Instituto de Óptica (CSIC)
C/ Serrano 121, Madrid
sergio.barbero@io.cfmac.csic.es

ARVO's 2007 Annual Meeting
Program number: 3130/B993

Analytical Tools for Intraocular Lens Design with Aspheric Surfaces

Sergio Barbero & Susana Marcos

1 Motivation

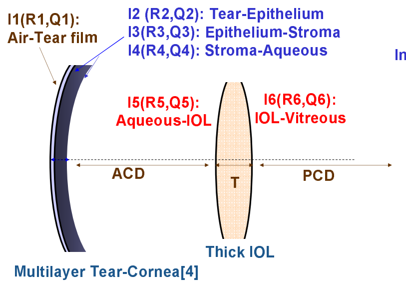
- To present a complete methodology to develop Intraocular Lens (IOL) designs and evaluate their performance based on an analytical formulation.
- To explore the possibilities of the methodology to propose more efficient optical designs using aspheric surfaces.

2 Background

- Ray tracing methods [1] : Exact computations of the rays trajectories through an eye model. Exact but expensive and blind procedure
- Analytical methods [2,3]: Provide equations relating the optical performance with the different parameters of an eye model. Efficient and controlled way of searching for different possible designs.

3 Methods

Pseudoaphakic eye model



Fixed parameters
Medium dispersions[5], Internal cornea shape, IOL thickness

Customized parameters
Anterior corneal shape, ACD, IOL thickness, PCD

Design parameters
IOL radii of curvature and asphericities

Defocus and spherical aberration

Ray transfer formalism: $\begin{bmatrix} Y_1 \\ U_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} Y_0 \\ U_0 \end{bmatrix}$

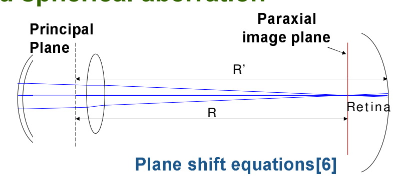
Defocus (Taylor term) equation: $W_{20} = f(R_i, t_i, \lambda)$

Third-order aberration theory

Karl Schwarzschild (1873-1916)

Spherical aberration (Taylor term): $W_{40} = f(P, R_i, Q_i, t_i, \lambda)$

P: Pupil radius; R_i: Radii of curvature; Q_i: Asphericies
t_i: Thicknesses; λ: Wavelength



Plane shift equations[6]

Equivalent defocus (D): $Me = \dfrac{4\sqrt{3}RMS}{Radius^2}$

Optimization algorithms

- Nelder-Mead: Simple direct search algorithm[7]
- Quasi-Newton: Gradient- based algorithm[7]

4 Results

Custom pseudoaphakic eye model for IOL design

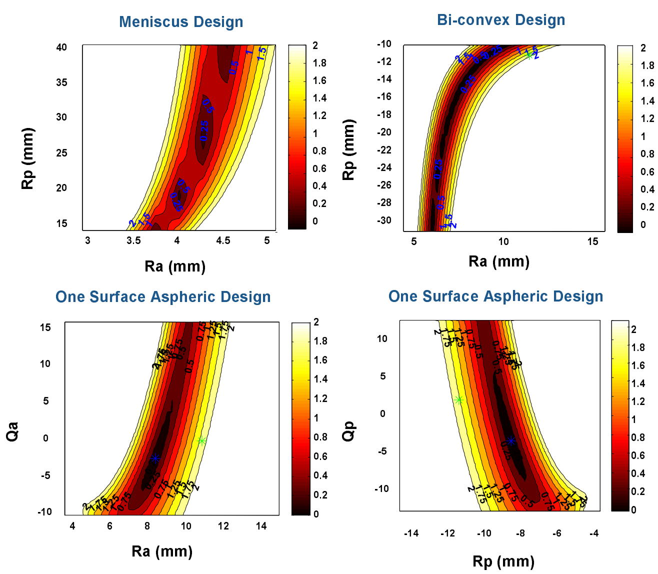
	Interface					
	I1	I2	I3	I4	I5	I6
Radius	7.79	7.79	7.56	6.4[4]	11.04	-11.04
Q	-0.49	-0.49	-1.9	-0.38[4]	-1.04	0
	Medium					
	M1	M2	M3	M4	M5	M6
Thickness	0.004[4]	0.054[4]	0.473[4]	4.29	1.164	17
Refractive Index	$n(\lambda)_a$	$n(\lambda)_c$	$n(\lambda)_c$	$n(\lambda)_a$	$n(\lambda)_s$	$n(\lambda)_v$

Parameters of a case example customized pseudoaphakic eye model (eye 7[8] with an 22 D Tecnis Z9000 IOL). $n(\lambda)_a$ $n(\lambda)_v$ $n(\lambda)_c$ and $n(\lambda)_s$ denote the refractive index dispersion formulae for the aqueous, vitreous, corneal and silicon media[5]. Medium: M1: Tear film, M2: Epithelium, M3: Stroma, M4: Aqueous, M5: IOL, M6: Vitreous

Optimization algorithms

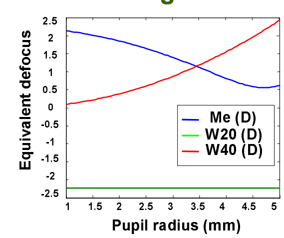
- We achieved optimum designs using gradient (Quasi-Newton) or non-gradient (Nelder-Mead) algorithms, but with different design parameters.
- Quasi-Newton algorithm is more efficient because the number of iterations is smaller than using Nelder-Mead algorithm (30 versus 480).

Bi-dimensional exploration of IOL designs

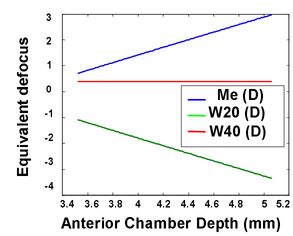


Ra, Rp: IOL anterior and posterior radius Qa,Qp: IOL anterior and posterior asphericity

Pupil size in IOL design



Ocular biometry uncertainity



Tolerance analysis

Anterior radius	Posterior radius	Anterior asphericity	Posterior asphericity	Thickness	Refractive index
±0.23 mm	±0.33 mm	±1.66	±4.28	±0.12	±0.0017

Tolerance limits (model of table 2) for the design parameters

Limitations of the technique

- No consideration of the actual corneal topography, tilt and decentrations of the IOL and the misalignment of the line of sight with respect to the optical axis.
- Performing ray tracing over complete customized eye models[9] reveal an extra amount of around 1 D. Yet, our customized eye designs are more robust than generic designs (0.95 D versus 2.22 D)

5 Conclusions

1. An analytical procedure is presented to obtain optimal spherical/aspheric IOL designs.
2. We have proposed to use analytical optimization and tolerance analysis algorithms to explore better designs
3. Using individual biometric data improves considerably the final optical performance

Acknowledgements

EURYI Award to S. Marcos
Grant FIS2005-04382 to S. Marcos
I3P-CSIC to S. Barbero

6 References

1. D. A. Atchison, "Optical Design Of Intraocular Lenses .1. On-Axis Performance," Optom. Vis. Sci., 66, 492-506 (1989).
2. D. A. Atchison, "Design Of Aspheric Intraocular Lenses," Ophthalmic Physiol. Opt. 11, 137-146 (1991).
3. C. W. Lu, and G. Smith, "The Aspherizing Of Intraocular Lenses," Ophthalmic. Physiol. Opt. 10, 54-66 (1990).
4. S. Barbero, "Refractive power of a multilayer rotationally symmetric model of the human cornea and tear film," JOSA-A , 23, 1578-1585 (2006).
5. D. A. Atchison, and G. Smith, "Chromatic dispersions of the ocular media of human eyes," JOSA-A, 22, 29-37 (2005).
6. G. Smith, D. A. Atchison, and S. Barbero, "Effect of defocus on on-axis wave aberration of a centered optical system," JOSA-A, 23, 2686-89 (2006).
7. R. R. Fletcher, Practical methods of optimization (John Wiley & Sons Ltd, 1987).
8. A. de Castro, P. Rosales, and S. Marcos, "Tilt and decentration of intraocular lenses in vivo from Purkinje and Scheimpflug imaging," J. Cataract. Refract. Surg, 33, 418-429 (2007).
9. P. Rosales, and S. Marcos, "Customized computer models of eyes with intraocular lenses," Opt. Express 15, 2204-2218 (2007).