Theoretical Optical Performance of an Equal Conic Intraocular Lens and Comparison to Spherical and Aspheric IOLs

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The author(s) acknowledge financial interest in the subject matter of this presentation.

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Acknowledgement…

- Contributors on this project…
  - Don Sanders, MD, PhD
  - John Clough, LensTec
  - Hayden Beatty, LensTec
  - Jim Simms, LensTec

Background…

- Recent studies have shown that aspheric IOLs can provide patients with significant optical benefits over traditional spherical surface IOLs.

1: Altmann GE, Nichamin LD, Lane SS, Pepose JS. Optical performance of 3 intraocular lens designs in the presence of decentration. J Cataract Refract Surg. 2005 Mar;31(3):574-85.

2: Bellucci R, Morselli S, Piers P. Comparison of wavefront aberrations and optical quality of eyes implanted with five different intraocular lenses. J Refract Surg. 2004 Jul-Aug;20(4): 297-306.

3: Packer M, Fine IH, Hoffman RS, Piers PA. Improved functional vision with a modified prolate intraocular lens. J Cataract Refract Surg. 2004 May;30(5):986-92.

4: Kershner RM. Retinal image contrast and functional visual performance with aspheric, silicone, and acrylic intraocular lenses. Prospective evaluation. J Cataract Refract Surg. 2003 Sep;29(9):1684-94.

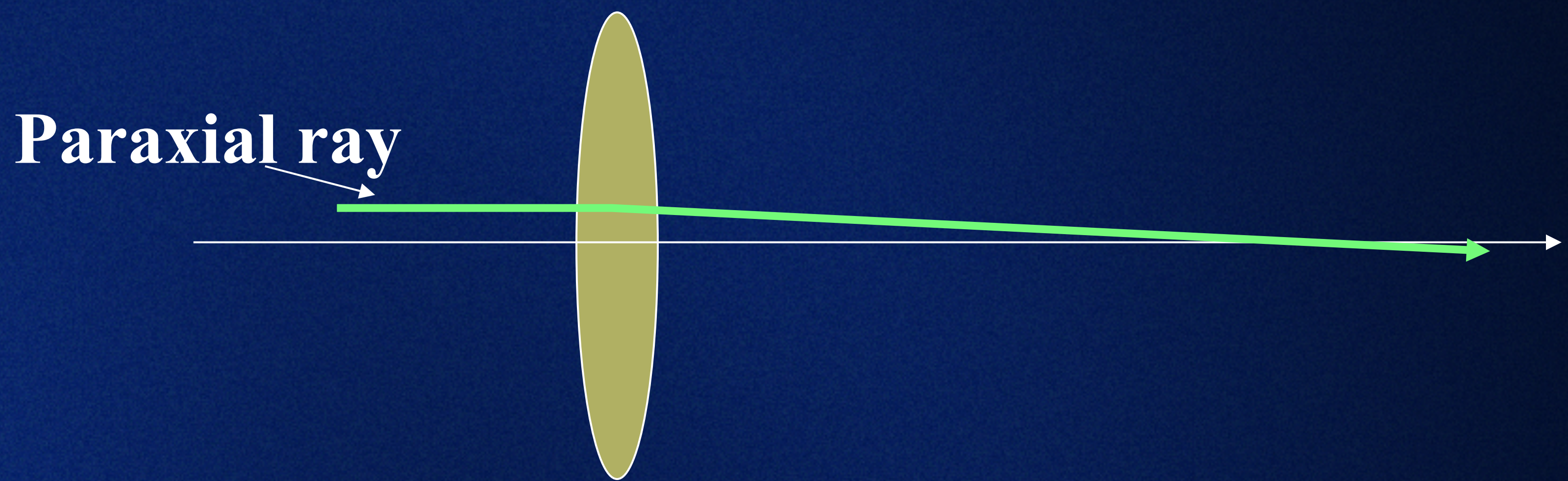
Optical benefits…

- The optical benefits are due to a reduction in optical aberrations at the retina.
- Primarily, *spherical aberration* is reduced.

Spherical aberration

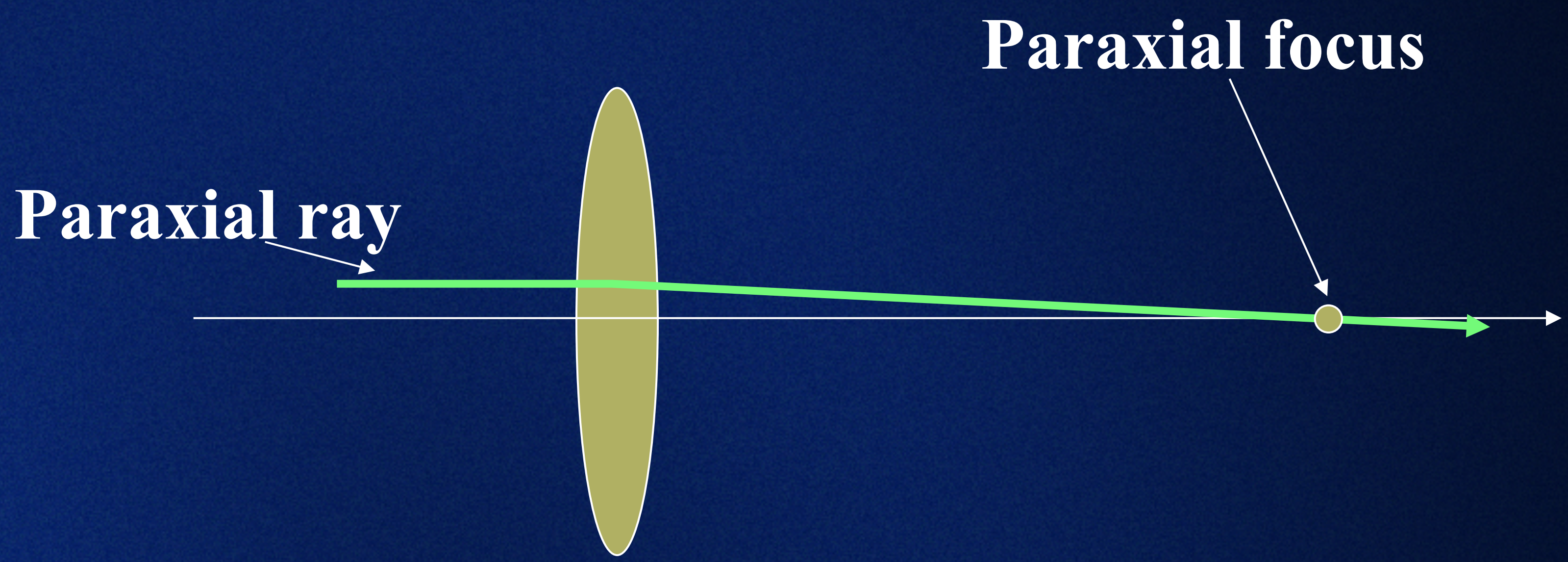
- Spherical aberration occurs when rays away from the paraxial region do not intersect at the paraxial focus.

Paraxial ray…



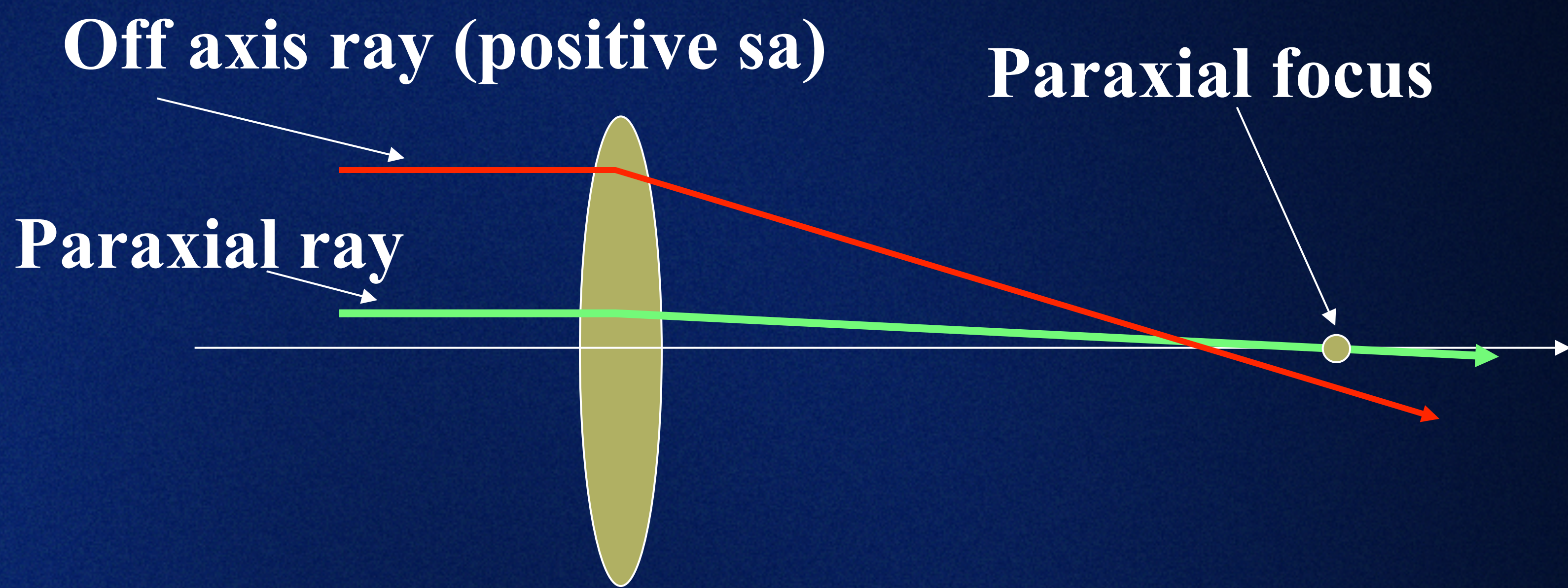
A paraxial ray is an optical ray traced "near" the optical axis.

Paraxial focus...



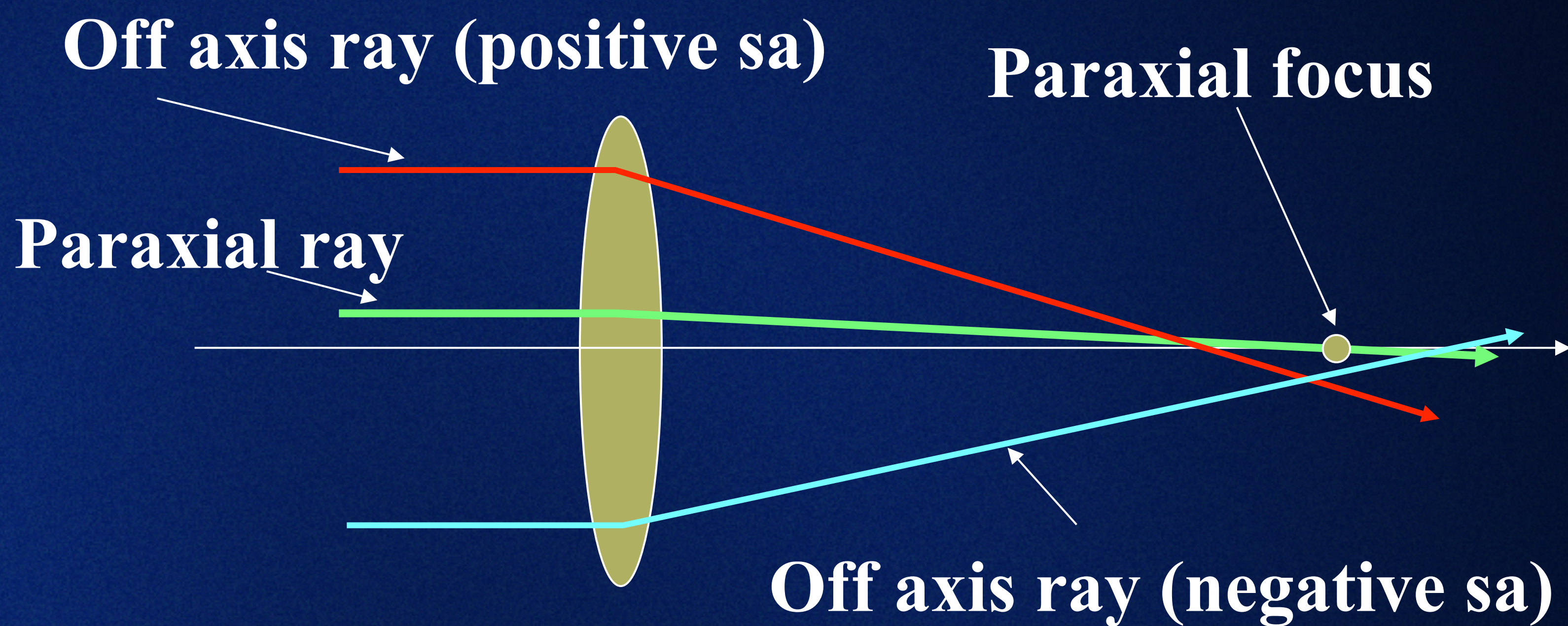
The paraxial focus is where the paraxial ray crosses the optical axis after refraction by the lens.

Positive spherical aberration...



When an off-axis ray is refracted by the lens and crosses the axis in FRONT of the paraxial focal point, the ray exhibits POSITIVE spherical aberration.

Negative spherical aberration…



When an off-axis ray is refracted by the lens and crosses the axis in BACK of the paraxial focal point, the ray exhibits NEGATIVE spherical aberration.

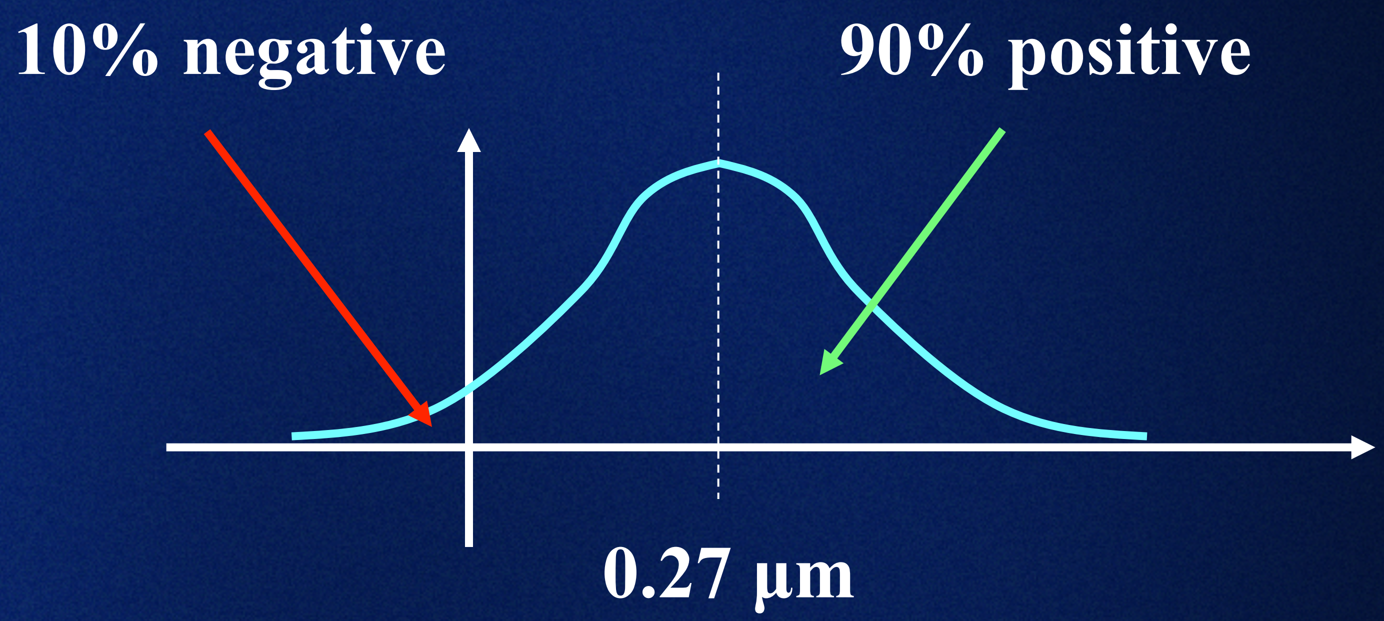
Corneal spherical aberration…

- The mean corneal spherical aberration has been reported to be about +0.27 microns[1]
- About 90% of the population has positive corneal spherical aberration — About 10% of the population has negative corneal spherical aberration[2]

[1]Holladay JT, et al, A new intraocular lens design to reduce spherical aberration of pseudophakic eyes. J Refract Surg., 2002 Nov-Dec;18(6):683-91.

[2]Krueger RR, et al, Wavefront Customized Visual Correction, Chapter 42, p. 368, 2004.

Approximate distribution of corneal spherical aberrations



Spherical IOLs

- A biconvex IOL with spherical surfaces exhibits positive spherical aberration.
- Thus, usually, spherical IOLs ADD positive spherical aberration to the already positive corneal spherical aberration

Aspheric IOLs

- Aspheric IOLs attempt to improve pseudophakic vision by controlling spherical aberrations
- One strategy is to design a lens with negative spherical aberrations to balance the normally positive corneal spherical aberrations
- Another strategy is to design a lens with minimum spherical aberrations so that no additional spherical aberration is added to the corneal spherical aberrations
  - Could be an asymmetric design
  - Could be a symmetric design

Comparison of IOLs

- Given these IOL design strategies we want to investigate their potential strengths and weaknesses
- First, we will describe the designs…

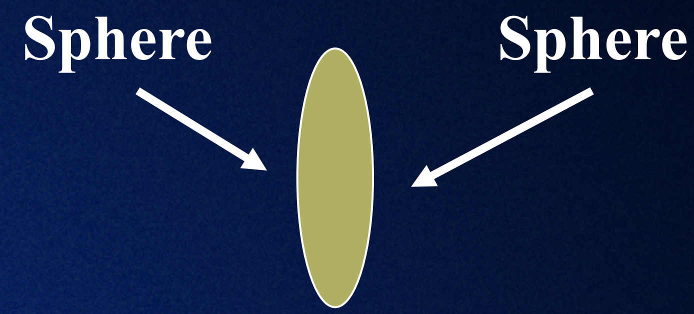
22 D IOL designs…

Parameter	Spherical surface IOL	Negative spherical aberrations	Asymmetric zero spherical aberrations
Ref. index	1.427	1.458	1.427
R1	8.234	11.043	7.285
K1	0	-1.03613	-1.085667
4^{th} & 6^{th} coef		-0.000944, -0.0000137	
R2	-8.234	-11.043	-9.470
K2	0	0	-1.085667

Altmann, et al, Optical performance of 3 intraocular lens designs in the presence of decentration, J Cataract Refract Surg. 2005;31(3):574-85.

22 D IOL design shapes…

Spherical surface IOL

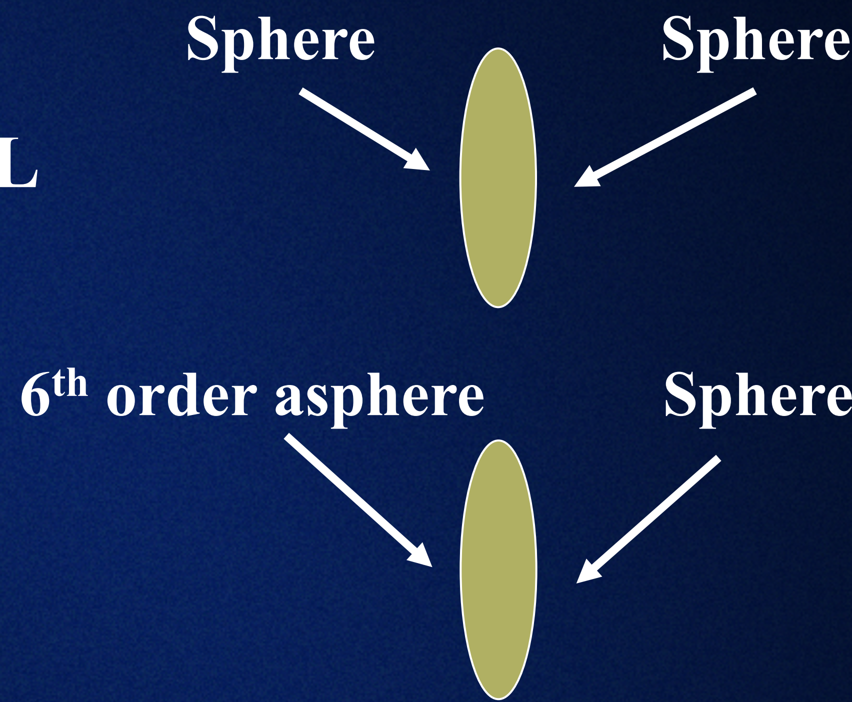


Propagation of light →

22 D IOL design shapes...

Spherical surface IOL

Negative spherical aberrations IOL



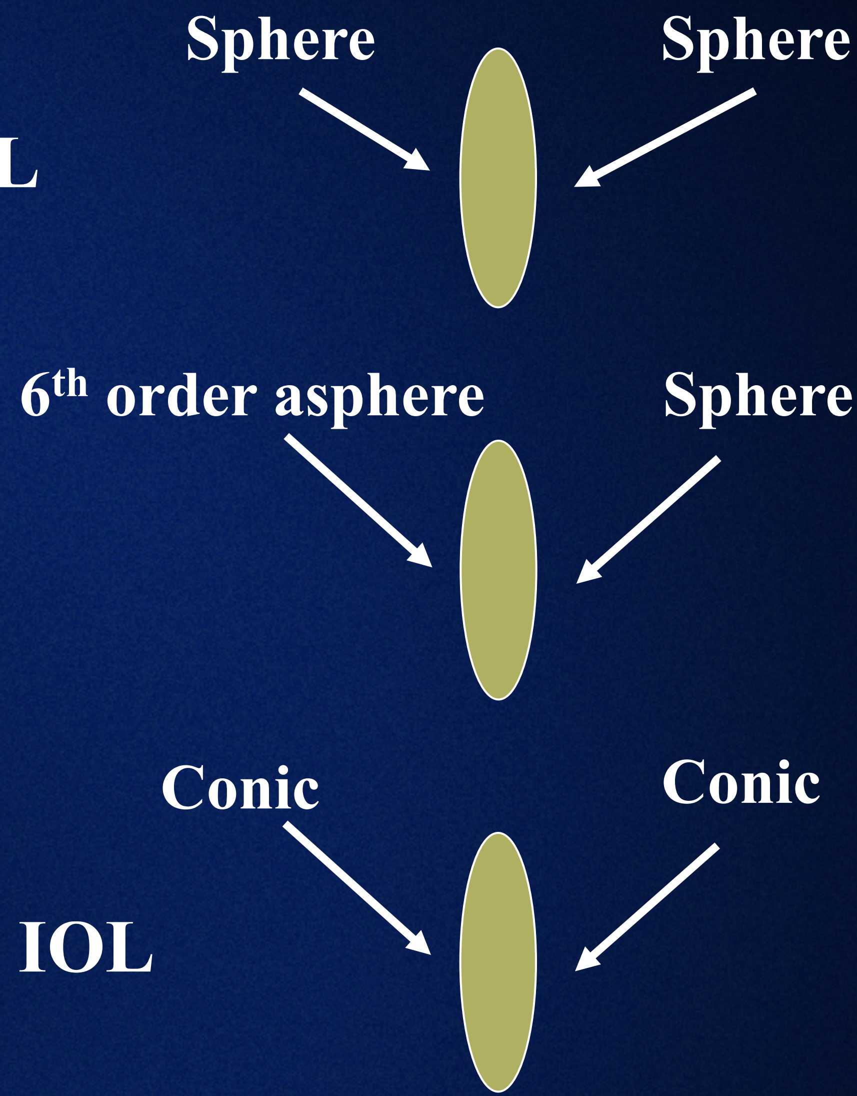
Propagation of light →

22 D IOL design shapes...

Spherical surface IOL

Negative spherical aberrations IOL

Asymmetric zero spherical aberrations IOL

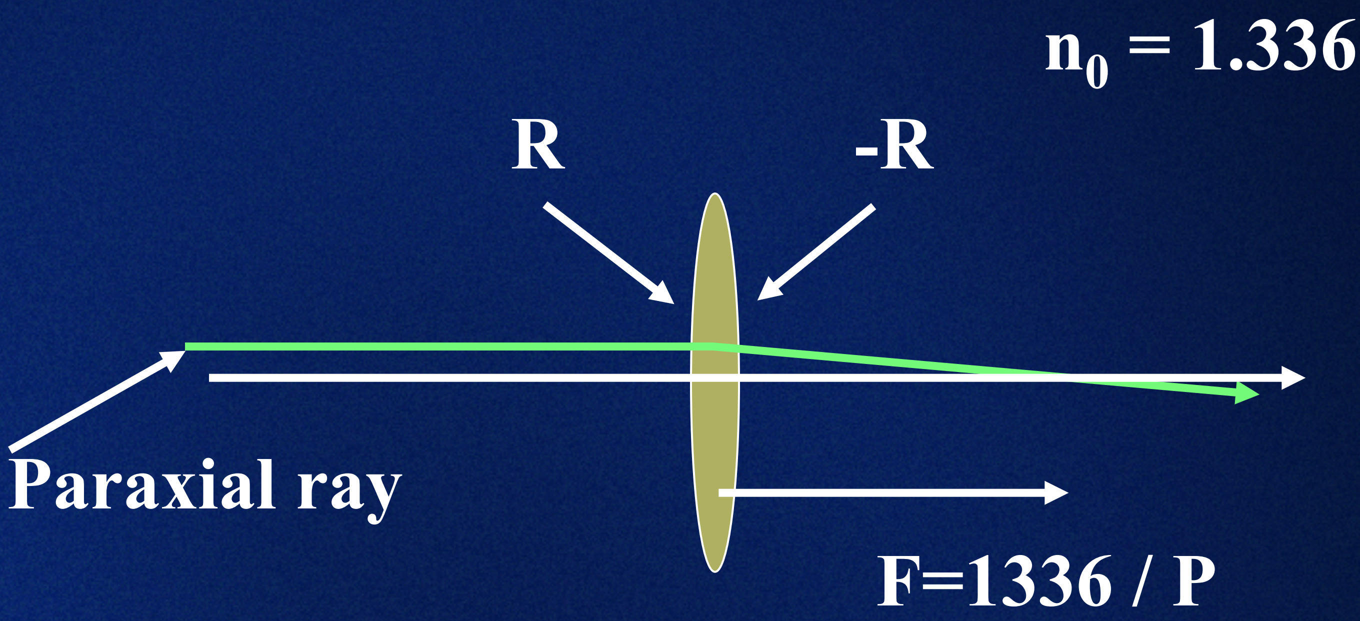


Propagation of light →

Equal conic, low spherical aberrations IOL…

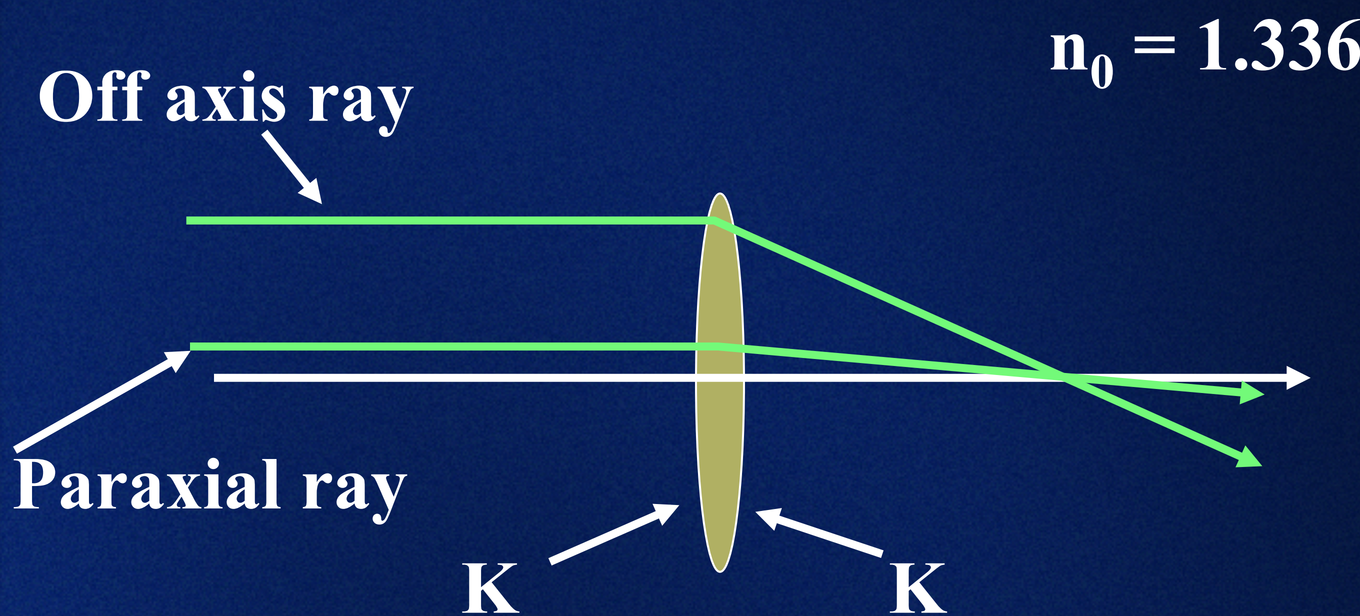
- Want to use conic surface for both anterior and posterior
- Want both surfaces equal
- Want low spherical aberrations

Equal conic design strategy...



First, we find the apical radius for the front and back surfaces to give the desired power.

Equal conic design strategy…



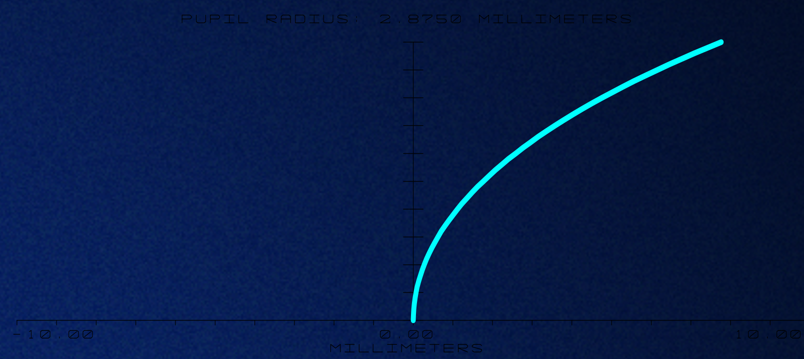
Next, we find the conic K parameter so that off axis rays intersect the paraxial focus.

22 D IOL designs…

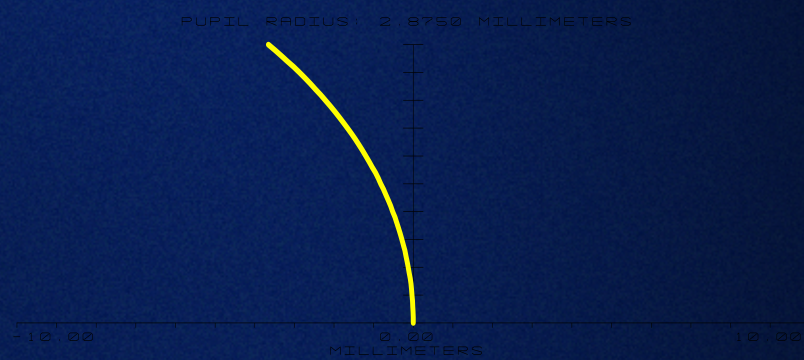
Parameter	Sphere / Sphere	6^{th} Order asphere / Sphere	Conic 1 / Conic 2	**Equal conic**
Ref. index	1.427	1.458	1.427	**1.4585**
R1	8.234	11.043	7.285	**11.093**
K1	0	-1.03613	-1.085667	**-1.23**
4^{th} & 6^{th} coef		-0.000944, -0.0000137		
R2	-8.234	-11.043	-9.470	**-11.093**
K2	0	0	-1.085667	**-1.23**

Longitudinal aberrations…

Negative spherical aberration



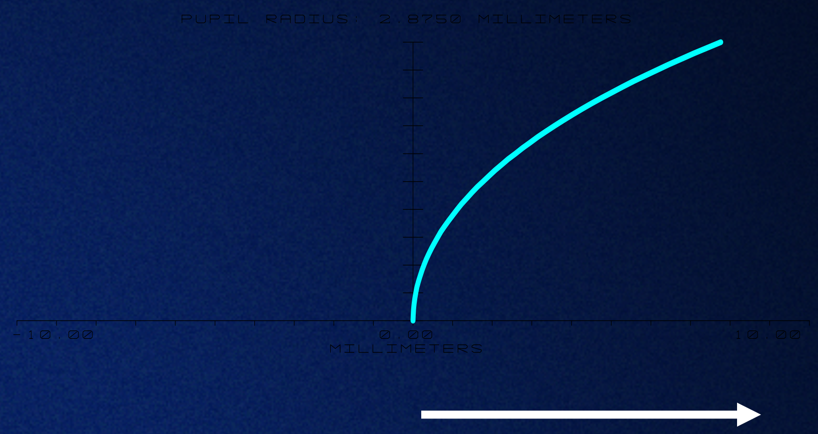
Spherical



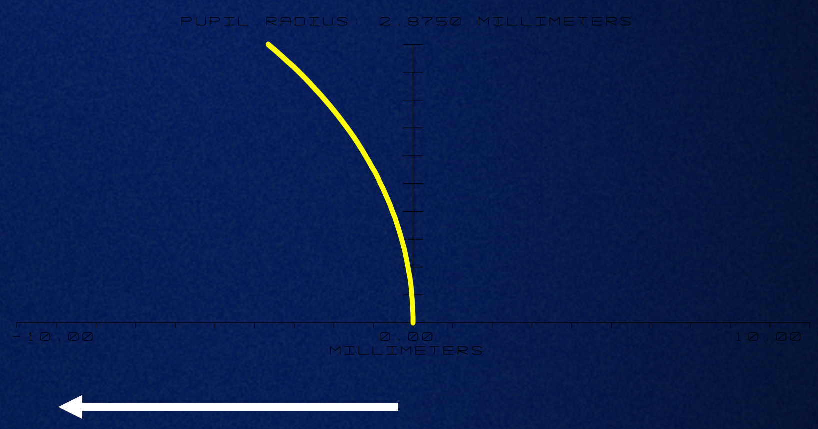
Note: spherical aberration in opposite directions.

Longitudinal aberrations…

Negative spherical aberration



Spherical



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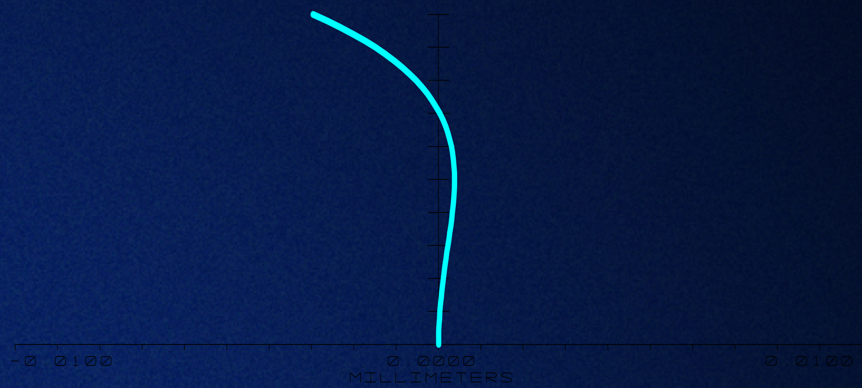
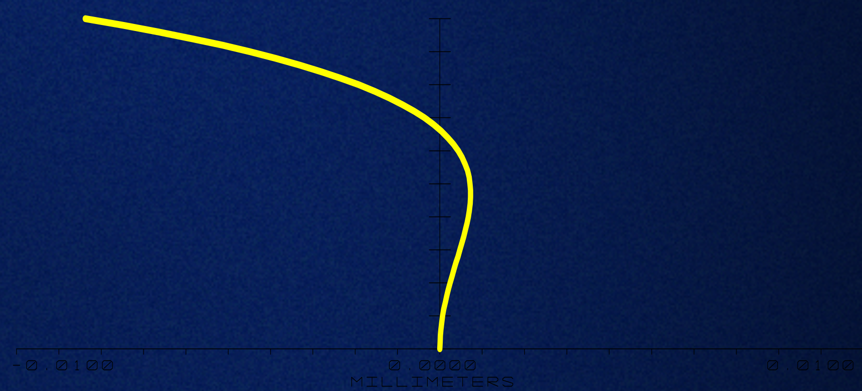
Longitudinal aberrations…

Equal conic



Unequal conic



Note: scale is 1000 x smaller than previous slide.

More important…

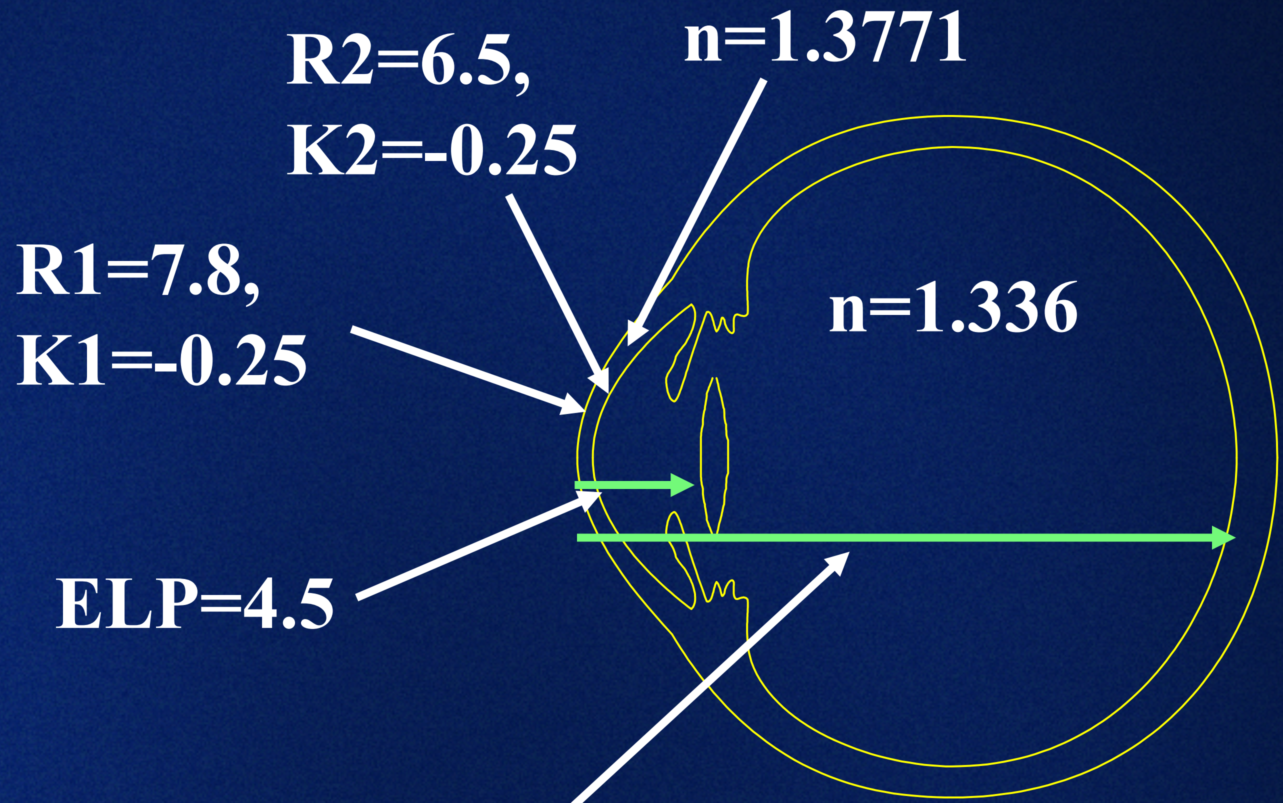
- Rather than just look at the performance of the IOL alone, it is more important to consider how it performs in the eye.
- To facilitate this analysis, we use a simple aspheric eye model.

Choice of eye model…

- Negative spherical aberration IOL was optimized for anterior cornea K = -0.1414
- "Zero" spherical aberration IOLs work best with anterior cornea with $K = -1/n^2 = -0.53$
- Mean cornea has K = -0.26
- Kooijman[1] eye model has K = -0.25, (we use this model)

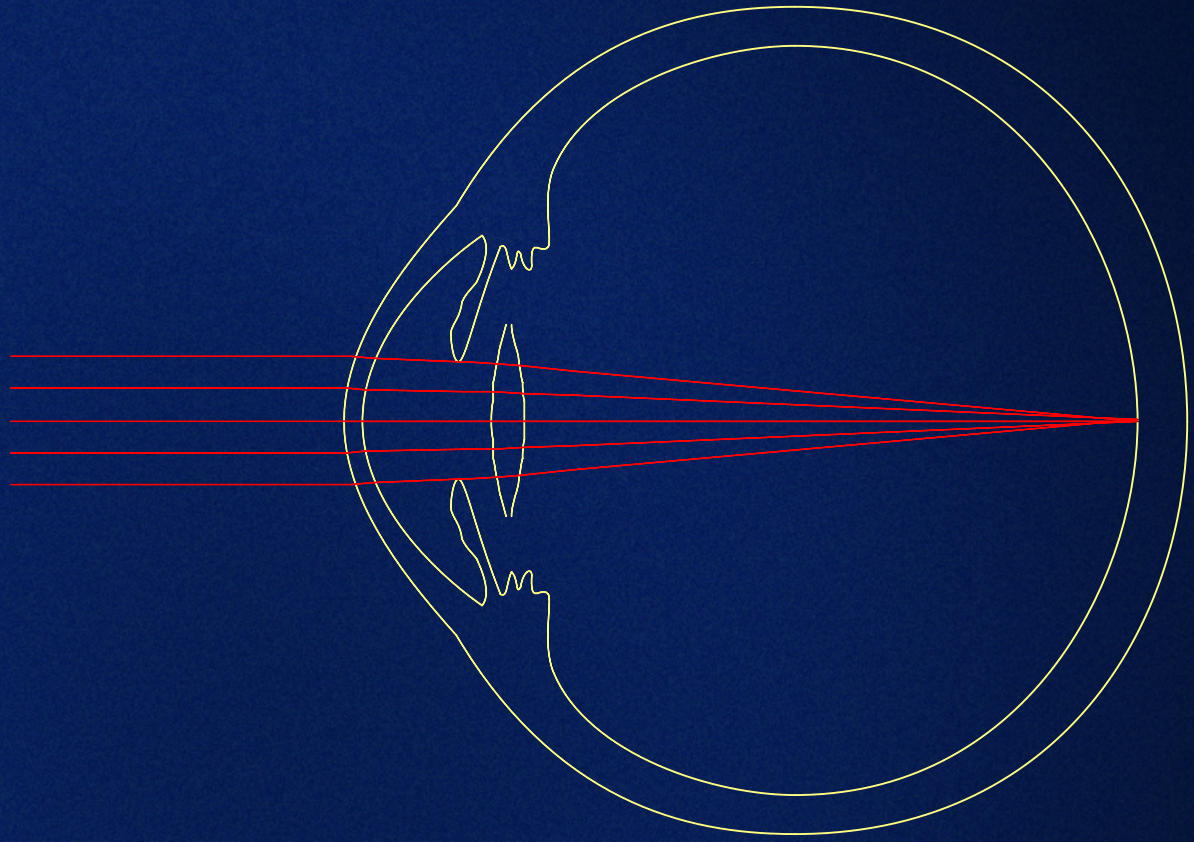
[1]Atchison and Smith, Optics of the human eye, Butterworth-Heinemann, 2000, p.255.

Kooijman/optical model



AL adjusted to give best focus for 3 mm pupil.

Centered performance…



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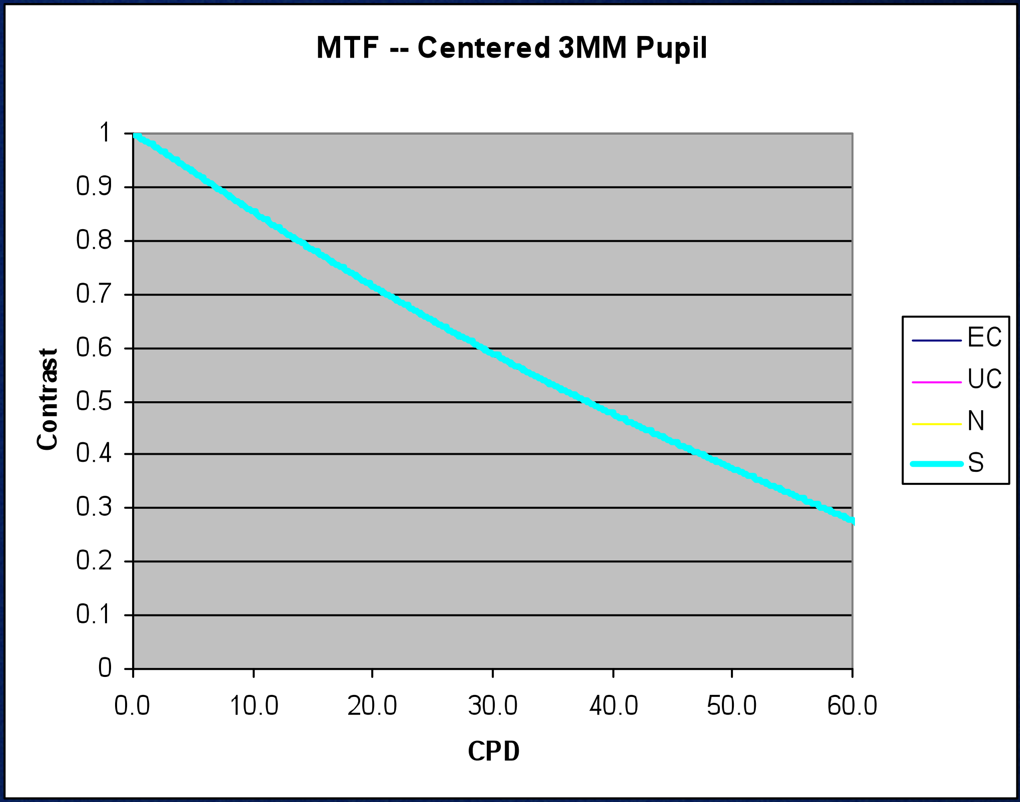
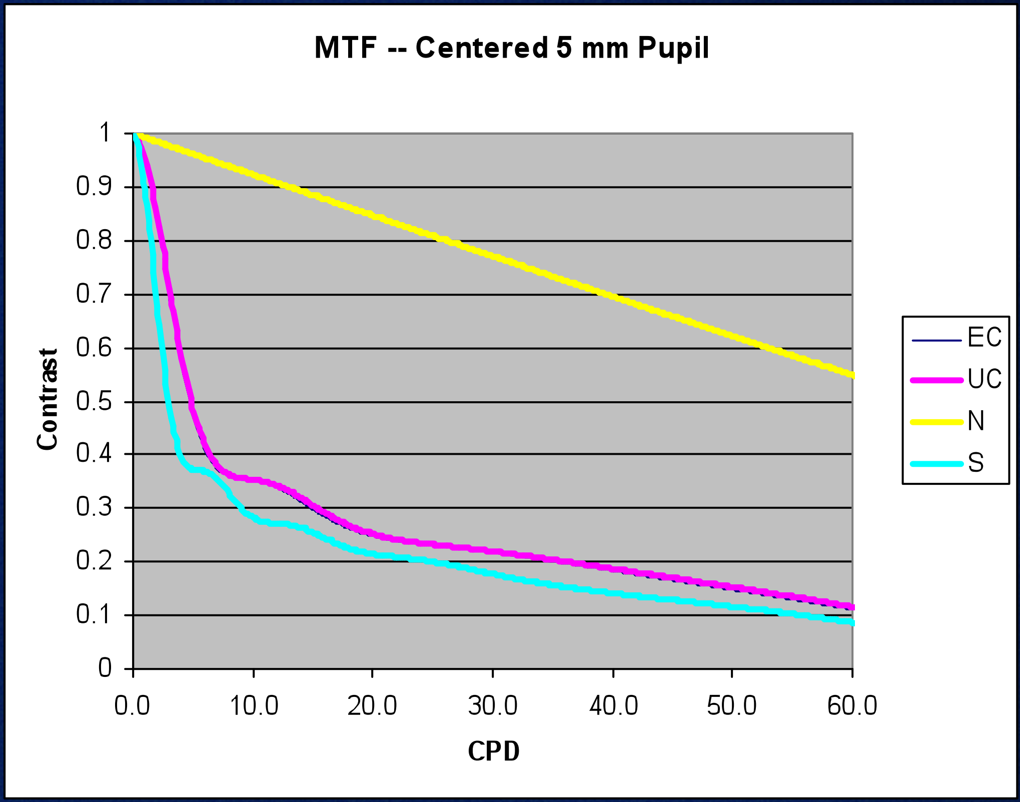
Centered – 3 mm Pupil



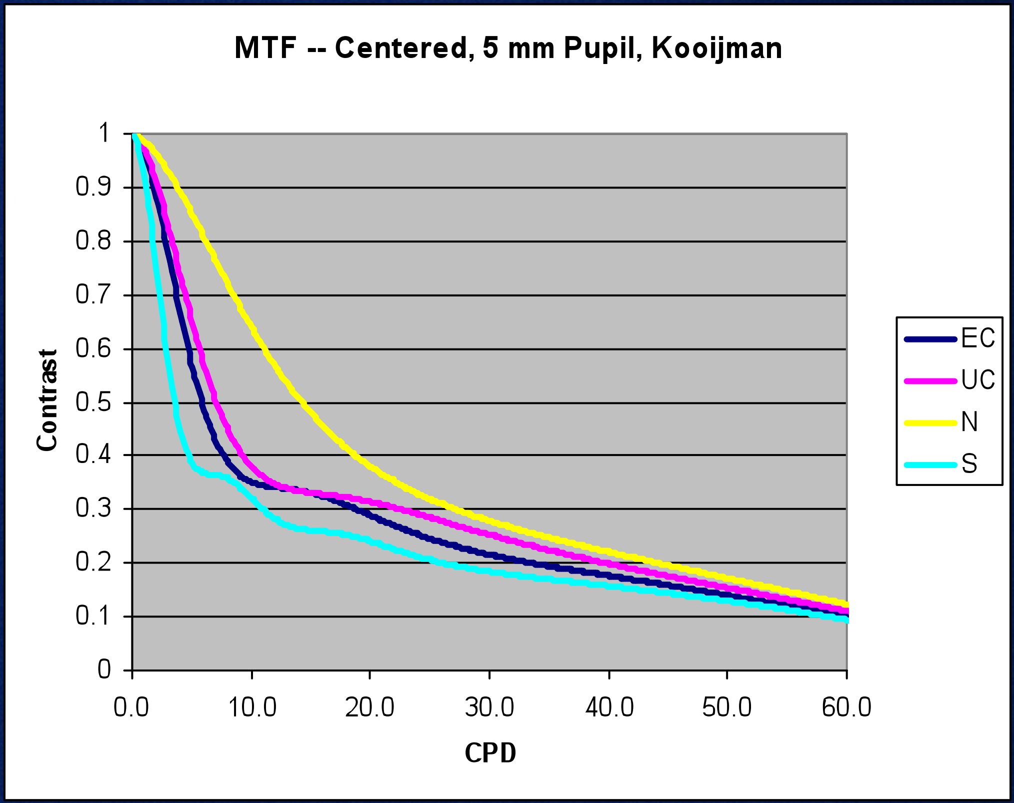
All IOLs work pretty well here – MTF is limited by diffraction.

Centered – 5 mm Pupil, K=-0.1414



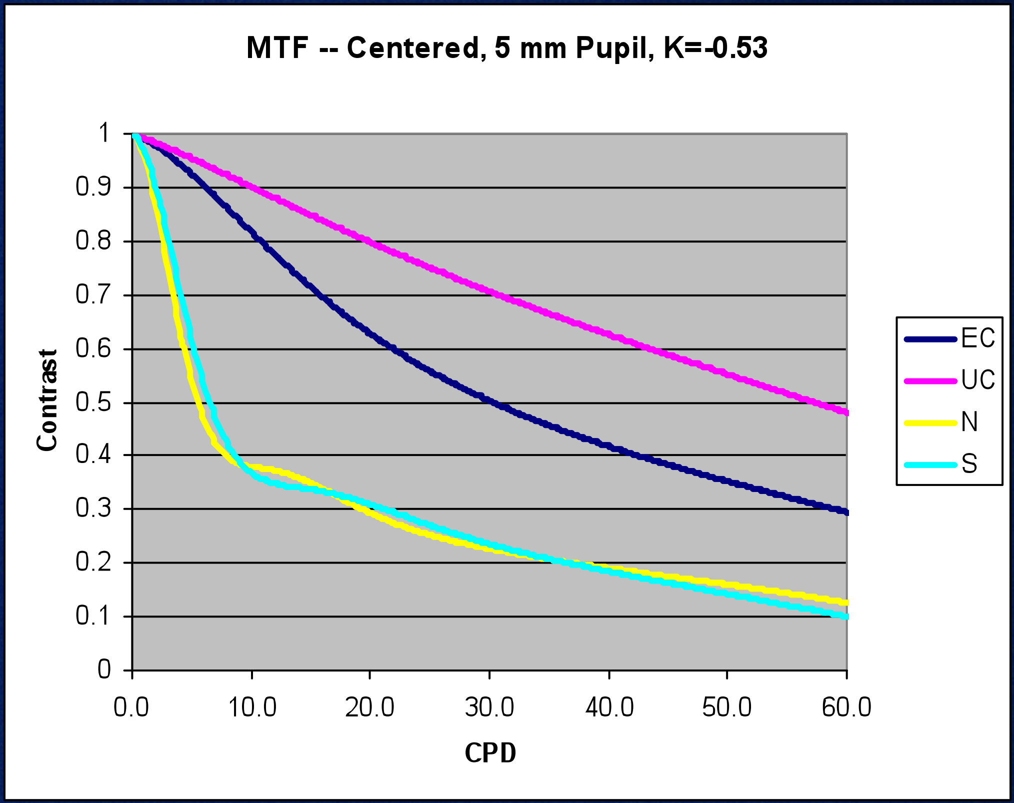
This is where negative spherical aberration IOL works best.

Centered, 5 mm Pupil, K=-0.25



As the eye model is adjusted, note how dramatically the performance is modified.

Centered, 5 mm Pupil, K=-0.53

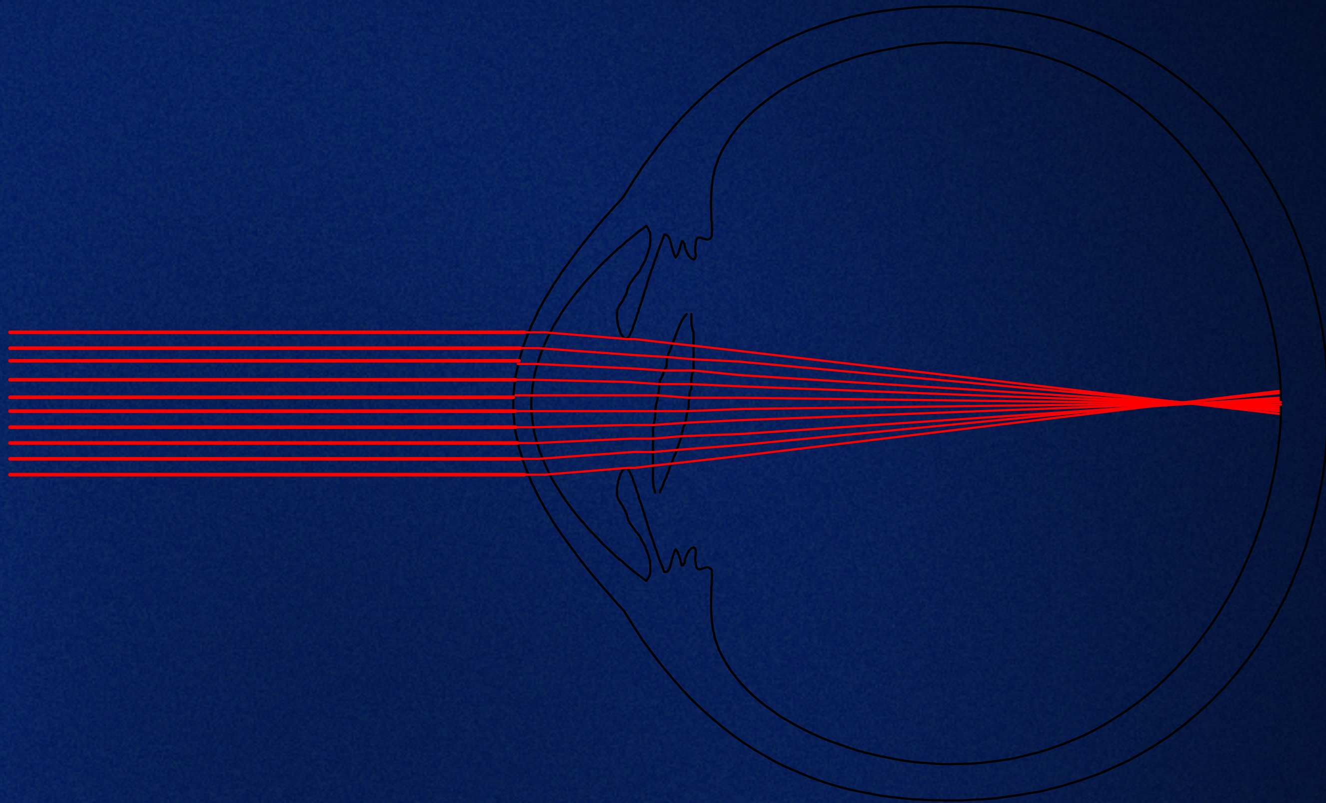


When the cornea has spherical aberrations near zero, the "zero" spherical aberration IOLs perform best.

Centered IOL observations…

- Over this range of K values, the spherical IOL is has lowest performance
- The best performer in the group of conic surface IOLs depends upon the K value
- For the mean K of -0.25, the negative spherical aberration IOL performs best

Tilt…



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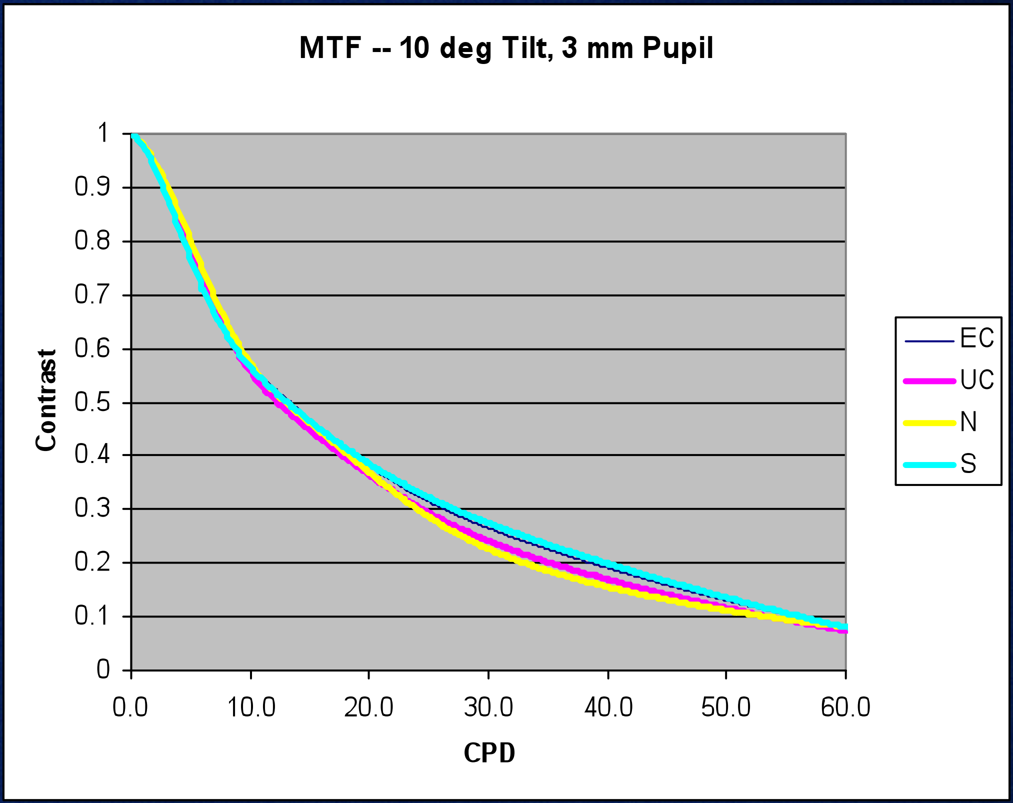
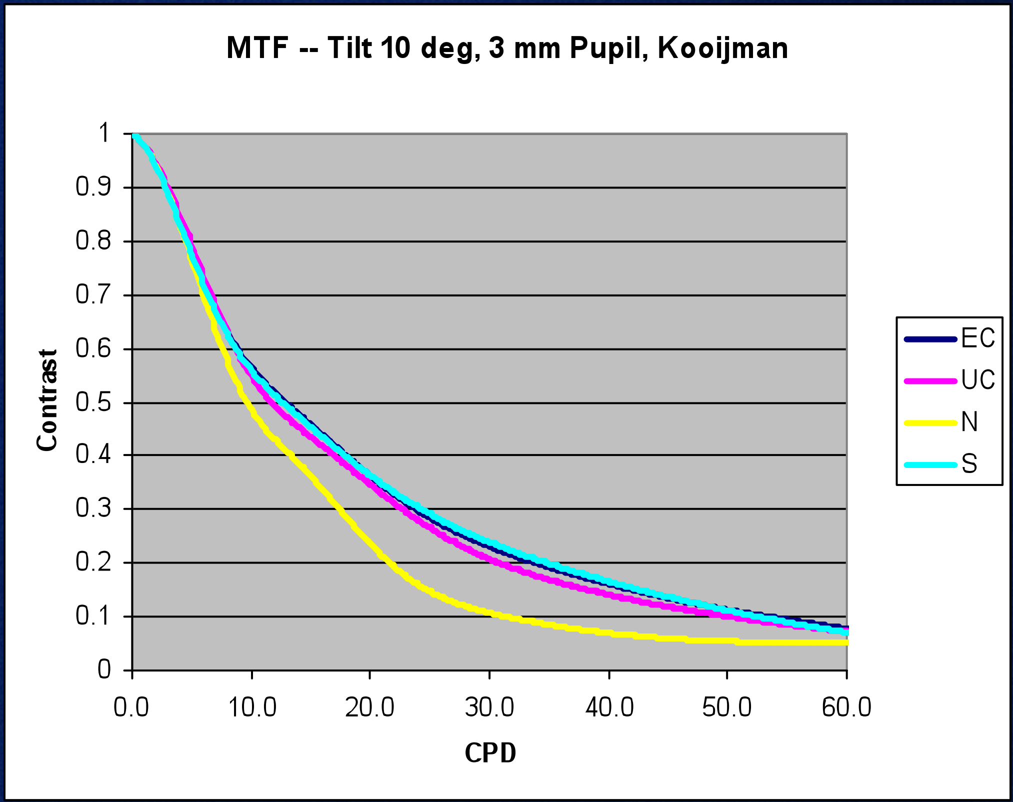
10 deg tilt – 3 mm pupil, K=-0.1414



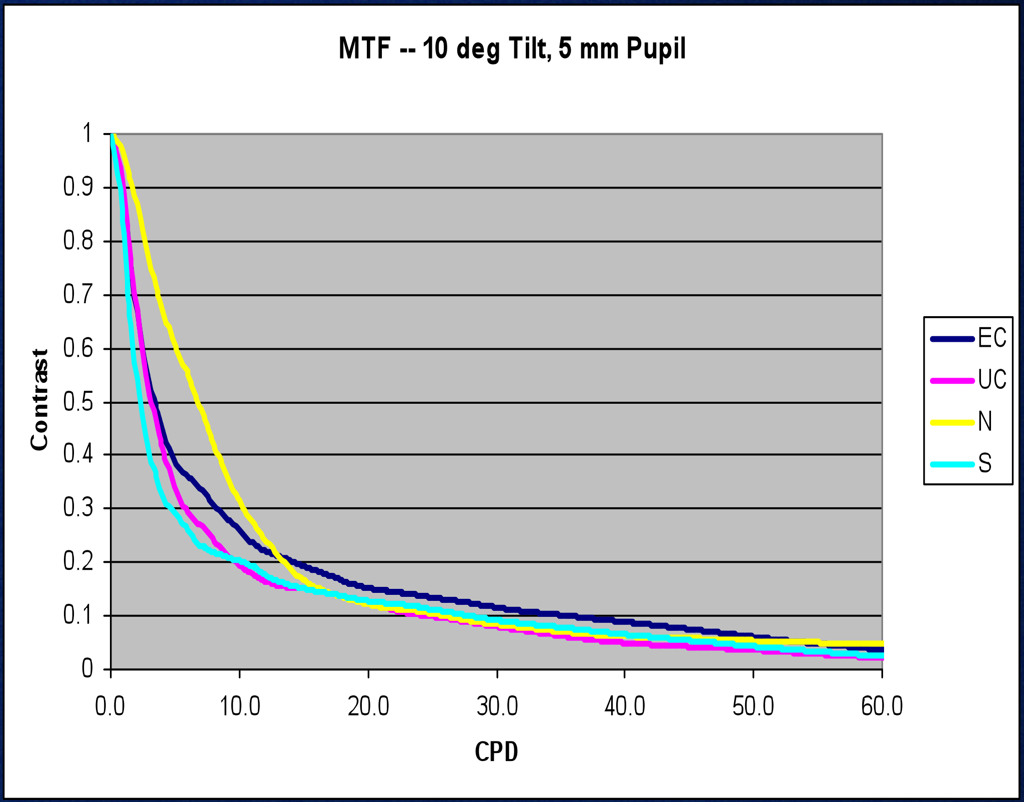
For this eye model, all IOLs perform about the same.

10 deg tilt, 3 mm pupil, K=-0.25



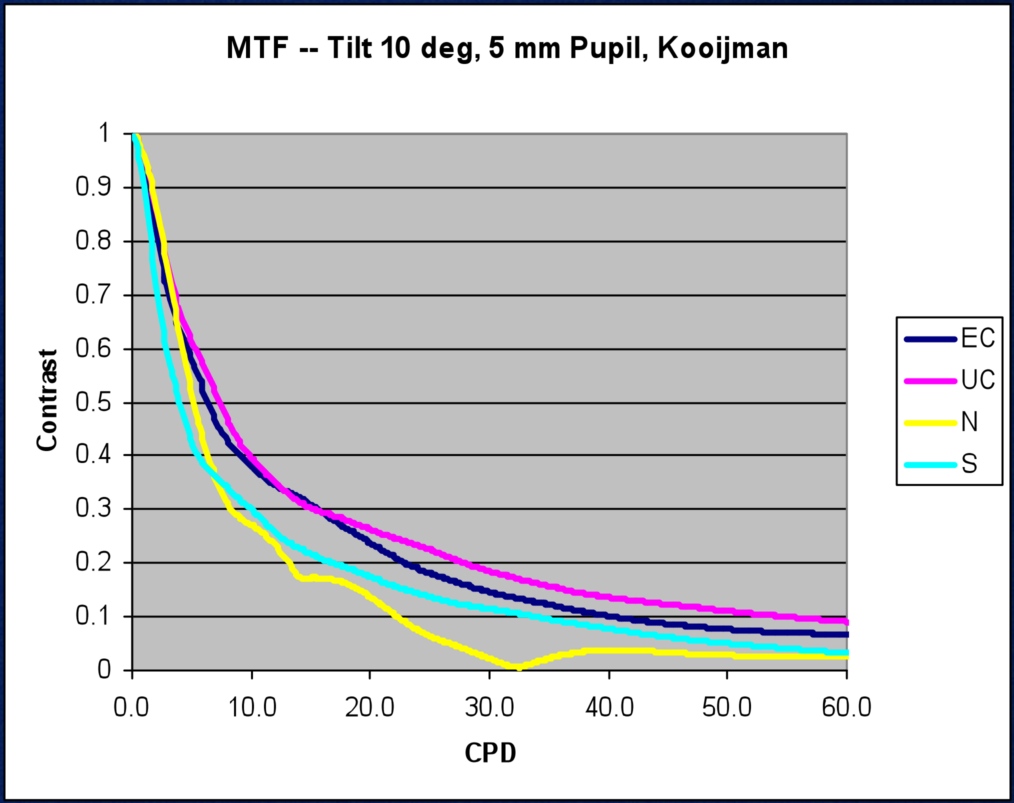
For mean corneal shape, the negative spherical aberration IOL performance starts to fall off.

10 deg tilt, 5 mm pupil, K=-0.1414



Performance for all IOLs close again…

10 deg tilt, 5 mm pupil, K=-0.25

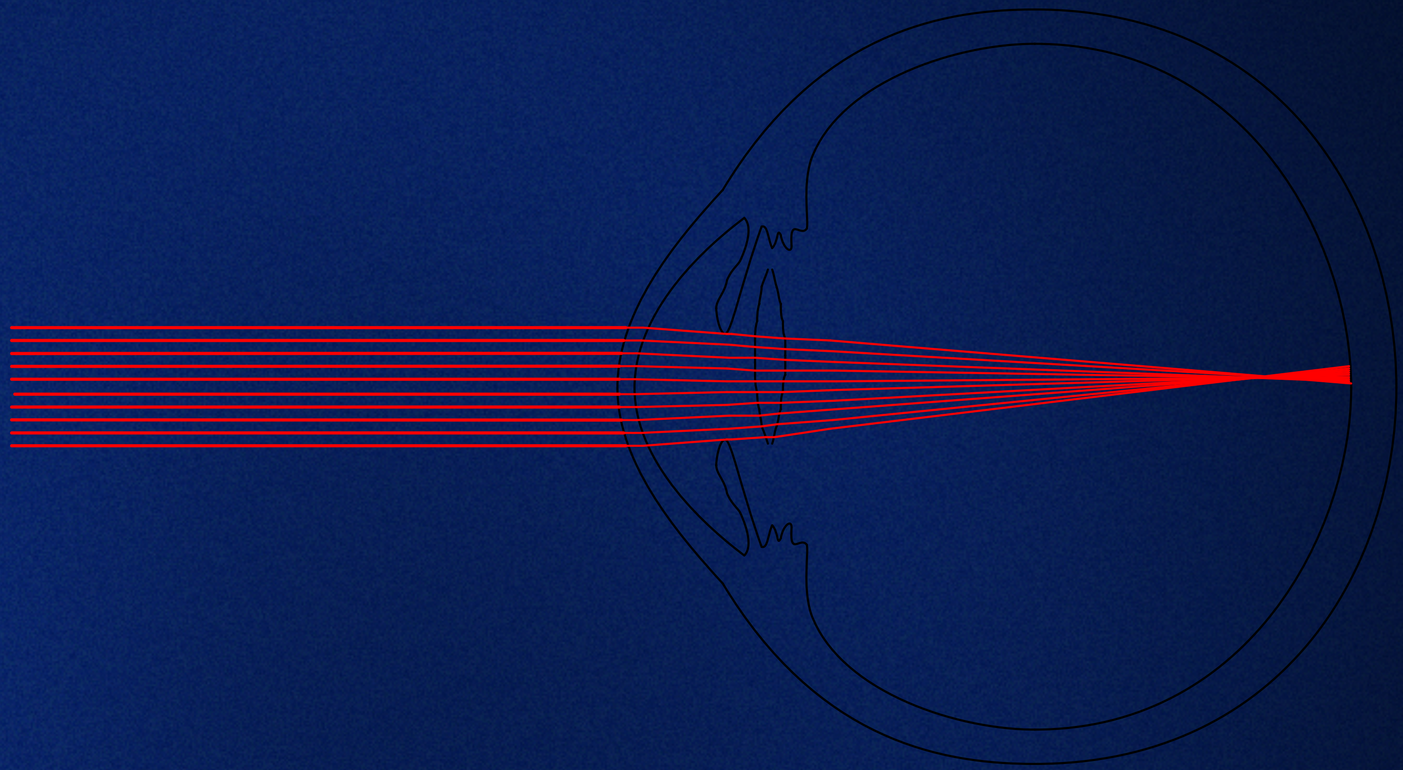


"Zero" spherical aberration IOLs start to perform better for mean corneal shape.

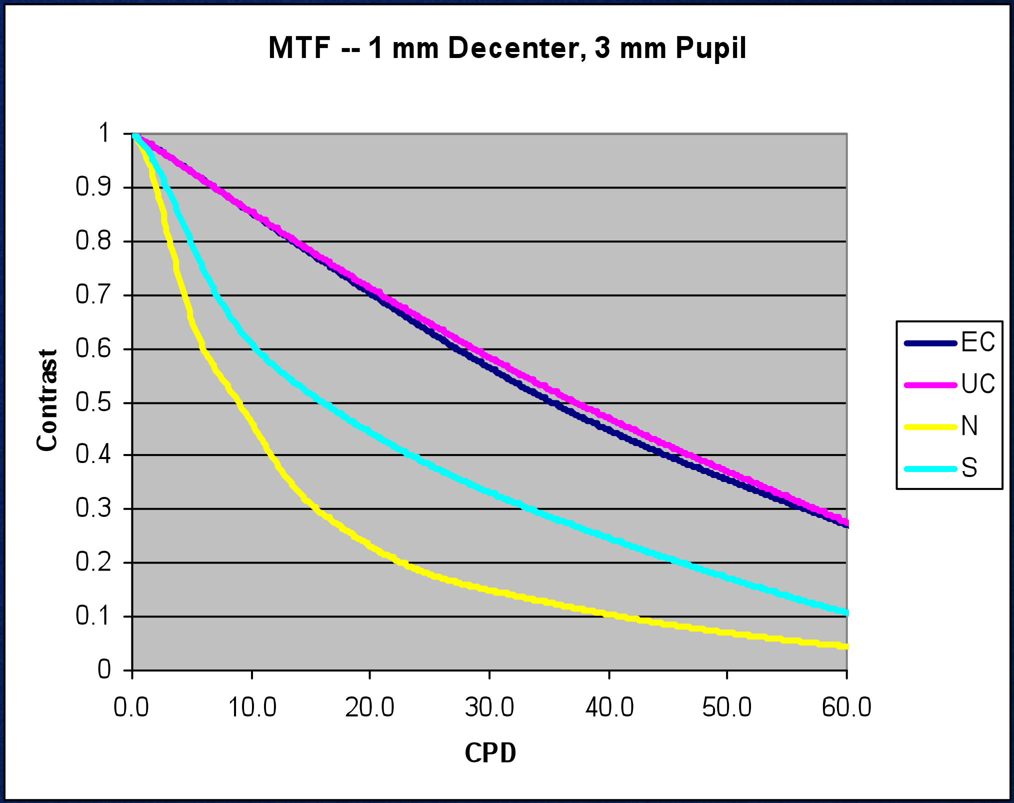
Tilt observations…

- Depending upon the corneal eccentricity:
  - The performance of the IOL designs are comparable
  - For some cases, the zero spherical aberration IOLs out perform the spherical surface and negative spherical aberration IOLs

Decentration...

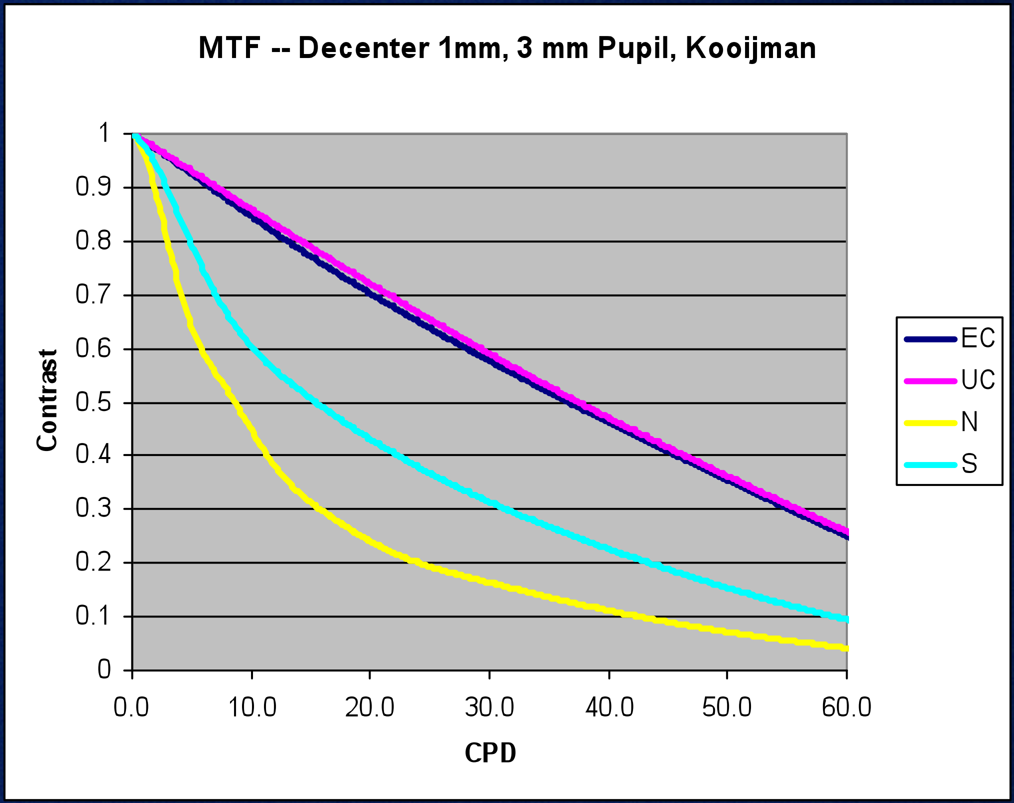


Decentration 1 mm, 3 mm pupil, K=-0.1414



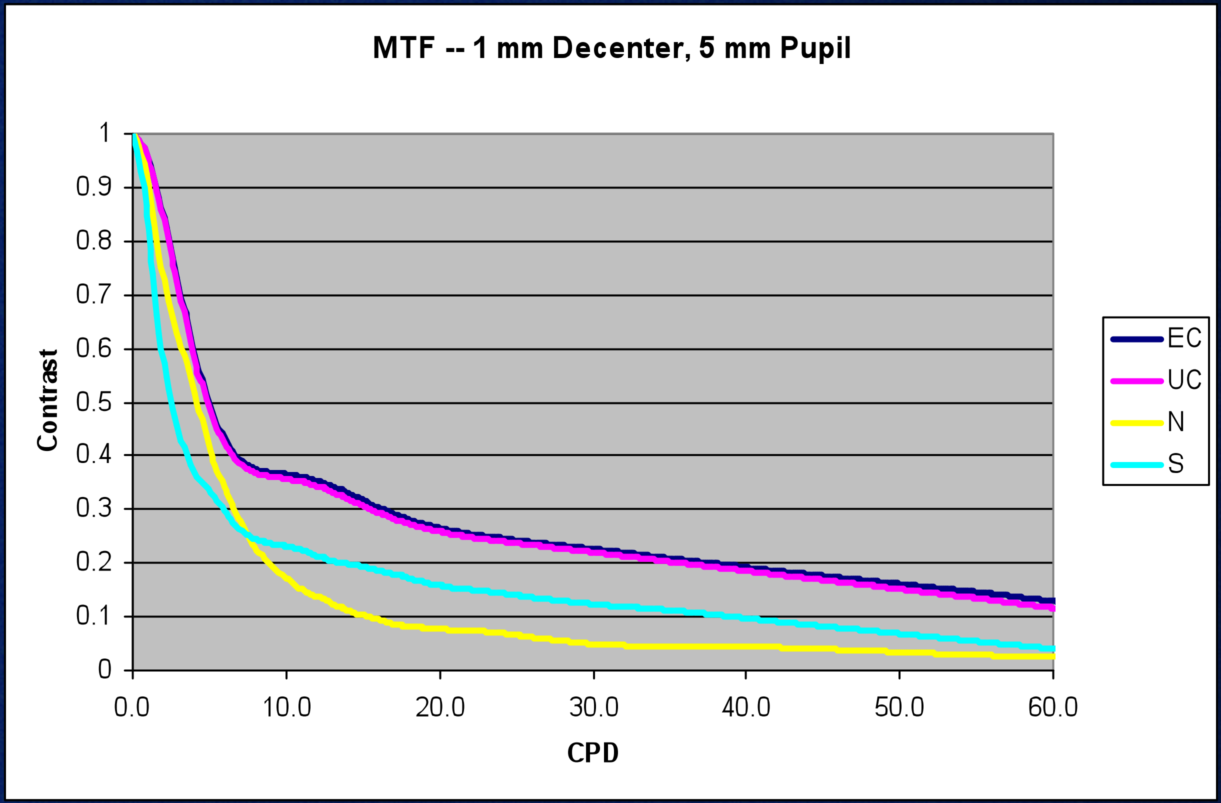
Clearly, the spherical surface and negative spherical aberrations IOLs have trouble with decentration.

Decentration 1 mm, 3 mm pupil, K=-0.25



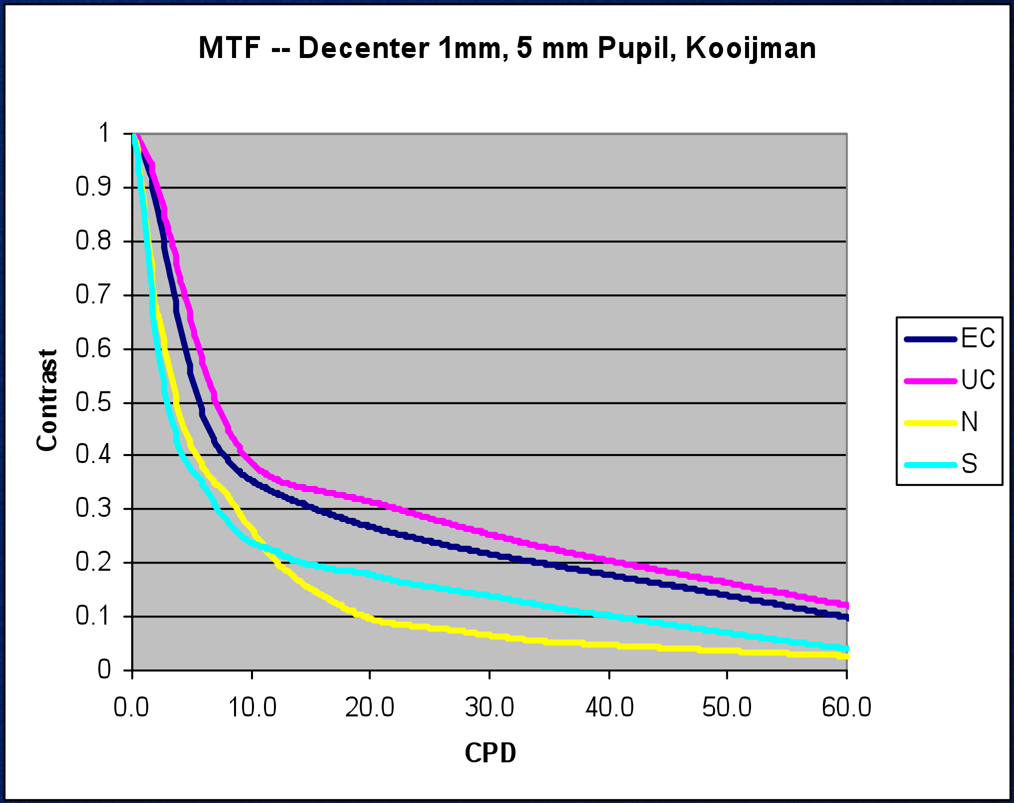
This trend does not depend upon the corneal shape factor.

Decentration 1 mm – 5 mm pupil, K=-0.1414



The same optical behavior is seen for the 3 and 5 mm pupils.

Decentration 1 mm, 5 mm pupil, K=-0.25

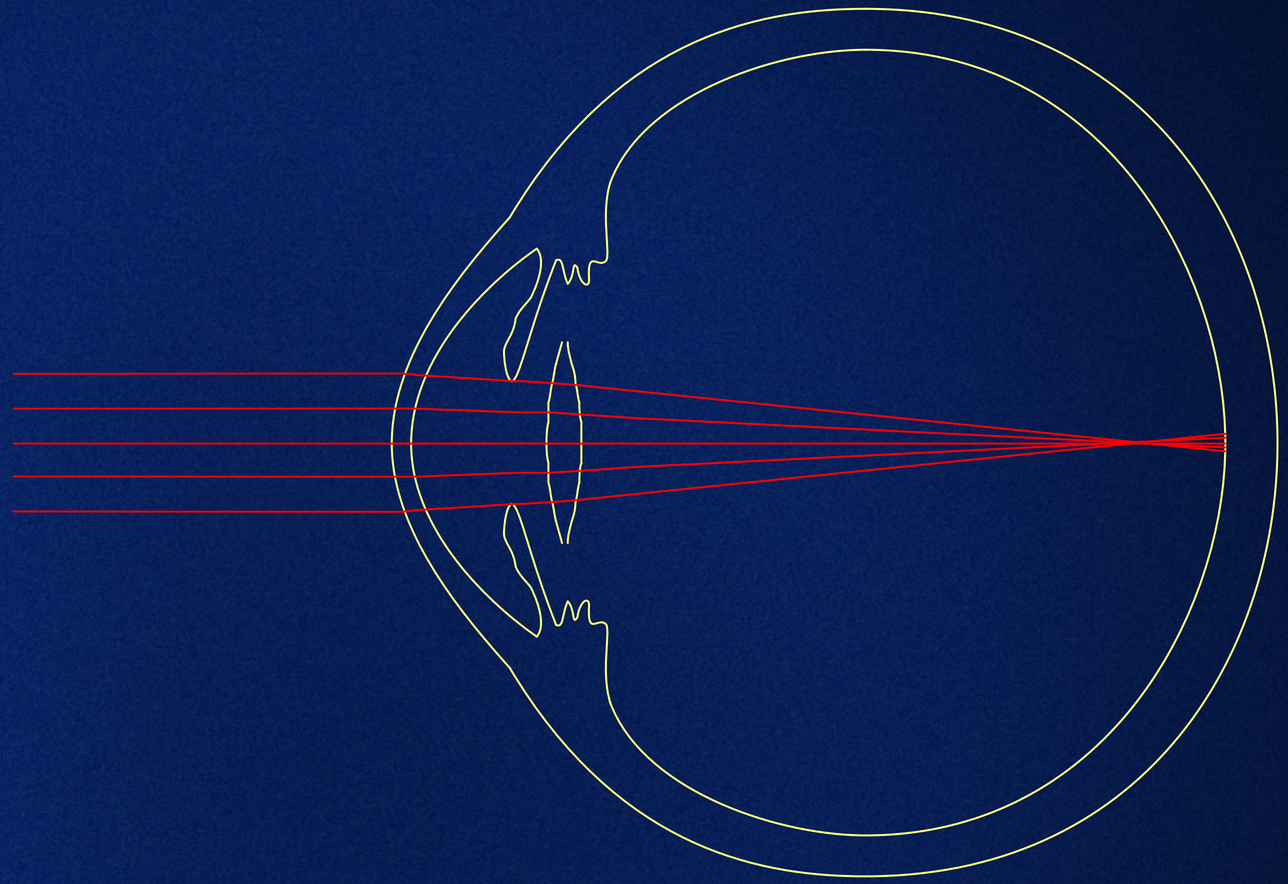


Again, the same trend that does not depend upon corneal eccentricity.

Decentration observations…

- For 1.0 mm decentration:
  - The spherical surface and negative spherical aberration IOLs do not perform as well as zero aberration IOL designs
  - The trends for decentration does not depend upon pupil size or corneal eccentricity

Defocus…



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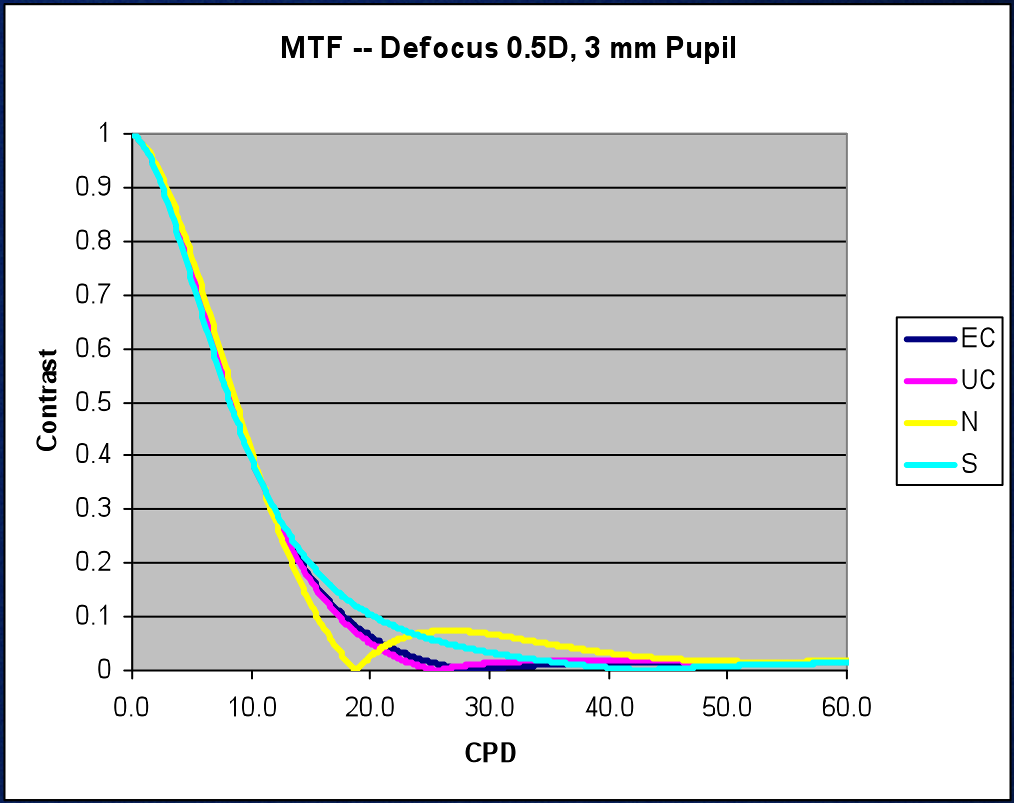
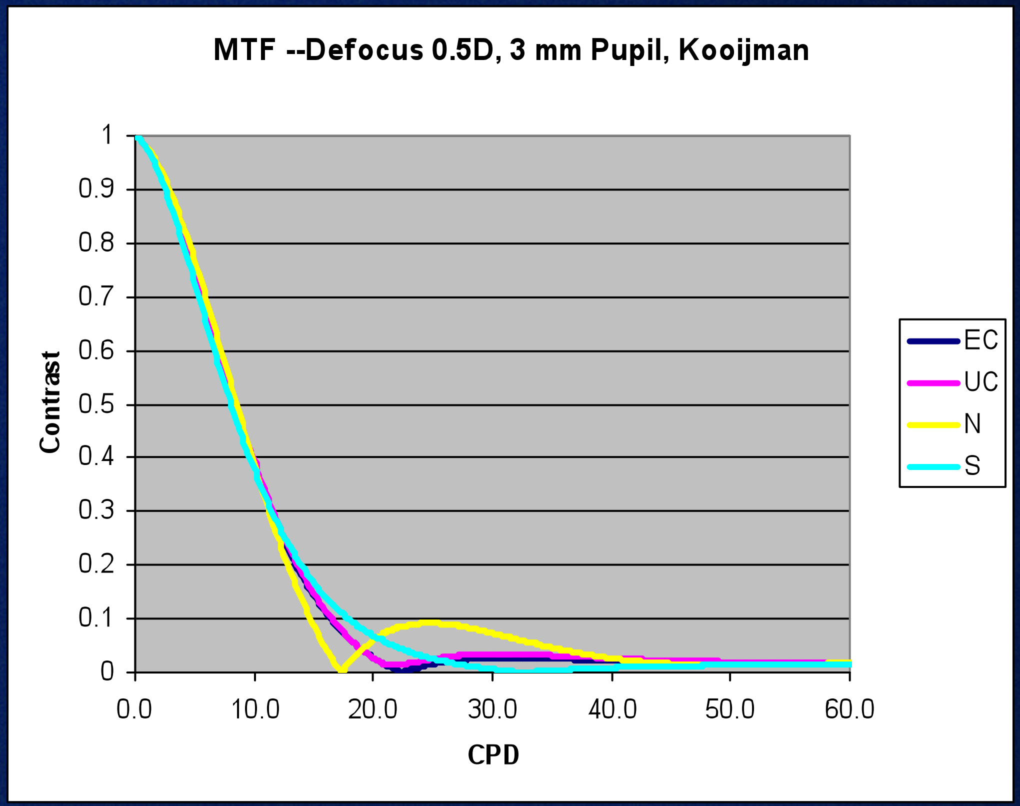
Defocus 0.5D, 3 mm Pupil, K=-0.1414

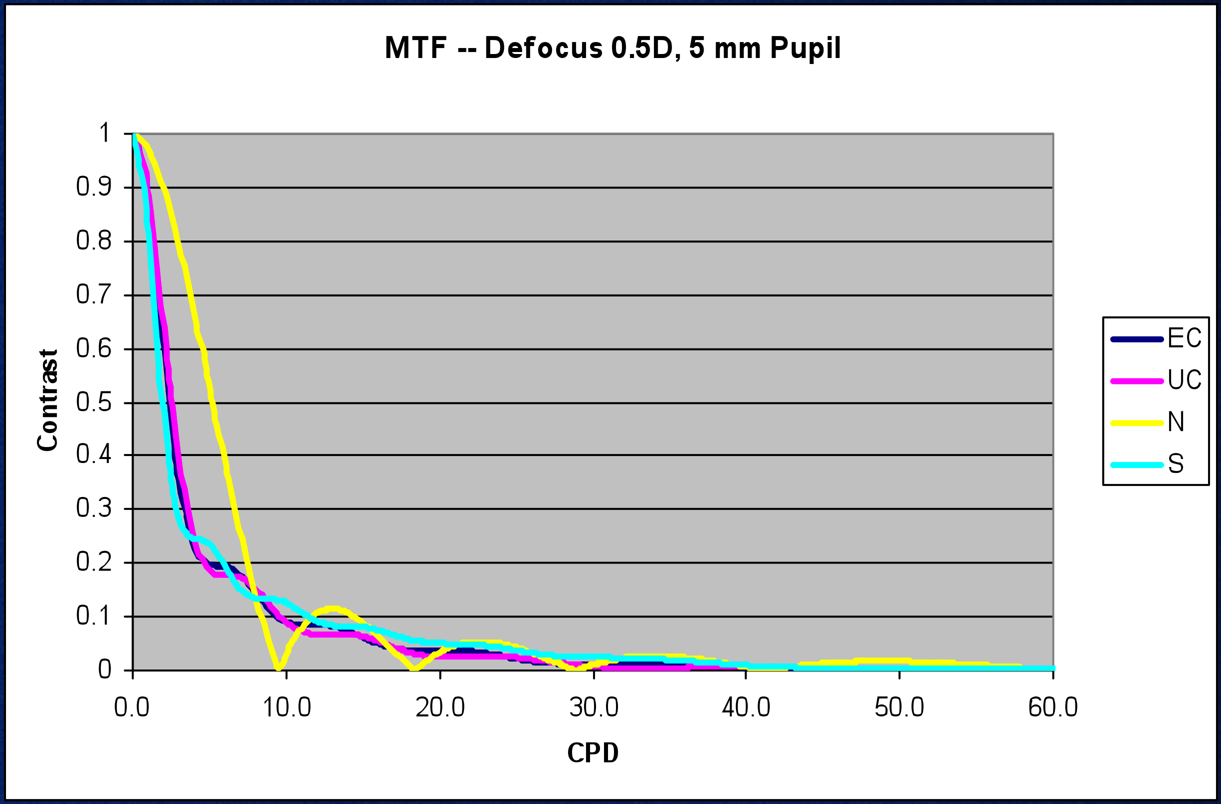


For a 3 mm pupil, the corneal eccentricity does not affect optical performance to a large degree – an seen in this and the next slide.

Defocus 0.5D, 3 mm Pupil, K=-0.25

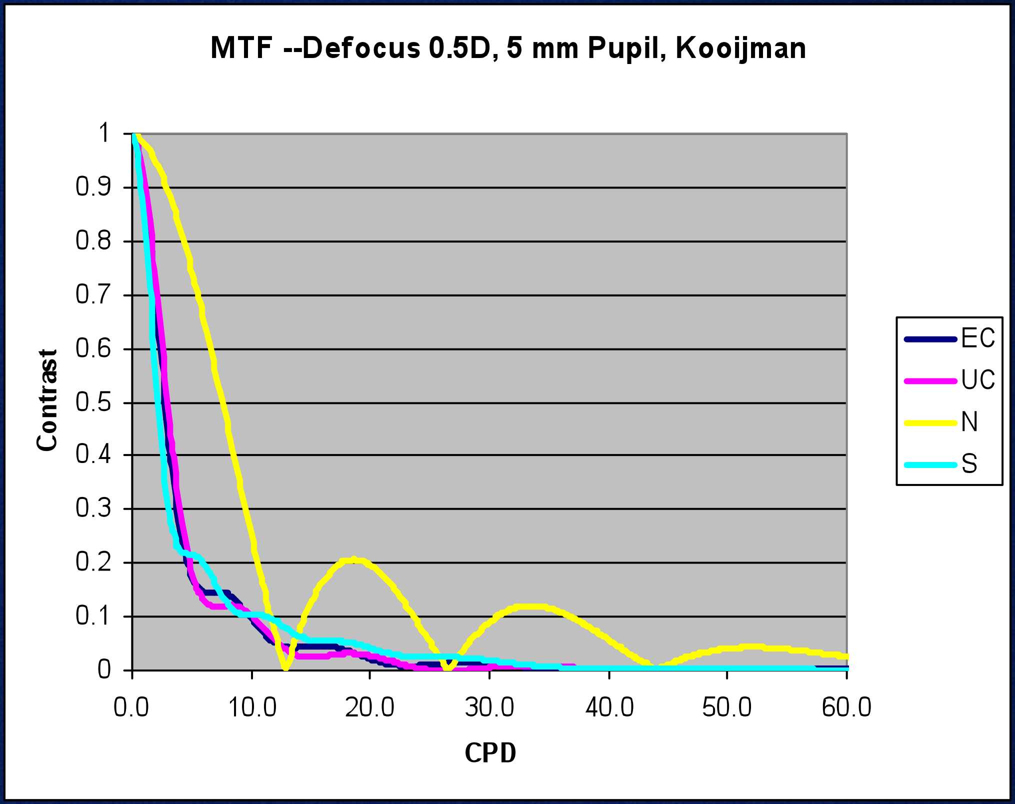


Defocus 0.5D, 5 mm Pupil, K=-0.1414



The general performance of the IOLs for 0.5D of defocus and 5 mm pupil does not appear to depend upon corneal eccentricity.

Defocus 0.5D, 5 mm Pupil, K=-0.25



As a side issue, the large ripples corresponding to the negative spherical aberration IOL indicate regions of contrast reversal.

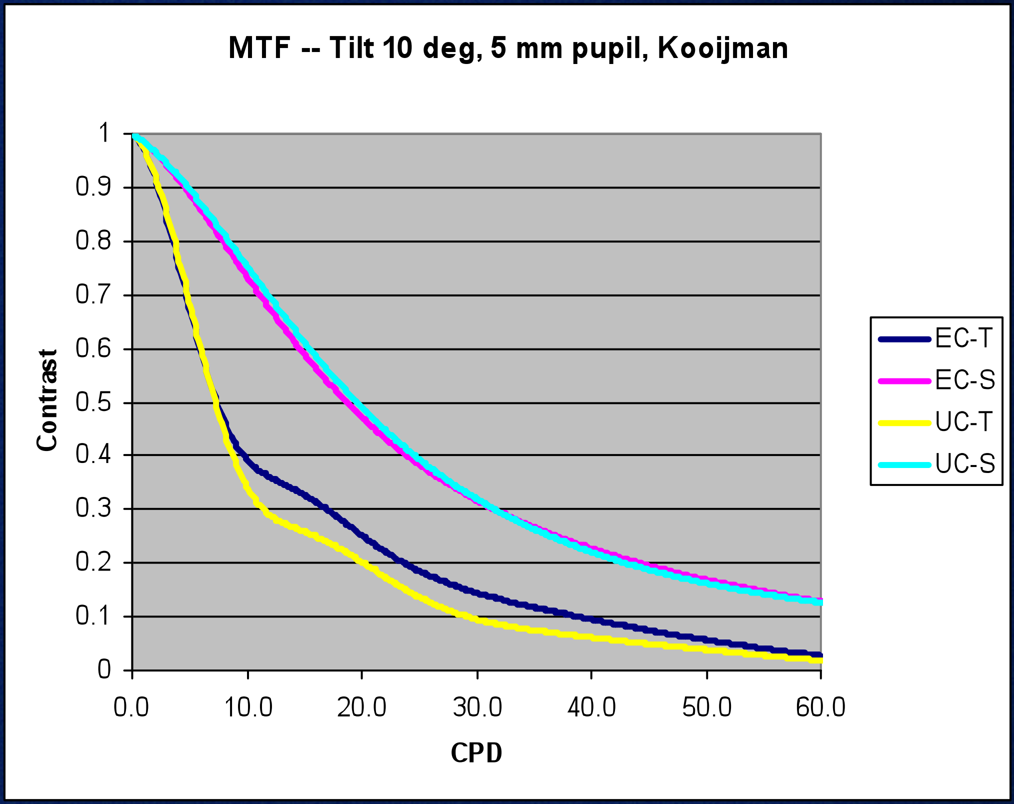
Defocus observations…

- For 0.5 D of defocus at 3.0 and 5.0 mm pupils, the performance of all IOLs are about equal.
- The negative spherical aberration IOL shows more contrast for low frequency objects than the other IOLs
- The negative spherical aberration IOL showed significant regions of contrast reversal at 5.0 mm pupil

Closer look at EC & UC

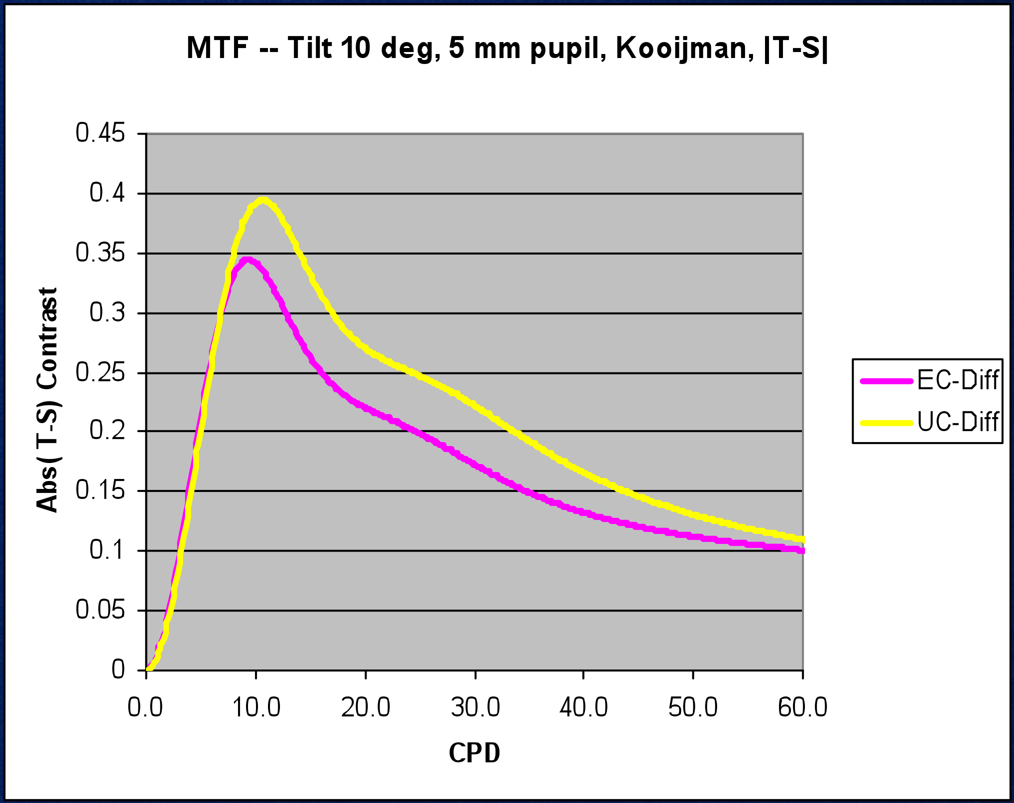
- The equal conic IOLs and unequal conic IOL designs appear to perform about the same
- Want to consider variability in tangential and sagittal MTF components in more detail

Tilt of 10 deg, 5 mm pupil



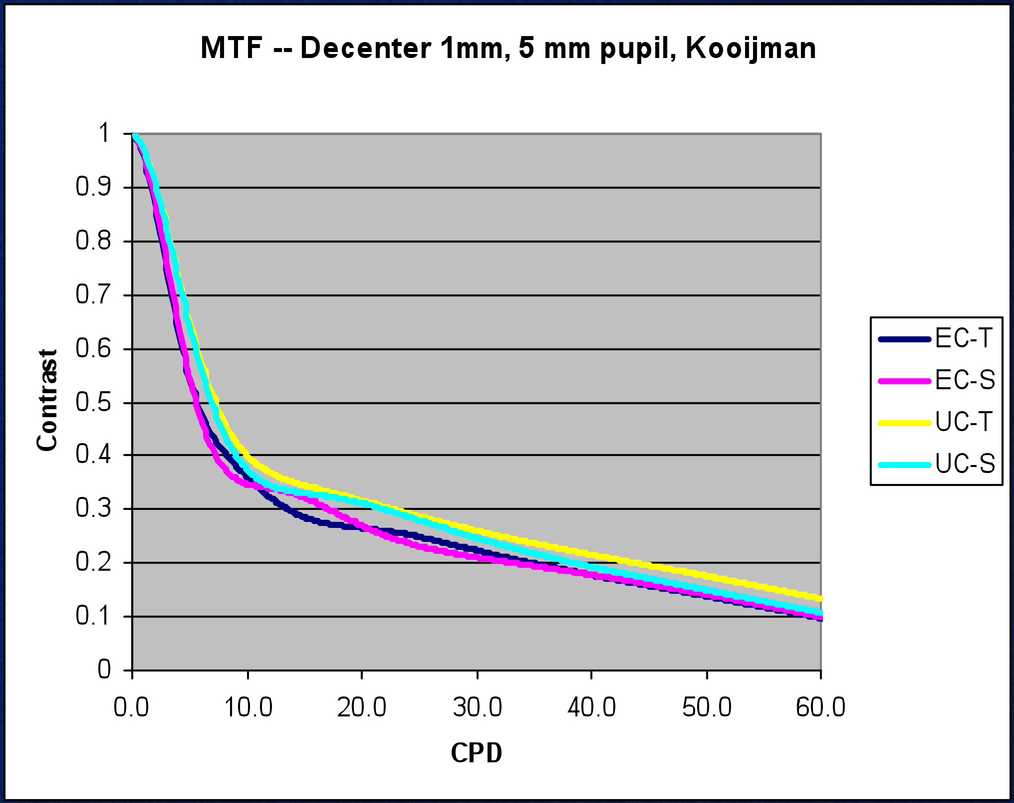
The tangential and sagittal MTF components indicate a greater variability for the unequal conic design compared to the equal conic design.

Tilt |T-S| graph



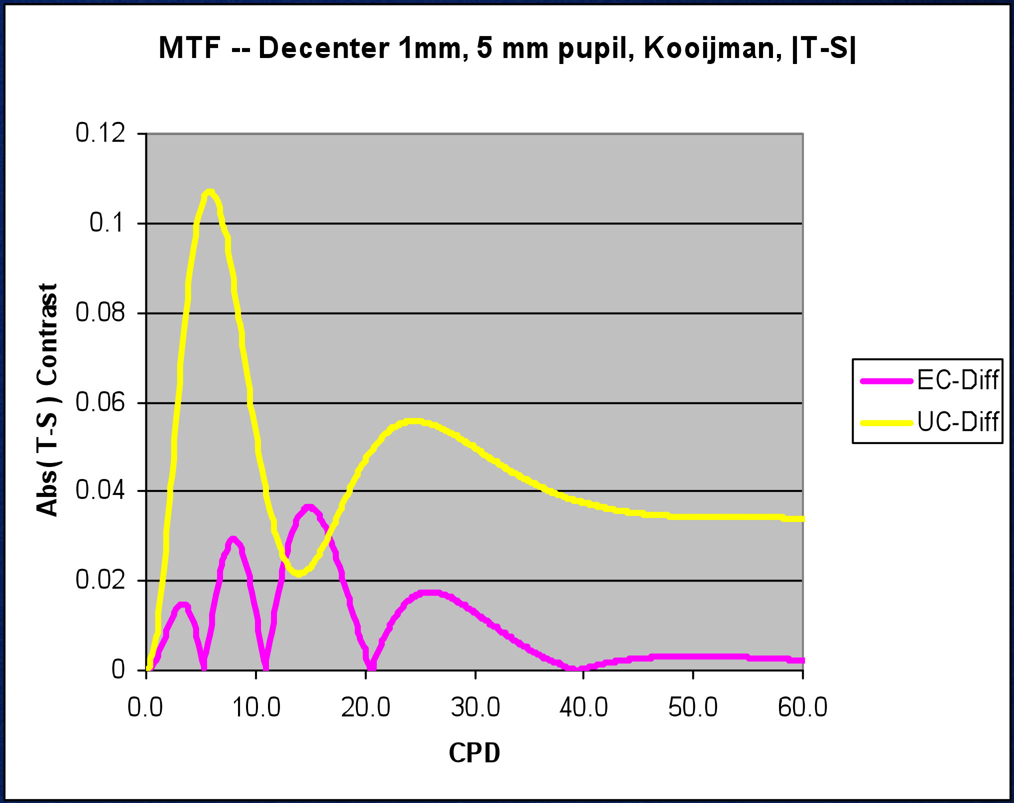
The magnitude of the differences between the tangential and sagittal MTF components clearly show more variability for the unequal conic design.

Decentration



It is more subtle which lens design is more variable.

Decentration |T-S| graph



By comparison of the magnitude of the difference between tangential and sagittal MTF, we see that the equal conic design has less variability.

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Discussion

- There are various conditions in which one IOL design will perform better than another, but generally…
  - Aspheric IOLs perform better than spherical surface IOLs
  - For the level of alignment errors investigated here, zero spherical aberration IOLs perform better than spherical surface IOLs and negative spherical aberration IOLs

Discussion…

- Recognizing the variability in corneal eccentricity, it may be prudent to decide upon the use of an aspheric IOL design as a function of measured corneal aberrations (not ocular aberrations)
- This IOL selection strategy was suggested by Krueger et al.

Krueger RR, et al, Wavefront Customized Visual Correction, Chapter 42, p. 368, 2004.

Summary

- Aspheric IOLs have optical advantages over spherical IOLs
- For small alignment errors and positive spherical aberration corneas, negative spherical aberration IOLs perform best
- For larger alignment errors, “zero” spherical aberration IOLs perform best

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Summary

- "Zero" spherical aberration IOLs perform well over a wider range of corneal shapes and alignment errors than negative spherical aberration IOLs
- The equal and unequal conic IOL designs perform are very similar
- The equal conic IOL design performs slightly better than the unequal conic IOL design in terms of smaller variability in tangential and sagittal MTF components

Thank you!

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