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The changes of shape of the human cornea with age

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ABSTRACT

Purpose: To assess the changes of shape and alignment of the anterior and posterior surfaces of the mean cornea with age, as they can help to explain the optical quality of the aging eye. **Methods**: A group of 407 normal corneas of 211 subjects with ages ranging from 4 to 79 years old was analyzed by fitting their elevation topographies to a general biconic plus a Zernike expansion of the residual. **Results**: The anterior apex curvature increases with age, and becomes more prolate along the meridian of maximum curvature. The curvatures and conic constants of the posterior surface remain constant, which causes a peripheral thinning [2]. Zernike coefficients z_4^0 & z_6^0 show big changes in both surfaces. In addition the cornea rotates as a solid body by 2 minutes of arc per year, thus increasing its misalignment with the keratometric axis with age. **Conclusion**: The mean cornea shows highly significant changes with age, which might cause an important increase of corneal HOA.

METHODS

Setting: Antwerp University Hospital [5]

Instrument: Pentacam Scheimpflug camera (Oculus Optikgeräte, Wetzlar, Germany)

Subjects: 211 healthy subjects (62 male, 149 female; 204 Caucasian, 7 non-Caucasian)

Ages: Range 4-79 years old, mean 41.6 ± 14.5 years

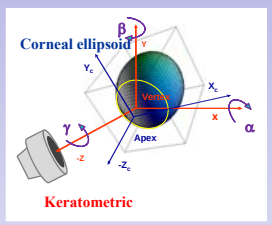
Valid samples: 407 elevation topographies (anterior & posterior) + pachymetry

The surface model

Canonic form:

$$z = \frac{c_x x^2 + c_y y^2}{1 + \sqrt{1 - (1+Q_x)c_x^2 x^2 - (1+Q_y)c_y^2 y^2}} + \sum_k c_k Z_k + HOR$$

Biconic — Zernike polynomial — Residual



General form:

$$\mathbf{x'} = \mathbf{R}(\mathbf{x} - \mathbf{x_0}) \quad \text{with} \quad \mathbf{x} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

3D Rotation
Euler angles: α, β, γ

Translation: x_0, y_0, z_0

Parameters

Biconic: R_{max}, R_{min}, Q_{max}, Q_{min}

Position/orientation: α, β, γ, x_0, y_0, z_0,

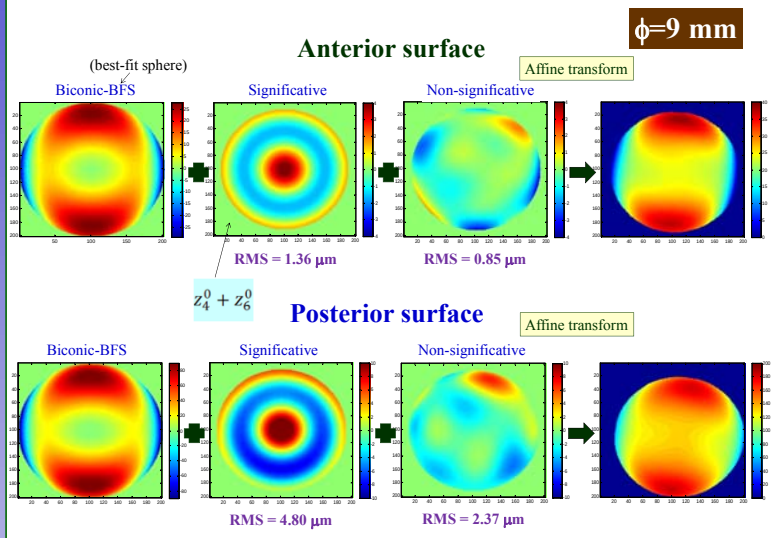
Zernike coefficients: $\{c_k\}$

For anteror & posterior surface

Corneal thickness: T_{min} , $T_{peripheral}$ = $<T>_{ring(8\text{-}9\ mm)}$

RESULTS 1: THE MEAN CORNEA

ϕ=9 mm



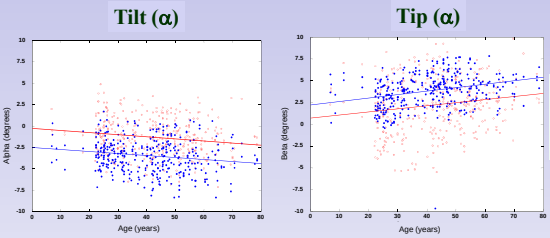
	Rmax (mm)	Rmin (mm)	Qmax	Qmin	z_4^0 (µm)	z_6^0 (µm)
Anterior	7.65 ± 0.26	7.54 ± 0.27	-0.40 ± 0.12	-0.40 ± 0.14	1.27 ±1.01	-0.48 ± 0.40
Posterior	6.24 ± 0.26	5.92 ± 0.29	-0.52 ± 0.14	-0.65 ± 0.17	4.15 ±1.73	-1.83 ± 1.02

	Tilt (α°)	Tip (β°)	Axis (γ°)
Anterior	-1.20 ± 2.86	1.83 ± 3.75	85.3±32.1
Posterior	-3.32 ± 2.45	3.85 ± 2.02	81.3 ±23.1

<Age>= 41.6 years

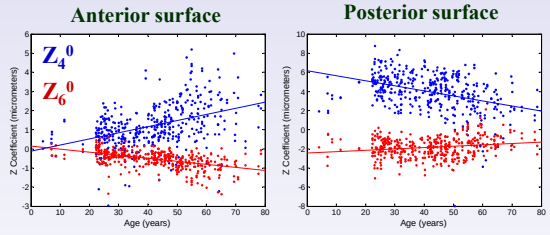
RESULTS 2: CHANGES WITH AGE (examples)

Misalignment



- High inter-subject variability
- Significant change (p < 0.01)
- Antero-posterior misalignment
- Solid body rotation (anterior velocity= posterior velocity)

Zernike coefficients



- Inter-subject variability
- Significant change (p < 0.01)
- Opposite signs:
  - Anterior versus posterior &
  - 4th versus 6th order
- Aspherical deformations
  - Anterior ↑
  - Posterior ↓

SUMMARY & CONCLUSIONS

Changes with age

ANTERIOR			
Parameter	Equation		P < 0.05
Rmax (mm)	7.850	-0.0051 *Age	yes
Rmin (mm)	7.721	-0.0046 *Age	yes
Qmax	-0.367	-0.0009 *Age	yes
Qmin	-0.294	-0.0023 *Age	yes
Z_4^0 (mm)	-0.026	+0.030 *Age	yes
Z_6^0 (mm)	0.171	-0.016 *Age	yes
Tilt (α°)	-0.31	-0.024 *Age	yes
Tip (β°)	0.71	+0.036 *Age	yes
Astig. Axis (γ°)	102.3	-0.356 *Age	yes

POSTERIOR			
Parameter	Equation		P < 0.05
Rmax (mm)	6.2441		No
Rmin (mm)	5.8721		No
Qmax	-0.4899		No
Qmin	-0.5348	-0.0026 *Age	yes
Z_4^0 (mm)	6.022	-0.046 *Age	yes
Z_6^0 (mm)	-2.370	+0.013 *Age	yes
Tilt (α°)	-2.510	-0.0235 *Age	yes
Tip (β°)	2.230	+0.04 *Age	yes
Astig. Axis (γ°)	99.530		No

	Equation		P < 0.05
Minimum Thickness(mm)	545.9		No
Peripheral Thickness (mm)	753.1	-0.5976 *Age	yes

1.- Previous findings confirmed:

- ✓ Both surfaces: prolate biconic (or ellipsoid) [Refs. 2,3]
- ✓ Corneal misalignment (tip & tilt) [Ref. 4]
- ✓ "Aspherical" Z_4^0 & Z_6^0 coef. are significative [Ref. 4]
- ✓ Anterior surface: More prolate & curved with age [Ref. 2]
  - ⇒ Peripheral thinning [Ref. 2]
- ✓ Balance external/internal changes with age [Ref. 1]

2.- New findings:

- ❖ Q_{min} changes but Q_{max} remains constant with age
- ❖ Corneal tip & tilt increase with age
- ❖ Anterior/posterior misalignment is constant
  - ⇒ **Solid body rotation**
- ❖ Z_4^0 changes dramatically in both surfaces
- ❖ Changes in tip, tilt, Z_4^0 & Z_6^0 suggest strong impact on optical quality (sph. aberration & coma.)

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