Interaction Between Topographic/Tomographic Parameters and Dry Eye Disease in Keratoconus Patients

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ABSTRACT

Purpose: To determine the interaction between corneal topographic and tomographic parameters and dry eye syndrome (DES) in keratoconus (KC) patients.

Methods: Seventy-seven eyes of 49 patients with KC (age 34.4 ± 11.6 years) were enrolled in this study. In these 77 eyes we recorded surface regularity index (SRI), surface asymmetry index (SAI) and Klyce/Maeda KC index (KCI) using the Topographic Modeling System (TMS-5, Tomey, Tennenlohe, Germany), Index of Surface Variance (ISV), Index of Vertical Asymmetry (IVA), KC Index (KI), Center KC Index (CKI), Index of Height Asymmetry (IHA) and Index of Height Decentration (IHD) using Pentacam (Pentacam HR, Oculus, Germany). Patients were subdivided into mild (grade 1–2) and severe stage (grade 3–4) KC groups according to Pentacam grading.

To analyse tear film parameters we assessed in 77 KC eyes McMonnies questionnaire, Schirmer test and break-up time and in 26 eyes (10 eyes with mild KC, 16 eyes with severe KC) high-speed videokeratoscopy (during interblinking interval) using a novel commercially not available system (Tear Inspect). With Tear Inspect the analysed tear film parameters were (1) time of first irregularities of Placido rings and (2) time of eyelid closure.

Patients were also subdivided into McMonnies questionnaire positive and negative groups.

Results: We did not find significant difference between patients with mild and severe KC in any of the examined tear film parameters ($p > 0.66$). There was no significant difference in SRI, SAI, KCI, ISV, IVA, KI, CKI, IHA and IHD in McMonnies test positive and negative KC patients ($p > 0.07$). There was no correlation between SRI, SAI, KCI, ISV, IVA, KI, CKI, IHA and IHD and any of the examined tear film parameters (without high-speed videokeratoscopy) neither in 77 KC patients nor in mild or severe KC eyes ($r < 0.3$).

Conclusions: There is no interaction between DES and topographic/tomographic changes in KC-patients.

Keywords: Cornea, corneal tomography, corneal topography, dry eye syndrome, high-speed videokeratoscopy, keratoconus

INTRODUCTION

Keratoconus (KC) is a bilateral, non-inflammatory corneal ectasia with an incidence of approximately 1 per 2000 in the general population. Classical histopathologic features include stromal thinning, iron deposition in the epithelial basement membrane, and breaks in Bowman’s layer. Despite intensive...
clinical and laboratory investigation, the etiology of KC remains unclear.\textsuperscript{1,2}

KC has well-described clinical signs, but early forms of the disease may be undiagnosed unless the corneal topography is studied. About 20 years ago Wilson and Klyce described that computer assisted topography analysis is a more sensitive tool in early diagnosis of KC than keratometry or keratoscopy.\textsuperscript{3-8} Since then, different corneal topographers and tomographers have been developed and are in clinical use. The topographers/tomographers provide different mathematical indices such as the Klyce/Maeda/Rabinowitz/Belin-Ambrósio indices to determine whether the eye shows keratoconic configuration and what is the severity of the disease.

Clinical experience shows that the ocular surface disease in KC is characterized by disorder of tear quality and significantly lower BUT and higher fluorescein and rose bengal staining scores compared to normal population.\textsuperscript{9} It has been proven in the past that some of the indices, which are used for KC detection, are also sensitive to dry eye syndrome (DES). De Paiva et al. reported that surface regularity index (SRI) and surface asymmetry index (SAI) could be used as objective diagnostic indices for DES and could show a reliable estimate for the severity of this disease.\textsuperscript{10}

The purpose of this study was to determine the interaction between corneal topographic and tomographic parameters and DES in KC patients.

**PATIENTS AND METHODS**

Seventy-seven eyes of 49 patients with KC (11 females and 38 males) aged between 18 and 62 years (mean age: $34.4 \pm 11.6$ years) were recruited from the Department of Ophthalmology, Saarland University Medical Center from October 2010 to March 2011. KC was diagnosed based on clinical and topographic evaluations. Subjects with previous history of ocular surgery or contact lens wear were excluded from the study.

In 77 KC eyes ophthalmic examinations consisted of best-corrected visual acuity measurements, slit-lamp examination, corneal topography and tomography, McMonnies and Schirmer tests, tear film breakup time (BUT) and in 26 KC eyes of additional high-speed video-topography. High-speed video-topography was performed using a novel commercially not available system (Tear Inspect).

All KC patients signed an informed consent before the examinations. However, we did not apply for an Institutional Ethics Committee Approval. All examinations were performed following the regulations of the Declaration of Helsinki.

The instruments used for corneal topography was the Topographic Modeling System (TMS-5, Tomey, Tennenlohe, Germany). The topographic parameters under test were the SRI, SAI and Klyce/Maeda KC index (KCI). For tomography we used the Pentacam (Pentacam HR, Oculus, Germany), where the Index of Surface Variance (ISV), Index of Vertical Asymmetry (IVA), KC Index (KI), Center KC Index (CKI), Index of Height Asymmetry (IHA), and Index of Height Decentration (IHD) values were measured.

There were patients with KC grade 1–4 according to Pentacam grading (Pentacam HR, Oculus, Germany), which has been adapted to classical Amsler or Muckenhirn stages. Using Pentacam grading there were eight eyes (10.4%) with KC grade 1, 25 eyes (32.5%) with grade 2, 26 eyes (33.8%) and 18 eyes (23.4%) with grade 3 and 4. Patients were grouped into grades 1 + 2 (mild KC, $n = 33$) and 3 + 4 (severe KC, $n = 44$).

Patients were also subdivided concerning DES using the McMonnies questionnaire (McMonnies positive with McMonnies score >14.5): There were 17 McMonnies questionnaire positive (they were defined as patients with DES) and 60 negative KC eyes in the complete study population.

**Corneal Topographic Indices of TMS-5**

The SRI describes the topography of the central part of the cornea within the central 4.5 mm diameter. The power of each point is compared with the adjacent points. The calculation is based on the determination of the most frequently occurring dioptric power and the comparative analysis of dioptric powers of adjacent points in 256 hemi-meridians in the 10 central rings. An SRI value <1.01 is considered normal (regular shape), while values above 1.97 are abnormal (irregular shape).

The SAI is determined from the centrally weighted summation of differences in corneal power between corresponding points 180 degrees apart over the 128 equally spaced meridians. Low SRI and SAI values correspond to a more regular and symmetric surface.\textsuperscript{5} Normal corneas have a fairly symmetric power distribution (SAI<0.5).

Within the Klyce–Maeda indices, KPI is the “KC prediction index”, which is derived from eight quantitative videokeratography-derived indices (Simulated Keratometry (SimK1, SimK2), SAI, Differential Sector Index (DSI), Opposite Sector Index (OSI), Centre-Surround Index (CSI), Irregular Astigmatism Index and Analysed Area). The method for calculating this index has been described earlier.\textsuperscript{11} Maeda and co-authors suggested that a value larger than 0.23 indicate KC.

KCI is derived using a binary decision-making tree with input from the KPI (KC prediction index) and four other indices (DSI, the OSI, the CSI and SimK2), described by Klyce and Maeda. The degree of the
KC-like pattern is determined and expressed as a percentage, which is the KCI%. Maeda and co-authors suggest that a value larger than zero is indicative of KC.11

**Corneal Tomographic Indices of Pentacam**

ISV describes the deviation of the individual corneal radii from the mean value and is elevated with irregular corneas (ISV ≥ 37). IVA gives the degree of symmetry of the corneal radii with respect to the 180° meridian as axis of reflection. IVA is elevated in cases of oblique axes, KC or limbal ectasias (IVA ≥ 0.28). KI is elevated in KC (KI > 1.07). CKI is elevated in central KC (CKI ≥ 1.03). IHA gives the degree of symmetry of height data with respect to the horizontal meridian as axis of reflection. IHA is analogous to IVA, but sometimes more sensitive (in KC, IHA ≥ 19). IHD is calculated from first harmonic of Fourier analysis of height and is a measure for vertical decentration. IHD yields higher values in KC (IHD ≥ 0.014).12

**Tear Film Parameters**

The BUT was evaluated using a slit-lamp microscope with a cobalt-blue filter. Fluorescein eye drops were instilled in the conjunctival sac of the patients. The subjects were then instructed to blink several times for a few seconds to ensure homogeneous distribution of fluorescein. The interval between the last complete blink and the appearance of the first corneal black spot in the stained tear film was measured. A BUT value of <10 s was considered abnormal.

Tear production was assessed using Schirmer’s test without topical anaesthesia. The standardized strips of filter paper were placed in the lateral canthus away from the cornea and left in place for 5 min with the eyes closed. Readings were reported in millimeters of wetting within 5 min. A reading of <5 mm refers to the diagnosis of DES.

All patients were interviewed by McMonnies questionnaire, which includes 14 questions that focus on clinical “risk factors” for dry eye. The index score can range from 0 to 45. Values greater than 14.5 indicate dry eye diagnosis based on previous sensitivity and specificity estimates.13

Our high-speed video-topography system represents a novel commercially not available system with a novel sensor design. There are no published data on repeatability of Tear Inspect. The system is able to simultaneously analyze the tear film behavior with respect to its three different layers (mucin, liquid and lipid) and the lipid layer in detail. Two CMOS-cameras (complimentary metal oxide semiconductor) (IDS, Obersulm, Germany, UI-1548LE-M) were integrated in the sensor to measure the time dependency of the tear film conditions, each focusing at a different focal plane. Capturing the virtual image of a Placido grid (PG) reflected off the tear film, the first camera follows the principle of videokeratoscopy, while the second camera targets the lipid layer and, therefore, is focused on the anterior surface of the tear film. Depending mainly on the liquid layer, changes in the tear film over time lead to a change in reflectivity, and to a visible change in the virtual image of the PG.14,15

After alignment of the instrument and two complete blinks a video was recorded in the interblinking interval. Each subject was asked to avoid head movements and to fixate continuously during the examination.

The recorded videos were analysed subsequently. The outcome measures selected for analysis were time of first irregularities of Placido rings (TIP), time of eyelid closure (TEC) and direction of lipid layer movement.

**Statistical Analysis**

For statistical analysis of the data SPSS (SPSS release 19, IBM, Armonk, NY) was used. Data were analysed descriptively with mean, standard deviation and median values.

Nonparametric Mann–Whitney test was performed to compare topographic and tomographic data between mild and severe KC groups, between McMonnies positive and negative eyes, and tear film parameter values between mild and severe KC groups.

Spearman correlation analysis was used to determine the correlation between the topographic parameters (SAI, SRI and KCI) and tomographic parameters (ISV, IVA, IHI, CKI, IHA and IHD).

Spearman correlation analysis was used to determine the correlation between the topographic parameters SAI, SRI and KCI, tomographic parameters ISV, IVA, IHI, CKI, IHA, IHD, and tear film parameter values BUT, McMonnies questionnaire and Schirmer test.

To compare the binary results (positivity) of McMonnies questionnaire, Schirmer test and BUT and mild/severe KC a chi-Square test was used.

Spearman correlation analysis was used to determine the correlation between age and tear film, and age and topographic/tomographic parameters.

At the Spearman correlation analysis the Rho (r) correlation coefficient was interpreted as follows: 0–0.3, no correlation; 0.3–0.6, weak correlation; 0.6–0.8, moderate correlation; >0.8, strong correlation.

**RESULTS**

**Demographic Data**

Table 1 describes the demographic parameters for both KC groups. There were no statistical significant
differences concerning age and gender between mild and severe stage KC patients.

### Topographic and Tomographic Data

Corneal topographic parameters SRI, SAI and KCI of TMS-5 and corneal tomographic parameters ISV, IVA,KI, CKI, IHA and IHD of Pentacam are displayed at Table 2.

All topographic and tomographic parameters, except IHA ($p = 0.06$) were significantly different in MKC and SKC groups ($p < 0.001$) (Table 2, Figure 1). Topographic parameters SAI, SRI, KCI and the tomographic parameters ISV, IVA, KI, CKI and IHD correlated from weakly to moderately in KC patients ($0.8 < r < 0.3$), but SAI, SRI and KCI did not correlate with IHA ($r < 0.3$) (Table 3).

There was no significant difference in topographic (SRI, SAI, KCI) or tomographic (ISV, IVA, KI, CKI, IHA, IHD) parameters comparing McMonnies test positive and negative patients ($p > 0.07$) (Table 4). Topographic and tomographic parameters did not correlate with age ($r < 0.3$).

### Tear Film Parameters

Tear film parameters of MKC and SKC patients are displayed in Table 5.

The mean BUT was $8.4 \pm 2.9$ seconds in the MKC and $8.1 \pm 2.2$ in the SKC patients. There were $24 (73\%)$ patients with BUT values lower than 10 seconds in MKC and $33 (75\%)$ in SKC.

The Schirmer test value averaged $19.6 \pm 10.5$ mm in MKC and $18.6 \pm 11.4$ in SKC. Only in twelve subjects ($15.6\%$ from all keratoconus patients) Schirmer test values were $5$ mm or lower.

The mean McMonnies index was $10.0 \pm 5.7$ and $10.1 \pm 6.7$ in MKC and SKC, respectively. Seventeen keratoconus patients ($22\%$) were McMonnies positive (7 in mild and 10 in severe stage).

We did not find significant difference in tear film parameters (BUT, McMonnies, Schirmer test, TIP, TEC) between patients with MKC and SKC ($p > 0.66$) (Table 5).

Chi-square test did not show significant difference in McMonnies questionnaire, Schirmer test and BUT.

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**TABLE 1** Demographic parameters of keratoconus (KC) patients (Mean ± SD; median).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean ± SD; median (years)</th>
<th>Male (%)</th>
<th>Mean SEQ ± SD; median (Dptr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild KC</td>
<td>33</td>
<td>37 ± 12; 34</td>
<td>69.7</td>
<td>-2.5 ± 4.2; -1.9</td>
</tr>
<tr>
<td>Severe KC</td>
<td>44</td>
<td>36 ± 12; 32</td>
<td>72.7</td>
<td>-7.2 ± 5.3; -5.8</td>
</tr>
</tbody>
</table>

Mild KC = KC stages 1 + 2; severe KC = KC stages 3 + 4; SEQ = spherical equivalent of refraction.

**TABLE 2** Mean ± SD; median values of the topographic parameters SRI, SAI and KCI, and the tomographic parameters ISV, IVA, KI, CKI, IHA and IHD in mild (MKC) and severe (SKC) keratoconus (n = 47) keratoconus eyes.

<table>
<thead>
<tr>
<th>Group</th>
<th>SRI</th>
<th>SAI</th>
<th>KCI</th>
<th>ISV</th>
<th>IVA</th>
<th>KI</th>
<th>CKI</th>
<th>IHA</th>
<th>IHD</th>
<th>$p$ Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild KC</td>
<td>$0.6 \pm 0.5$</td>
<td>$1.6 \pm 0.7$</td>
<td>$1.4$</td>
<td>$50.5 \pm 30.7$</td>
<td>$51.9$</td>
<td>$1.6 \pm 16.2$</td>
<td>$58.0$</td>
<td>$0.6 \pm 0.2$</td>
<td>$0.6$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Severe KC</td>
<td>$1.4 \pm 0.5$</td>
<td>$3.2 \pm 1.4$</td>
<td>$2.8$</td>
<td>$60.1 \pm 35.1$</td>
<td>$95.0$</td>
<td>$1.3 \pm 0.3$</td>
<td>$1.2$</td>
<td>$1.3 \pm 0.1$</td>
<td>$1.3$</td>
<td>$&lt;0.001$</td>
</tr>
</tbody>
</table>

Nonparametric Mann–Whitney test was performed to compare topographic and tomographic data between MKC and SKC eyes. Surface Regularity Index = SRI; Surface Asymmetry Index = SAI; Keratoconus Index = KCI; Index of Surface Variance = ISV; Index of Vertical Asymmetry = IVA; Keratoconus Index = KI; Center Keratoconus Index = CKI; Index of Height Asymmetry = IHA; Index of Height Decentration = IHD.

Chi-square test did not show significant difference in McMonnies questionnaire, Schirmer test and BUT.

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positivity in mild and severe keratoconus patients ($p > 0.23$) (Table 5).

There was no correlation between topographic (SRI, SAI and KCI) or tomographic (ISV, IVA, KI, CKI, IHA and IHD) parameters and any of the examined tear film parameters (except high-speed videokeratoscopy) neither in the entire study group ($r < 0.3$) nor in MKC or SKC eyes ($r < 0.3$).

The mean TIP in MKC was 13.0 ± 8.2 s, whereas it was 12.5 ± 5.7 s SKC. For all subjects, TIP occurred at the apex of the keratoconus, in the majority of cases in the nasal inferior quadrant (Figure 2). For 26 keratoconus eyes the mean TEC was 25.8 ± 21.4 s in the MKC group and 25.1 ± 16.1 s in SKC group. Both, in MKC and SKC the lipid movement was bottom-up at the beginning and nasally directed immediately before blinking.

McMonnies index and age correlated weakly in the entire study population ($r = 0.32$), but all other tear film parameters did not correlate with age ($r < 0.3$).

**DISCUSSION**

Keratoconus was first described in detail in 1854. Despite the intensity of research activities over the last few decades into its aetiology and pathogenesis, the cause(s) and possible pathomechanisms for development of KC remain poorly understood. Several hypotheses propose genetic, environmental, biomechanical and biochemical causes and mechanisms.

In our study we focused on the relationship of corneal topography/tomography to tear film properties in keratoconus patients. Clinical experience shows, that the majority of patients with keratoconus develop symptoms, which are typical for DES. Together with the fact, that some of the keratoconus screening indices are also sensitive to DES, the
TABLE 4 Mean ± SD; median values of the topographic parameters SAI, SRI and KCI, and the tomographic parameters ISV, IVA, KI, CKI, IHA and IHD in McMonnies positive (n = 17) and negative (n = 60) keratoconus eyes. Nonparametric Mann–Whitney test was performed to compare topographic and tomographic data between McMonnies positive and negative eyes.

<table>
<thead>
<tr>
<th></th>
<th>SRI</th>
<th>SAI</th>
<th>KCI</th>
<th>ISV</th>
<th>IVA</th>
<th>KI</th>
<th>CKI</th>
<th>IHA</th>
<th>IHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>McMonnies negative</td>
<td>1.02 ± 0.6; 1.03</td>
<td>2.5 ± 1.3; 2.2</td>
<td>67.5 ± 32.3; 79.1</td>
<td>100.1 ± 46.5; 93.5</td>
<td>1.07 ± 0.4; 0.9</td>
<td>1.2 ± 0.1; 1.2</td>
<td>1.06 ± 0.07; 1.04</td>
<td>30.08 ± 24.6; 23.5</td>
<td>0.1 ± 0.06; 0.1</td>
</tr>
<tr>
<td>McMonnies positive</td>
<td>1.3 ± 0.6; 1.1</td>
<td>2.7 ± 1.7; 2.1</td>
<td>58.8 ± 31.9; 66.2</td>
<td>83.8 ± 23.4; 84.0</td>
<td>0.9 ± 0.3; 0.9</td>
<td>1.1 ± 0.07; 1.1</td>
<td>1.04 ± 0.04; 1.04</td>
<td>28.3 ± 20.7; 21.5</td>
<td>0.08 ± 0.03; 0.08</td>
</tr>
<tr>
<td>p Values</td>
<td>0.07</td>
<td>0.9</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
<td>0.6</td>
<td>0.9</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Surface Regularity Index = SRI; Surface Asymmetry Index = SAI; Klyce/Maeda keratoconus index = KCI; Index of Surface Variance = ISV; Index of Vertical Asymmetry = IVA; Keratoconus Index = KI; Center Keratoconus Index = CKI; Index of Height Asymmetry = IHA; Index of Height Decentration = IHD.

TABLE 5 Tear function parameters in different stages of keratoconus (KC).

<table>
<thead>
<tr>
<th>Group</th>
<th>BUT</th>
<th>McMonnies questionnaire</th>
<th>Schirmer test</th>
<th>TIP</th>
<th>TEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD; median Time (s)</td>
<td>Positive (&lt;10 s) N (%)</td>
<td>Total N (%)</td>
<td>Mean ± SD; median (points)</td>
<td>Positive (&gt;14.5) N (%)</td>
</tr>
<tr>
<td>Mild KC</td>
<td>8.4 ± 2.9; 8.0</td>
<td>24 (73%)</td>
<td>33 (100%)</td>
<td>10.0 ± 5.7; 10.0</td>
<td>7 (21%)</td>
</tr>
<tr>
<td>Severe KC</td>
<td>8.1 ± 2.2; 8.5</td>
<td>33 (75%)</td>
<td>44 (100%)</td>
<td>10.1 ± 6.7; 8.0</td>
<td>10 (22%)</td>
</tr>
<tr>
<td>p Value</td>
<td>$p^a = 0.93$</td>
<td>$p^b = 0.82$</td>
<td>$p^a = 0.82$</td>
<td>$p^b = 0.23$</td>
<td>$p^a = 0.65$</td>
</tr>
</tbody>
</table>

Mild KC = KC stages 1–2; severe KC = KC stages 3–4; BUT = break-up time; SRI = surface regularity index; SAI = surface asymmetry index; TIP = time of first irregularities of Placido rings; TEC = time of eyelid closure.

$p^a$ Values compare mild and severe keratoconus groups (Mann–Whitney test).

$p^b$ Values compare mild and severe keratoconus groups (chi-square test).
interaction between topographic or tomographic indices and parameters indicating dry eye have to be studied. The most conspicuous finding of our study is that objective parameters indicating DES and topographic/tomographic changes designed to detect keratoconus configurations do not interact in keratoconus patients. There was no correlation between SRI, SAI, KCI, ISV, IVA, KI, CKI, IHA, IHD and BUT, Schirmer-score, or McMonnies score in our data set of keratoconus patients (Table 6). This means, that neither anterior corneal properties which in part are influenced by the tearfilm behavior nor posterior corneal properties which are not affected by the tearfilm behavior are correlated with DES. Nevertheless, Scheimpflug systems such as Pentacam are inappropriate to analyse tear film properties due to limited resolution in axial direction.

TABLE 6  Spearman correlation analysis was used to determine the correlation between the topographic parameters SRI, SAI and KCI, the tomographic parameters ISV, IVA, KI, CKI, IHA and IHD, and break-up time (BUT), McMonnies questionnaire and Schirmer test values.

<table>
<thead>
<tr>
<th>BUT (s)</th>
<th>Schirmer test (mm)</th>
<th>McMonnies (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRI -0.11</td>
<td>0.06</td>
<td>0.16</td>
</tr>
<tr>
<td>SAI 0.01</td>
<td>-0.04</td>
<td>0.009</td>
</tr>
<tr>
<td>KCI -0.01</td>
<td>-0.11</td>
<td>-0.005</td>
</tr>
<tr>
<td>ISV 0.10</td>
<td>-0.09</td>
<td>-0.08</td>
</tr>
<tr>
<td>IVA 0.10</td>
<td>-0.15</td>
<td>-0.02</td>
</tr>
<tr>
<td>KI 0.08</td>
<td>-0.07</td>
<td>-0.12</td>
</tr>
<tr>
<td>CKI -0.006</td>
<td>0.08</td>
<td>-0.12</td>
</tr>
<tr>
<td>IHA 0.01</td>
<td>-0.09</td>
<td>-0.11</td>
</tr>
<tr>
<td>IHD 0.07</td>
<td>-0.11</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

r Values are displayed. There are no r values showing weak, moderate or strong correlation.

Surface Regularity Index = SRI; Surface Asymmetry Index = SAI; Klyce/Maeda keratoconus index = KCI; Index of Surface Variance = ISV; Index of Vertical Asymmetry = IVA; Keratoconus Index = KI; Center Keratoconus Index = CKI; Index of Height Asymmetry = IHA; Index of Height Decentration = IHD.

In contrast, Placido-based topographers are not analysing true height data, but (local) curvature deviations from a fit sphere and are proven to sufficiently measure tear film properties.

In our study mean BUT was 8.4 ± 2.9 s in MKC and 8.1 ± 2.2 s in SKC. Schirmer test values were 19.6 ± 10.5 mm and 18.6 ± 11.4 mm, respectively (Table 5). This is in contrast to the results of a previous study of Dogru et al.,9 who detected lower BUT and Schirmer test values in keratoconus patients (also without previous contact lens wear) compared to our results. The difference between both studies may be explained by different constellation of the study population. Dogru et al. used the central corneal power and radius of curvature to grade keratoconus patients into mild, moderate and severe groups. We used Pentacam grading and patients were subdivided into mild (grade 1–2) and severe stage (grade 3–4) KC groups. The age of our patients was similar to those of Dogru et al., however, the gender distribution was different. In the keratoconus group by Dogru et al. there were 16 females (41% of all keratoconus patients) while in our study there were only 11 females (22% of all keratoconus patients). Unlike our study the latter study was performed in Turkey, where the air temperature is higher as compared to Germany. Wolkoff et al.16 have shown that higher air temperature and the use of air-conditioning systems may worsen eye irritation symptoms and tear film stability.

Dogru et al.9 described, that the ocular surface disease in keratoconus is characterised by disorder of tear quality, squamous metaplasia and goblet cell loss, all of which seem to be related to the extent of keratoconus progression. In our study, there was no significant difference in tear film parameters between patients with mild and severe keratoconus (p > 0.66) (Table 5).

In our study more than 20% of keratoconus patients were diagnosed as dry eye patients, but the prevalence of DES based on objective measures (BUT,
Schirmer test, TIP and TEC of Tear Inspect) and the McMonnies questionnaire was comparable in both groups of keratoconus (Table 5). The prevalence of dry eye from large epidemiological studies reveals a range of about 5% to over 35% at various ages. Dogru and Tsubota reported, that patients without systemic disease aged ≥50 years usually first present dry eye.17,18 In our study, mean age of keratoconus patients with DES was 40.8 years (McMonnies positive), about one decade earlier than reported in healthy subjects. McMonnies index of keratoconus patients was weakly correlated with age, which shows that similar to a normal population, dry eye disease progresses with age in keratoconus.

De Paiva et al. suggested that SAI and SRI may have the potential to be used as objective diagnostic indices for DES, as well as means to evaluate the severity of dry eye disease.10 They described in a small case series that chronic ocular desiccation and aqueous tear deficiency can produce inferior corneal steepening in topography analysis and high astigmatism resembling keratoconus. We could clarify that in keratoconus patients SAI and SRI are inappropriate to be used as indicators for dry eye and we could not determine an impact of DES (McMonnies test positivity) on anterior corneal topographic parameters of keratoconus patients (Table 4). In other words, the typical subjective symptoms of dry eye in keratoconus patients are not reflected by objective topographic or tomographic parameters.

In conclusion, there is no interaction between measures of DES and topographic/tomographic changes of keratoconus patients. With other words, DES does not influence topographic/tomographic parameters in keratoconus patients and keratoconus progression does not result in progression of DES.

ACKNOWLEDGEMENTS

We thank supports of the DAAD Scholarship (A/09/82643) for the author’s study (E.Z) and the Alexander-von-Humboldt foundation for supporting the work of Dr N. Szentmáry at the Department of Ophthalmology of Saarland University, Homburg/Saar, Germany.

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper. The authors confirm that they do not have any commercial or proprietary interest in any material presented in this paper.

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