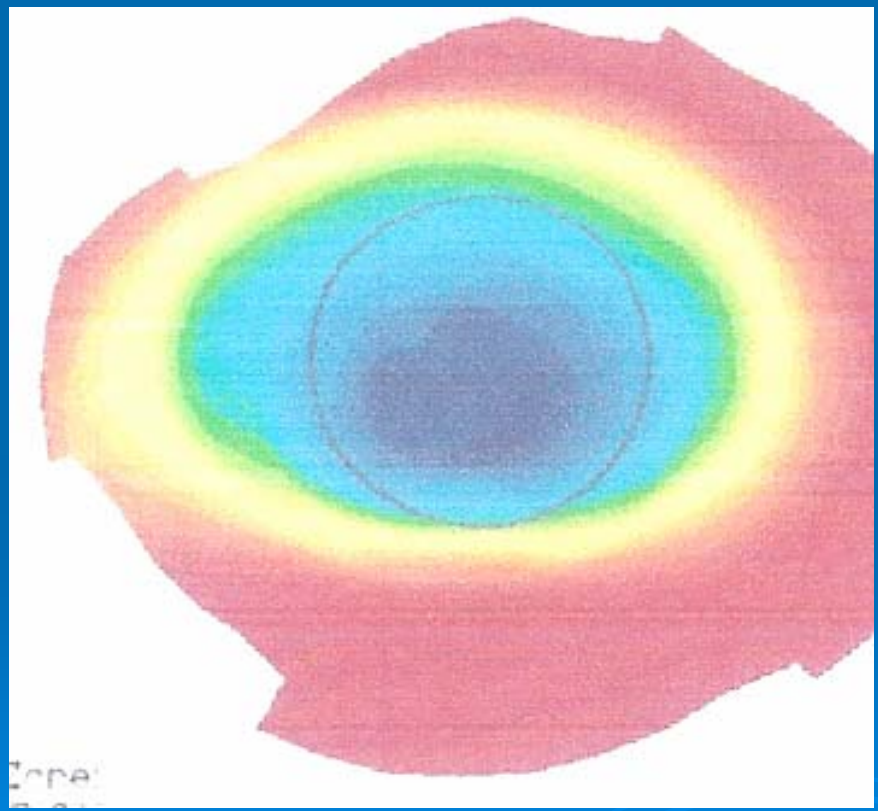
Wavefront High Order Aberrations Rms Error (μ): **0.52**



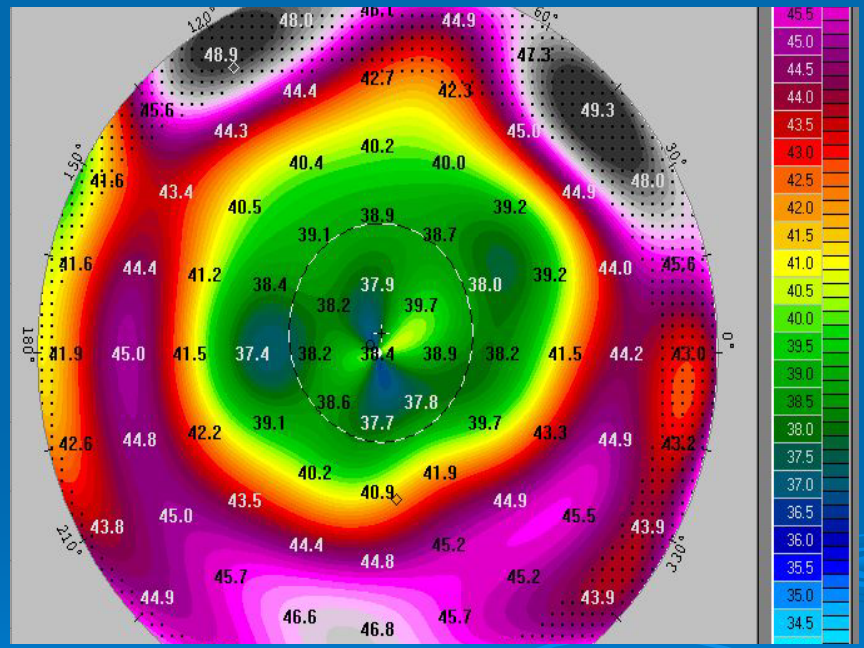
Eye Image Limbus Diam: **13.4 mm** Pupil: **6.6 x 6.5 mm @63° (avg 6.6)**



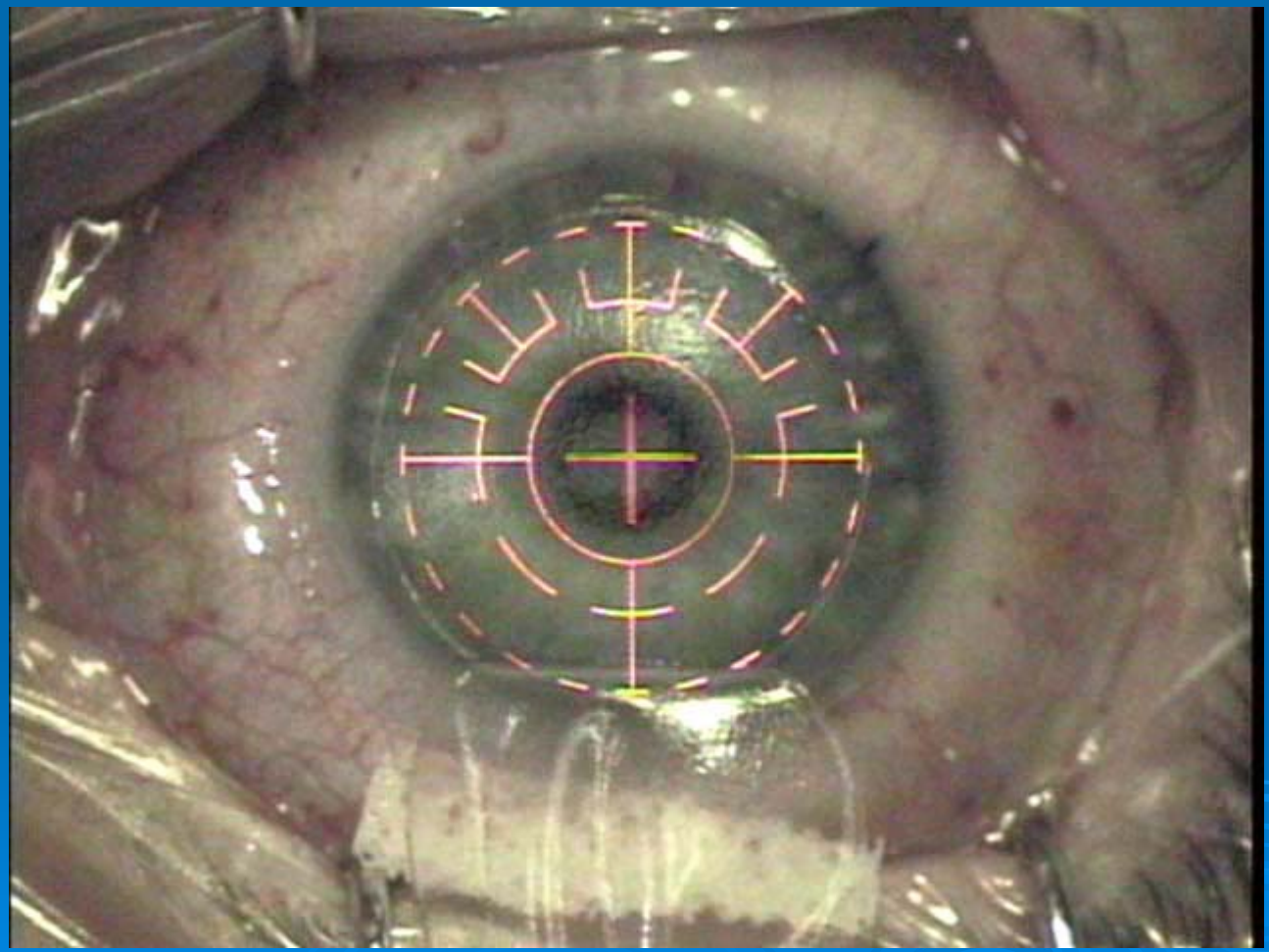
Nidek Topography shows relative overcorrection centrally with mid-peripheral 2nd spherical aberration



Pentacam topography shows secondary cylinder



Video: Wavefront ablation of with-the-rule cylinder

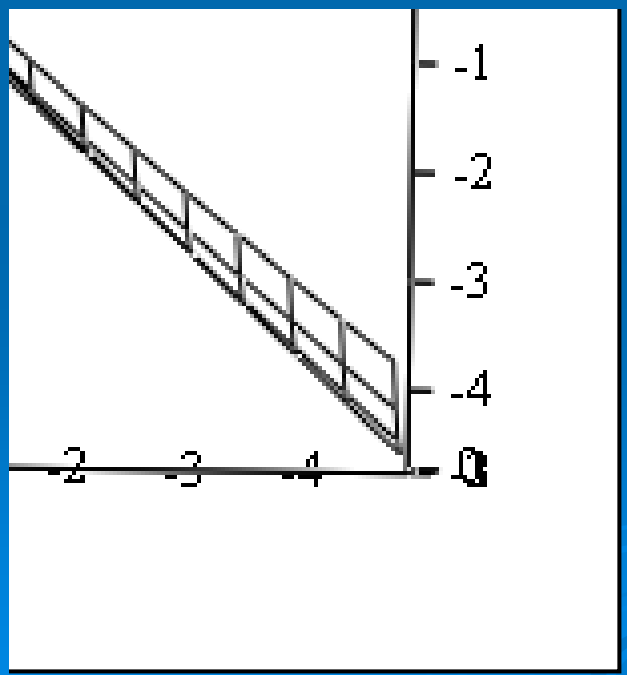


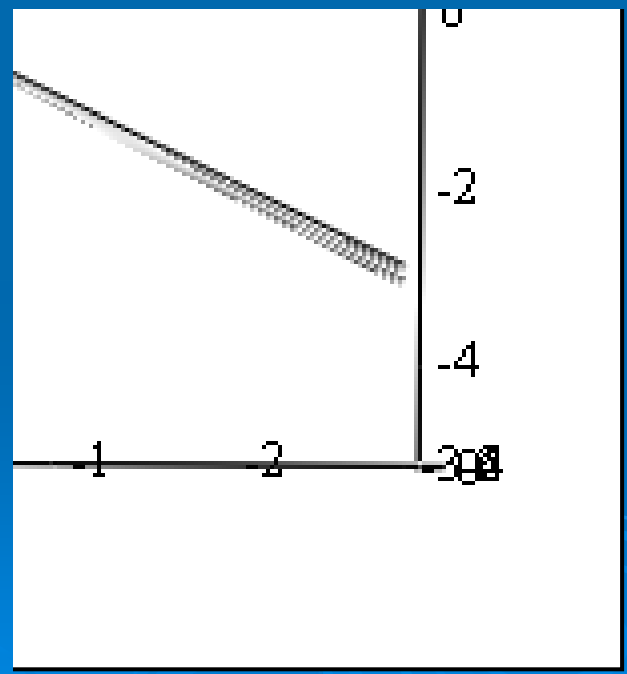
Low Myopia Wavefront

shows less over-correction of both sphere and cylinder

S=1.07s +0.01s2 +0.17c +0.08c2 +0.05sc

C=1.02c +0.01sc

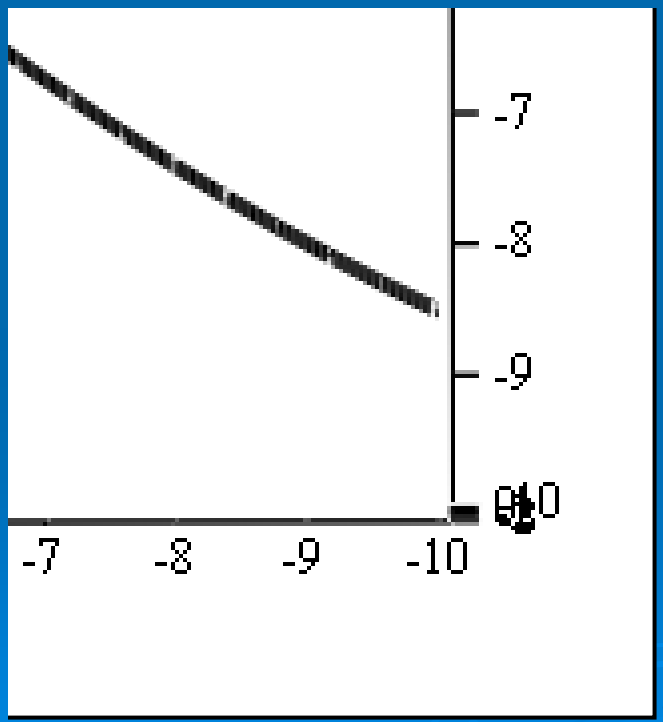


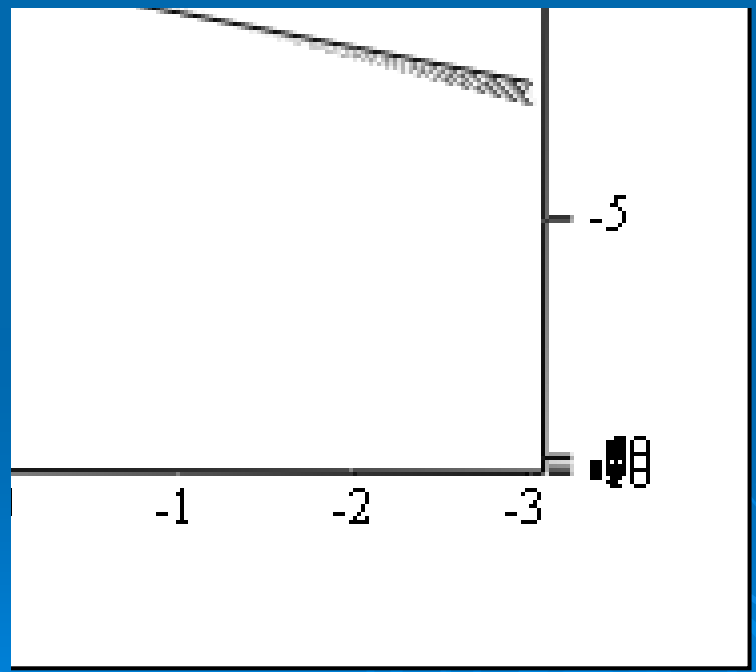


High Myopia Wavefront:
Overcorrection with sphere,
Mild overcorrection with cylinder

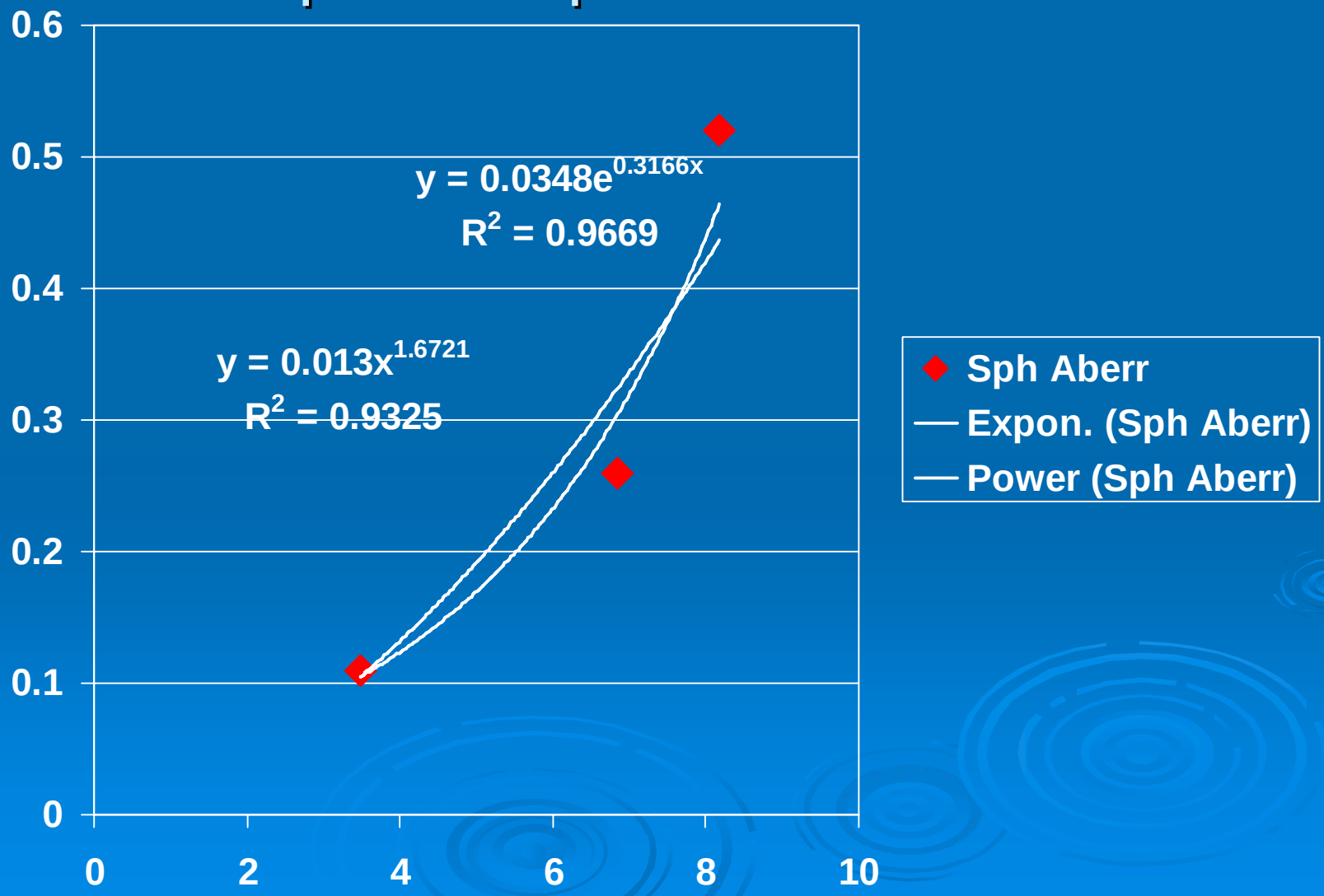
S=1.22s +0.04s2

C=1.32c +0.06sc





In theory and in our results, spherical aberration is directly proportional to the lens power squared



Conclusion

- The calculated nomograms show overcorrection and coupling of sphere and cylinder
- Topography and ablation profiles show an imbalance between central and peripheral ablation.
- Newer wavefront ablation profiles require less nomogram adjustment and induce less higher-order aberrations than previous standard ablation profiles.