Stochastic Eye Model Predicting the Population Response to Cataract and Refractive Surgery

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Modeling the eye

Gullstrand eye model

Lotmar, 1971;
Navarro et al. 1985;
Liou & Brennan 1997;
...

Other eye models
How general is the Gullstrand model?

Canonic proportions (average biometry) ≠ individual subjects

598 eyes

Refraction +1D: 4 eyes (0.67%)

30 eyes (5%)
“Human eyes are neither radially symmetrical nor uniform. Their higher-order aberrations can no more be described by a single schematic eye (...) There is a rich variety of higher-order aberrations of the human eye, with the eyes of no two persons being exactly alike. The variety is so great (...) that no single set of Taylor (aberration) coefficients can meaningfully be said to be typical.”

Walsh, Charman and Howland, JOSA A (1984)
Stochastic eye modeling in the literature

* Sorsby et al. (BJO 1981)
* Thibos et al. (OPO 2002)
* Zhao (Opt Lett 2009)
* Wang et al. (Int. JO 2012)
* Rozema et al. (IOVS 2011)
* Rozema et al. (IOVS 2016)

Optical balance correlation
Stochastic eye modeling in the literature

- Sorsby et al. (BJO 1981)
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Statistical eye model: Modeling populations
Input data

312 healthy right eyes

**Biometry:**
- Corneal topography (2 surfaces)
- Central thickness
- Anterior chamber depth
- Lens thickness
- Axial length
- Lens power (Bennet, 1988)
- Lens radii (Rozema et al. 2012)

**Optical performance:**
- Refraction, autorefractometer
- Wavefront, iTrace

**Estimated:**
- Lenstar
- Pentacam

**Refractive indexes, lens conic constants, etc.**
(Navarro eye model)
Distribution of SE refraction

Bimodal Gaussian Distribution
(mixture of 2 Gaussians)

Distribution of biometric parameters

Most ocular parameters show Gaussian distributions

K, CCT, ACD, T and $P_L$ are all Gaussian,

L is somewhat skewed

But refraction is NOT Gaussian...

Stochastic modeling: 1 parameter

Corneal power

"Univariate Gaussian distribution"

\[ f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]

Determined by \( \mu \) and \( \sigma \)
"Multivariate Gaussian distribution"

\[ f_X(x) = \frac{1}{(2\pi)^{k/2}|C|^{1/2}} \exp\left(-\frac{1}{2}(x-M)^T C^{-1} (x-M)\right) \]
Dimensional reduction: eigencorneas

Corneal topography: 2 surfaces + central thickness

91 parameters → 12 decorrelated parameters

Figure 3. Basis functions (eigencorneas) for anterior (top row) and posterior (bottom row) surfaces of the right eyes processed separately (each 45 parameters) using Zernike coefficients. The first basis function is the average, followed by the first 7 eigenvectors sorted according to decreasing eigenvalues.

Strong simplification & statistical independency

Rodriguez et al. OPO (2014)
Statistical eye model: SyntEyes

18 parameters:

12 eigencorneas
(8th order corneal Zernikes + CCT)
Anterior chamber depth
Lens thickness
Ant. and post. lens radius
Lens power
Axial length

\[
f_x(x) = \sum \frac{1}{(2\pi)^{k/2}|C|^{1/2}} \exp\left( -\frac{1}{2} (x - M)'C^{-1}(x - M) \right)
\]

Random number generator applied to \( f_x(x) \)

Reconstructed data

Rozema et al. IOVS (2016)
Validating the SyntEyes model
1. Biometry

Rozema et al. IOVS (2016)
Validation: 2. Wavefront

Population (bars) vs. synthetic (line) Zernike coefficients

Rozema et al. IOVS (2016)
Examples and applications
Normal eyes

Post refractive

Pseudophakic

Rozema et al. IOVS (2016)
Post-refractive eyes
(Munnerlynn algorithm and broad Gaussian beam)

71 myopic eyes before and after LASEK

Rozema et al. IOVS (2016)
1000 SyntEyes implanted with a Morcher 89a “Bag in the Lens” IOL targeting emmetropia for three pupil diameters, compared to previously measured subjective refraction data of 320 pseudophakic eyes.

Rozema et al. IOVS (2016)
Other applications: reconstruction of Stenström’s historical data (1947)

When mean & covariance are available

Coming soon: keratoconic SyntEyes

Rozema et al. ARVO (2016)
Thank you for your attention!

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