First Clinical Impressions on the Integrated Corneal Tomography and Corneal Deformation with Scheimpflug Imaging

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ABSTRACT

The purpose of this study is to report the preliminary findings and the retrospective clinical impressions of the integrated corneal tomography and corneal deformation parameters with a dynamic ultra-high-speed Scheimpflug camera equipped with a noncontact tonometer. Twelve eyes of six patients were evaluated by the Scheimpflug imaging system of the Pentacam HR and Corvis ST (OCULUS Optikgeräte GmbH, Wetzlar, Germany) devices. The parameters used were the Belin/Ambrósio deviation (BAD-D) and Corvis biomechanical index (CBI), as well as the recently published tomographic and biomechanical index (TBI), combined with a detailed clinical data and evaluation of normal eyes and patients with different stages of corneal ectasia.

Keywords: Case series, Corneal diseases, Corneal topography, Ectasia/diagnosis, Keratoconus, Tomography.


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INTRODUCTION

Corneal topography refers to the anterior measurement of the cornea and has been useful for the past few decades in the detection of several pathologies, such as keratoconus and corneal astigmatism. However, the first alteration in mild and subclinical forms of corneal ectasia is the subtle elevation of the posterior corneal curvature, which is difficult to identify through conventional topographic exams.

Corneal ectasia is classified based on the thinning and protrusion of corneal structures. Its progression to more advanced disease is multifactorial and depends on both intrinsic factors, such as corneal biomechanics and genetic predisposition, and extrinsic factors, such as eye rubbing and associated atopy, as well as the amount of tissue altered during surgical procedures in predisposed individuals. With increased demand for refractive surgery and the use of femtosecond lasers, it is important to consider that the residual postoperative stroma may decompensate in a predisposed cornea.

There are currently two devices available on the market for performing corneal biomechanics measurements in vivo: The ocular response analyzer (Reichert Ophthalmic Instruments, Depew, New York, USA), which is a dynamic bidirectional application device, and the Corvis ST (Oculos Optikgeräte GmbH, Wetzlar, Germany), which is a noncontact tonometer with an air pulse that uses an ultra-high-speed Scheimpflug camera to monitor corneal deformation. Despite its potential, the former has demonstrated limited ability for screening of ectatic disease. The latter features advanced parameters that can help detect early ectasia and fruste keratoconus with higher accuracy. In addition to the CBI, which has been shown in the literature as an excellent predictor of early ectasias, the BAD and TBI parameters based on Scheimpflug corneal tomography and corneal deformation parameters greatly contribute to the understanding of corneal ectasia.

The purpose of this study is to report a series of cases using the Corvis ST device along with tomographic and clinical parameters to determine the risk of developing corneal ectasia in patients with subtle predisposing topographic changes.

CASE REPORTS

Case 1

A 38-year-old male diagnosed with keratoconus in the left eye 15 years earlier presented for follow-up complaining of progressive vision loss in the left eye. The patient's uncorrected visual acuity (UCVA) was Counting Fingers (CF) 6 FT in the right eye (OD) and CF 3 FT in the left eye.
(OS). His best-corrected visual acuity (BCVA) was 20/20 OD (sph −6.75, cyl + 0.75 at 106) and 20/25 OS (sph −6.25, cyl +1.75 at 177).

The central corneal thickness was 576 μm OD and 546 μm OS. Anterior corneal curvature measured using Pentacam® HR revealed a very mild inferior steepening OD with Kmax 42.2D and inferior–superior asymmetry of 1.0D. A topometric pattern of keratoconus stage 2 was identified in the left eye with Kmax 48.2D and inferior–superior asymmetry of 5.7D.

The deviation value from BAD-D (version 3) was 0.84 OD, which was below the cut-off value for forme fruste keratoconus. The patient was diagnosed with keratoconus stage 2 OS based on the corneal topography classification proposed by Amsler according to a Kmax of 48.2D, with BAD-D of 4.42 on corneal tomography; CBI was 0 OD and 0.09 OS; TBI values were 0.43 OD and 1.00 OS (Fig. 1). This was consistent with the diagnosis of forme fruste keratoconus OD and mild keratoconus OS, not unilateral ectatic disease OS.

**Case 2**

A 17-year-old male presented for keratoconus evaluation. The patient’s UCVA was 20/40 OD and 20/60 OS. His BCVA was 20/20 OD (sph −1.75, cyl −0.75 at 174) and 20/20 OS (sph −1.75, cyl −0.50 at 165).

The front sagittal curvature measured using Pentacam® HR demonstrated with-the-rule astigmatism with Kmax of 47.6D OD and 46.7D OS. Tomographic evaluation demonstrated central steepening in both eyes. Pachymetric progression indices were normal; BAD-D was 1.81 OD and 1.42 OS, over the cut-off value of normality. The CBI was 0.05 OD and 0 OS, and TBI values were 0.12 OD and 0.31 OS (Fig. 2). These values were consistent with the diagnosis of mild (fruste) ectasia, which we consider to be as high susceptibility for progression.

**Case 3**

A 28-year-old female scheduled an appointment to enquire about refractive surgery. The patient was a
contact lens wearer but has not worn contacts for 4 days prior to the appointment. She had no prior history of any major eye diseases or surgeries. The patient’s UCVA was CF at 6 FT in both eyes. Her BCVA was 20/20 OD (sph −4.25, cyl −0.50 at 100) and 20/20 OS (sph −5.25, cyl −0.50 at 17). The central corneal thickness was 596 μm OD and 590 μm OS.

The front sagittal curvature measured using Pentacam® HR demonstrated a with-the-rule astigmatism with Kmax of 48.9D OD and 48.8D OS. Tomographic evaluation demonstrated normal anterior and posterior curvature. Pachymetric progression indices were normal. The BAD-D was 2.15 OD and 2.34 OS, under the cut-off value of normality; CBI was 0.65 OD and 0.97 OS, and TBI values were 0.70 OD and 0.58 OS (Fig. 3).

**Case 4**

A 33-year-old male scheduled an appointment to enquire about refractive surgery. He was a contact lens wearer but had not worn contacts for 4 days prior to the appointment. His only significant ocular history was a corneal abrasion in 1991 in the right eye due to an injury with a stick. The patient’s UCVA was 20/400 OD and 20/200 OS. His BCVA was 20/20 OD (sph −4.25, cyl −1.25 at 4) and 20/20 OS (sph −4.00, cyl −0.50 at 140). The central corneal thickness was 549 μm OD and 548 μm OS.

The patient was found to have a normal topographic pattern in both eyes. The front sagittal curvature measured using Pentacam® HR demonstrated with-the-rule astigmatism with Kmax of 47.2D OD and 47.5D OS. Tomographic evaluation demonstrated normal anterior and posterior curvature. Pachymetric progression indices were normal. The BAD-D was 1.09 OD and 1.38 OS, over the cut-off value of normality; CBI was 0 in both eyes, and TBI values were 0.01 OD and 0.00 OS (Fig. 4), which are within normal values.

**Case 5**

A 36-year-old female scheduled an appointment to enquire about refractive surgery. She had no history of...
significant eye diseases or surgery. The patient’s UCVA was 20/30 OD and 20/20 OS. Her BCVA was 20/20 OD (sph −0.75, cyl −0.50 at 95) and 20/20 OS (sph −0.25, cyl −0.50 at 50). The central corneal thickness was 581 μm OD and 572 μm OS.

The front sagittal curvature measured using Pentacam® HR demonstrated irregular astigmatism with Kmax of 45.9D OD and 45.2D OS. Tomographic evaluation demonstrated nasal steepening in both eyes. Pachymetric progression indices were normal; BAD-D was 0.54 OD and 0.36 OS, under the cut-off value of normality; CBI was 0 in both eyes, and TBI values were 0.00 in both eyes as well (Fig. 5).

**Case 6**

A 21-year-old male who uses soft contact lenses scheduled an appointment to enquire about refractive surgery. He had not worn contact lenses for 2 weeks prior to the appointment. He had no history of significant eye disease other than an infection during childhood. The patient’s UCVA was 20/100 OD and 20/200 OS. His BCVA was 20/15 OD (sph −1.25, cyl −1.75 at 7) and 20/15 OS (sph −2.50, cyl −1.00 at 170). The central corneal thickness was 561 μm OD and 565 μm OS.

The patient presented with a normal topographic pattern in both eyes. The front sagittal curvature measured using Pentacam® HR demonstrated with-the-rule astigmatism with Kmax of 44.5D OD and 44.2D OS. Tomographic evaluation demonstrated normal anterior and posterior curvatures. Pachymetric progression indices were normal. The CBI was 0 in both eyes; BAD-D was 1.00 OD and 1.16 OS, acceptable in the cut-off value of normality. The CBI and TBI values were 0.00 in both eyes (Fig. 6).

**DISCUSSION**

Advanced diagnostic interpretations using corneal topography, three-dimensional corneal tomography,
and biomechanical evaluation are useful tools in the diagnosis of subtle cornea pathologies in patients who are asymptomatic.\textsuperscript{14}

Candidates for refractive surgery often have no to mild topographic changes that may progress to corneal ectasia after laser refractive surgery.\textsuperscript{15} Scheimpflug corneal tomography is effective in detecting moderate to severe changes of the anterior corneal surface but has lower sensitivity in mild ectasia or fruste keratoconus.\textsuperscript{16} It is worth mentioning that genetic factors contribute to alterations in the posterior cornea in most cases of keratoconus, and screening is done chiefly in young patients with a family history.\textsuperscript{17,18}

In our case series, we were able to detect patients with normal topographic changes but altered Corvis corneal deformation parameters, which helped us differentiate normal cornea from suspicious keratectasia. We considered normal topography patients with a normal curvature in frontal cornea mapping, a keratoconus percentage index (KISA\%) score lower than 60, and a paracentral inferior–superior value at 6 mm less than 1.45.\textsuperscript{19} Tables 1 and 2 display the summary of the main parameters for analysis of the cases. In Case 1, we noticed a typical occurrence of unilateral ectasia in one eye with subtopographic alteration in the fellow eye. All parameters were normal in the subclinical eye except for the TBI, which was above the cut-off value. It is important to clarify that the TBI artificial intelligence algorithm is not simply the integration of the BAD-D and the CBI. It computes raw data from the tomographic and biomechanical analysis from Scheimpflug images derived from Pentacam and Corvis ST using the random forest approach.\textsuperscript{11}

Case 2 demonstrates a bilateral fruste keratoconus presentation with absence of topometric advancement. The patient was advised to return for regular follow-up exams and monitoring. Of note, initial cases of unilateral keratoconus are rare but deserve special attention, as the fellow eye is often masked as a fruste forme or is undetected with conventional topographic examinations.\textsuperscript{10,20}

In Case 3, we noticed altered topography and Corvis parameters, and the patient was advised to not proceed

\textbf{Figs 4A and B:} Corvis\textsuperscript{®} ST: Biomechanical/tomographic assessment. (A) With-the-rule astigmatism in the right eye with a normal TBI. (B) Left eye shows the same pattern with a normal TBI.
with refractive surgery. In Cases 4, 5, and 6, mild topographic changes were seen; however, indices were normal. The data are illustrated in Table 1.

In a parallel study, Vinciguerra et al.\textsuperscript{12} showed that CBI had a 97.5% accuracy for detecting clinical ectasias. A recent retrospective study by Ambrosio et al.\textsuperscript{11,13} showed high sensitivity in detecting subclinical ectasias with normal topography when BAD, which provides a comprehensive screening, is combined with the newly developed TBI parameter.

The Corvis device's advanced parameters combined with clinical and tomographic changes increase the sensitivity and specificity of cases that would otherwise go unnoticed and could progress to corneal decompensation if subjected to surgery.

**CONCLUSION**

The interpretation of the biomechanical parameters of the cornea is challenging due to the behavior of the cornea's viscoelastic properties and by the relatively limited available data.\textsuperscript{21} Novel advanced parameters have been proven useful for improving the detection of subclinical ectasia cases and for providing additional information to guide clinical decision.

We were able to distinguish suspicious cases that would be considered normal by isolated front surface corneal topography from cases with an asymmetric pattern that would not likely have ectasia. Retrospective analysis of the advanced parameters of patients with relatively dubious clinical conditions demonstrated usefulness for clinical decision making mainly regarding the TBI. By combining data from corneal tomography of Pentacam® HR with the new parameters of Corvis ST, one could make a detailed and careful analysis to detect early patients who could develop corneal ectasias and who could otherwise go unnoticed.

Future prospective and retrospective studies should be done to further validate the integration of corneal biomechanics with Scheimpflug images, so that the ability of the TBI for characterizing ectatic corneal disease and
**Table 1: Ectasia cases**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Cutoff</th>
<th>Sens</th>
<th>Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>KKS</td>
<td></td>
<td></td>
<td></td>
<td>0.015</td>
<td>97.11</td>
<td>98.87</td>
</tr>
<tr>
<td>IHD</td>
<td>0.008</td>
<td>0.025</td>
<td>0.011</td>
<td>0.010</td>
<td>91.56</td>
<td>89.1</td>
</tr>
<tr>
<td>Kmax (front)</td>
<td>42.2</td>
<td>48.2</td>
<td>47.6</td>
<td>46.7</td>
<td>35.8</td>
<td>40.7</td>
</tr>
<tr>
<td>KISA</td>
<td>2.31</td>
<td>269.31</td>
<td>4.702</td>
<td>0.922</td>
<td>82.22</td>
<td>98.12</td>
</tr>
<tr>
<td>SRAX</td>
<td>6.75</td>
<td>91.84</td>
<td>7.62</td>
<td>1.49</td>
<td>14.75</td>
<td>88.22</td>
</tr>
<tr>
<td>I-S value</td>
<td>1.0</td>
<td>5.8</td>
<td>0.7</td>
<td>–0.5</td>
<td>1.21</td>
<td>96.22</td>
</tr>
<tr>
<td>Central-K</td>
<td>41.103</td>
<td>41.536</td>
<td>45.482</td>
<td>45.062</td>
<td>51.4</td>
<td>95.86</td>
</tr>
<tr>
<td>Anterior elevation at thinnest point using BFS 8.0</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>0</td>
<td>&gt;5</td>
<td>91.5</td>
</tr>
<tr>
<td>Posterior elevation at thinnest point using BFS 8.0</td>
<td>7</td>
<td>29</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>&gt;14</td>
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<tr>
<td>ART max</td>
<td>421</td>
<td>240</td>
<td>424</td>
<td>365</td>
<td>&lt;344</td>
<td>95.78</td>
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<tr>
<td>ART avg</td>
<td>598</td>
<td>385</td>
<td>512</td>
<td>458</td>
<td>&lt;473</td>
<td>96.89</td>
</tr>
<tr>
<td>Thinnest value</td>
<td>570</td>
<td>530</td>
<td>505</td>
<td>490</td>
<td>&lt;514</td>
<td>89.33</td>
</tr>
<tr>
<td>PRFI</td>
<td>0.14</td>
<td>0.96</td>
<td>0.21</td>
<td>0.27</td>
<td>0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>BAD (v3)</td>
<td>0.84</td>
<td>4.42</td>
<td>1.81</td>
<td>1.42</td>
<td>2.34</td>
<td>&gt;2.32</td>
</tr>
<tr>
<td>TBI</td>
<td>0.43</td>
<td>1.00</td>
<td>0.12</td>
<td>0.31</td>
<td>0.70</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Sens: Sensitivity; Spec: Specificity; KKS: Keratoconus stage; IHD: Index of height decentration; Kmax (front): Maximum axial curvature of the front surface; SRAX: Relative skewing of the steepest radial axes; I–S value: Inferior–superior asymmetry in keratometry; BFS 8.0 mm: Best fit sphere to 8.0 mm zone; ART: Ambrosio relational thickness calculated for the average and maximum progression indices (ART avg and ART max); PRFI: Pentacam random forest index; BAD (v3): Belin/Ambrosio deviation index (third generation [version 3]);
its progression, along with the intrinsic susceptibility for biomechanical decompensation, is clarified. Such knowledge will raise the bar of safety and efficiency for selecting and planning refractive and therapeutic procedures.

REFERENCES