Higher order statistical eye model for keratoconus

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This work presents and validates a stochastic eye model for keratoconus that may be used to develop new optical corrective strategies in these patients. This could be particularly useful for researchers that do not have access to original keratoconic data.

Purpose

In keratoconic eyes the cornea experiences a progressive conical deformation that considerably impedes the visual quality of the patient. Over the years many different methods have been proposed to correct for the optical aberrations induced by the condition, such toric spectacles, rigid gas-permeable contact lenses and scleral lenses. But while there is a great research interest in keratoconus corrections, it is not always easy for investigators to obtain a sufficiently large cohort of patients with a wide enough amount of biometric variability to test their solutions. For this reason we present and validate a stochastic model of the corneal and ocular biometry in keratoconic eyes capable of generating an unlimited number of random, but realistic biometry sets. These biometry include corneal elevation, intraocular distances and wavefronts, with the same statistical and epidemiological properties as the original keratoconic data it is based on.

Methods

The data of *145* keratoconic eyes of *145* patients (aged *18 – 60* years) was recorded with an autorefractometer, Scheimpflug imaging (Oculus Pentacam), optical biometer (Haag–Streit Lenstar) and an aberrometer (Tracey iTrace), which lead to a set of *97* biometric parameters. In order to reduce this number to *18* parameters, the Zernike coefficients of corneal elevation were compressed using Principal Component Analysis.[1] These data were subsequently fitted with a linear combination of two multivariate Gaussians through an Expectation Maximization algorithm,[2,3] from which it is possible to generate an unlimited number of random biometry sets with the same distributions as the original data.[4] These biometry sets can then be used to calculate the associated wavefronts and other ocular parameters, filling in parameters from the Navarro eye model[5] to account for missing values (e.g. lens asphericity). Equality between the original keratoconic data and the synthetic data was assessed using "two one-sided" tests (TOST).[6,7]

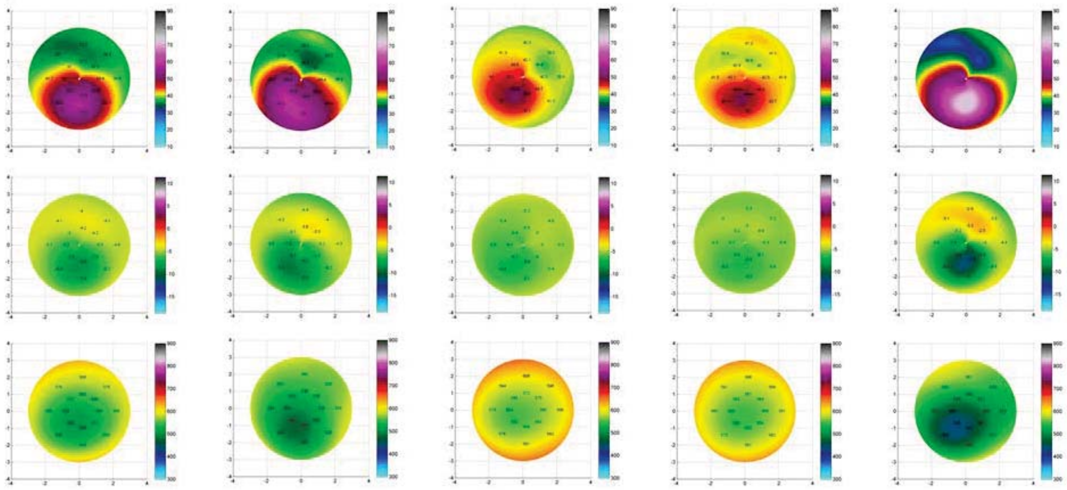

Figure 1:Five examples of keratoconic corneas generated by the stochastic model (columns), with the anterior topography (top), posterior topography (middle) and pachymetry (bottom).

Results

The model randomly generates corneas with keratometry patterns that closely resemble those of the late stages of keratoconus (Figure 1). In order to verify the accuracy of the wavefront calculations, the wavefronts derived from the measured biometry were compared to the originally measured wavefronts and found significantly equal (TOST, $p < 0.05$). Next the biometry of *1000* synthetic eyes were generated by the stochastic model, followed by ray tracing to obtain the associated wavefronts (Figure 2). Both the synthetic biometry data and the calculated wavefront were found

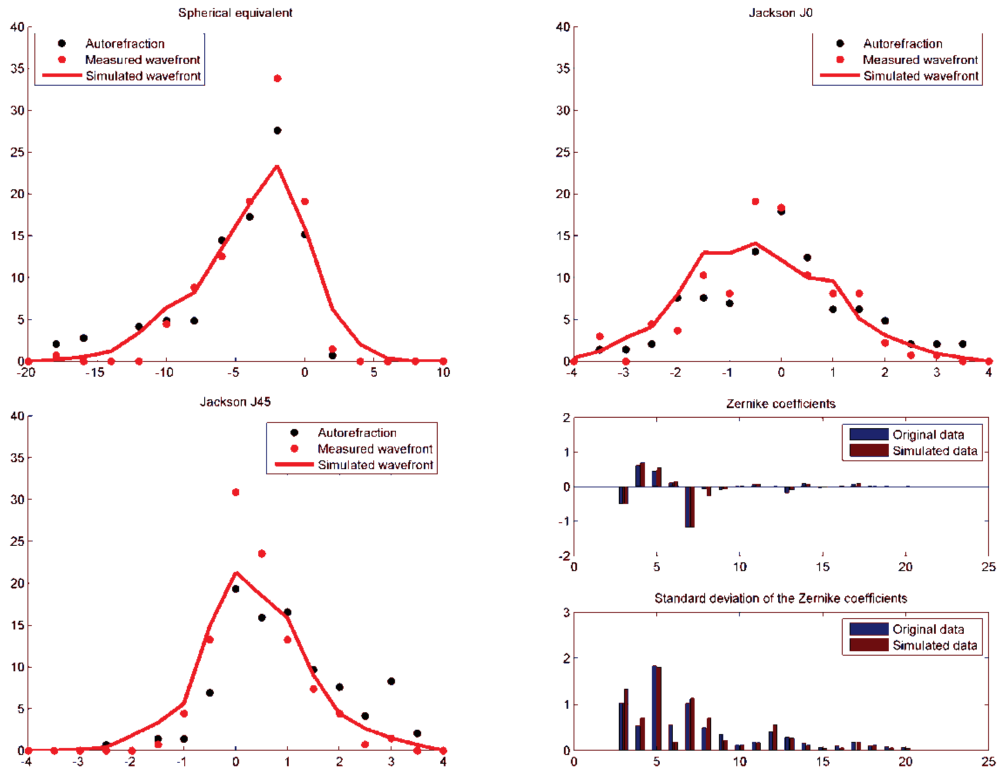

Figure 2: Agreement of spherical equivalent and Jackson cylinders for the autorefraction, the measured wavefront and the calculated wavefront for 1000 synthetic eyes. The agreement of the Zernike coefficients is shown at the bottom right.

Table 1: Comparison of the original and the synthetic data sets										
		***CCT* (mm)**	***ACD* (mm)**	***T* (mm)**	***L* (mm)**	**r_{la} (mm)**	**r_{lp} (mm)**	**P_L (D)**	**Corneal elevation (Ant +Post)**	**Total wavefront**
Original	***N***	*145*	*145*	*145*	*145*	*145*	*145*	*145*	*145*	*145*
	Mean	*0.498*	*3.23*	*3.76*	*24.09*	*11.33*	*-7.44*	*22.71*	*Various*	*Various*
	St Dev	*0.039*	*0.35*	*0.33*	*1.06*	*1.13*	*0.71*	*2.78*	*Various*	*Various*
Synthetic	***N***	*1000*	*1000*	*1000*	*1000*	*1000*	*1000*	*1000*	*1000*	*1000*
	Mean	*0.494*	*3.24*	*3.77*	*24.11*	*11.31*	*-7.43*	*22.68*	*Various*	*Various*
	St Dev	*0.041*	*0.36*	*0.32*	*1.07*	*1.11*	*0.70*	*2.76*	*Various*	*Various*
	TOST	*Pass*	*Pass*	*Pass*	*Pass*	*Pass*	*Pass*	*Pass*	*All passed*	*All passed*

CCT: central corneal thickness ; *ACD*: anterior chamber depth; *T*: lens thickness; *L*: axial length, r_{la}: anterior lens radius; r_{lp}: posterior lens radius; P_L: lens power according to Bennett-Rabbetts; TOST: two one-sided t test.

significantly equal to the originally measured data (TOST, $p < 0.05$; Table 1), thus making them statistically indistinguishable from one another at that particular tolerance.

Conclusions

Current eye model produces an unlimited amount synthetic biometry data that is indistinguishable from actual biometry. As such this model may be an interesting alternative to standard eye models for researchers that do not have access to actual biometry data. To our knowledge, this is also the first realistic eye model for keratoconus

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