Classification of keratoconus and pellucid marginal degeneration by corneal wavefront aberrations

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Background

The topic of keratoconus (KC) and pellucid marginal degeneration (PMD) being two different non-infectious ectatic disorders or PMD being a KC subgroup is currently discussed and a final decision is not in sight yet. Several research groups accomplished studies to evaluate the characteristics of KC and PMD for better differentiation between them using videokeratography, mean curvature maps or Zemike vector analysis. 1-3 There is still a demand for reliable clinical classifiers for differentiation between KC, PMD and normal eyes.

Purpose

To assess the ability of anterior and posterior corneal wavefront aberrations of eyes with KC, PMD and normal eyes to identify groups and to classify them without a priori classification.

Patients and Methods

A priori classification was accomplished using the qualitative topography classification system for corneal topography by Bogan et al. 4

Group 1: 55 eyes of 32 patients with early KC
- Corneal topography with an asymmetric bow-tie and skewed radial axes.
- No corneal scarring or other surface irregularities
- Discontinuation of contact lenses for at least 2 weeks

Group 2: 60 eyes of 43 patients with early PMD
- Corneal topography with inferior steepening and flattening of the central corneal curvature along a vertical axis.
- No corneal scarring or other surface irregularities
- Discontinuation of contact lenses for at least 2 weeks

Group 3: 64 healthy pre-LASIK eyes of 32 patients
- Corneal topography without any asymmetry suspicious for KC or PMD
- Uncomplicated follow-up after LASIK at least 12 months, no signs or symptoms of keratopathy
- Discontinuation of contact lenses for at least 2 weeks

From axial-keratometric data of the anterior corneal surface and elevation data of the posterior corneal surface a Zernike decomposition was performed

Anterior corneal surface wavefront reconstruction:
- Axial-keratometric data of the anterior corneal surface (Placido-based)
- 2°-7° order Zernike polynomials
- 6 mm pupil diameter
- VOG-Pro 7.14

Posterior corneal surface wavefront reconstruction:
- Elevation data of the posterior corneal surface (Scheimpflug-based)
- 2°-7° order Zernike polynomials
- 6 mm pupil diameter
- MATLAB 7.0

Statistical Analysis

Due to limitations caused by the a priori classification further statistical analyses were necessary to receive an objective classification of KC, PMD and normal eyes 5

Anterior and posterior corneal wavefront aberration data was analysed using: 1. Correspondence analysis to detect the most influential Zernike coefficients (ZC) for separation between KC, PMD and normal eyes.
2. Hierarchical cluster analysis to explore group structures without a priori classification.
3. Receiver operating characteristic curve (ROC) analysis to determine individual ZC with the highest discriminative ability to distinguish between KC, PMD and normal eyes.
4. Support vector machine (SVM) classification with linear and gaussian kernel to derive a decision rule with high generalisation ability to classify patient eyes into groups. Cross-validation was used to estimate the classification error on unseen data. Statistical analyses (1-4) were performed with R version 2.11.0. Kernel implementations (4) as contained in kernlab.

Results

2nd and 3rd order ZC were most influential for separation between KC, PMD and normal eyes

Clear grouping of patients into three major groups as a result of the first two hierarchical splits

Discriminative ability of anterior and posterior corneal ZC was different for KC, PMD and normal eyes and higher for anterior ZC

ROC curves for the three parameters with highest discriminative ability for the anterior corneal surface

ROC curves for the three parameters with highest discriminative ability for the posterior corneal surface

Best three classifying parameters of the anterior corneal surface for discrimination between the groups.

Best three classifying parameters of the posterior corneal surface for discrimination between the groups.

87 out of 100 patients were classified correctly using SVM classification based on all anterior ZC

Conclusions

- Identification of three groups (KC, PMD and normal eyes) without a priori classification based on group specific wavefront patterns.
- ZC from the anterior and posterior corneal surface classify between KC, PMD and normal eyes with high accuracy.
- Overall anterior corneal aberrations were more powerful than posterior corneal aberrations for classification between the three groups.
- Anterior primary vertical coma C_{y1} had the highest ability to discriminate between both KC vs. normals and PMD vs. normals.
- Anterior primary astigmatism G_{y} had the highest ability to discriminate between KC and PMD.

References