Corneal Parameters in Healthy Subjects Assessed by Corvis ST

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Abstract

Purpose: To evaluate corneal biomechanics using Corvis ST in healthy eyes from Iranian keratorefractive surgery candidates.

Methods: In this prospective consecutive observational case series, the intraocular pressure (IOP), central corneal thickness (CCT), and biomechanical properties of 1,304 eyes from 652 patients were evaluated using Corvis ST. Keratometric readings and manifest refraction were also recorded.

Results: The mean (±SD) age of participants was 28 ± 5 years, and 31.7% were male. The mean spherical equivalent refraction was –3.50 ± 1.57 diopters (D), the mean IOP was 16.8 ± 2.9 mmHg, and the mean CCT was 531 ± 31 𝜇m for the right eye. The respective means (±SD) corneal biomechanical parameters of the right eye were as follows: first applanation time: 7.36 ± 0.39 milliseconds (ms); first applanation length: 1.82 ± 0.22 mm; velocity in: 0.12 ± 0.04 m/s; second applanation time: 20.13 ± 0.48 ms; second applanation length: 1.34 ± 0.55 mm; velocity out: –0.67 ± 0.17 m/s; total time: 16.84 ± 0.64 ms; deformation amplitude: 1.05 ± 0.10 mm; peak distance: 4.60 ± 1.01 mm; and concave radius of curvature: 7.35 ± 1.39 mm. In the linear regression analysis, IOP exhibited a statistically significant association with the first and second applanation times, total time, velocity in, peak distance, deformation amplitude, and concave radius of curvature.

Conclusion: Our study results can be used as a reference for the interpretation of Corvis ST parameters in healthy refractive surgery candidates in the Iranian population. Our results confirmed that IOP is a major determinant of Corvis parameters.

Keywords: Central Corneal Thickness; Corneal Biomechanics; Corvis ST; Intraocular Pressure

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stress conditions. Currently, ophthalmologists are deeply interested in characterizing the corneal biomechanical properties in pathological conditions and after refractive surgery. Furthermore, corneal biomechanics affect intraocular pressure (IOP) measurement and may also be an important risk factor for the development of glaucomatous optic neuropathy.

To date, only two devices have been designed to evaluate corneal biomechanical properties in vivo: the Ocular Response Analyzer (ORA; Reichert Ophthalmics, Depew, NY), a dynamic bidirectional applanation device and the Corvis ST (Oculus Optikgeräte GmbH, Wetzlar, Germany), a dynamic non-contact Scheimpflug analyser device. Both devices use an air pulse to impress the cornea. In contrast to the ORA, which cannot display the dynamics of the corneal deformation process in real time, the Corvis ST uses the real-time corneal deformation data to analyze corneal biomechanics. To accomplish this, Corvis ST captures a series of horizontal Scheimpflug images using a high-speed camera that gathers 4,300 frames per sec within a 100 milliseconds (ms) period.

Currently, there are few reports regarding the normal distribution of Corvis ST parameters from different populations. Because ethnicity is a known determinant of corneal biomechanical properties, the normative database from various populations are very useful and can guide us in spotting abnormal cases. The aim of this study was to evaluate the corneal biomechanical properties using the Corvis ST in healthy eyes from Iranian patients who have been evaluated for keratorefractive surgery.

METHODS

Study Population

In this prospective case series, which was conducted from January 2012 to December 2013, corneal biomechanical parameters from Corvis ST were recorded for 1,304 eyes from 652 consecutive healthy keratorefractive surgery candidates with no eye disorders except myopia. A complete eye examination, including visual acuity measurement, slit-lamp biomicroscopy, and fundus exam using a 90-diopeter noncontact lens was performed on each eye. Cases with positive history (or objective signs) of ocular disorders (e.g., glaucoma, uveitis, corneal ectatic disorders, Fuchs’s corneal dystrophy, and diabetic retinopathy), chronic use of topical medications, previous ocular surgery, corneal scars or opacities, irregular astigmatism, systemic diseases, or inability to cooperate with any measurement device were excluded. The research protocol adhered to the tenets of the Declaration of Helsinki and detailed informed consent was signed by all individuals. The study protocol was approved by the Ethics Committee at the Shiraz University of Medical Sciences.

Measurements

Refraction was measured using an autorefractometer (Canon R-50; Canon Inc., Tokyo, Japan), and keratometric measurements were recorded from Pentacam HR (Oculus Optikgeräte GmbH, Wetzlar, Germany) scan reports. Ocular biomechanical parameters, IOP, and central corneal thickness (CCT) were obtained using Corvis ST. Corvis ST measures the biomechanical response of the cornea at the moment of the first and second applanations, and highest concavity events. IOP is calculated based on the timing of the first applanation event. Corvis ST measures and records the time to reach applanation (T1, T2), the length of the flattened segment in a Scheimpflug image (L1, L2), and corneal movement velocity during applanation (V1, V2) at the moment of both first and second applanations, respectively. It also measures the total time (T), deformation amplitude (DA), distance between bending points of the cornea (PD), and the concave radius of curvature (R) at the point of highest concavity. All of the described Corvis ST parameters were recorded for analysis.

Each instrument was calibrated at the outset of the study, and then at regular intervals (as per manufacturer recommendations). All measurements from each device were performed by the same qualified operator using the criteria provided by the devices manufacturer.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics software version 21 (SPSS Inc., Chicago, IL) and
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Table 1. Baseline characteristics of the study cohort

|                   | Right eyes $^a$ | Left eyes $^a$ |
|-------------------|----------------|---------------|
| SE, D             | $-3.50 \pm 1.57$ | $-3.47 \pm 1.59$ |
| Km, D             | $43.7 \pm 1.3$   | $43.7 \pm 1.3$ |
| Ka, D             | $1.2 \pm 0.8$    | $1.2 \pm 0.8$  |
| CCT, $\mu m$     | $531 \pm 31$     | $531 \pm 31$   |
| IOP, mmHg        | $16.8 \pm 2.9$   | $16.6 \pm 2.7$ |

$^a$Data are presented as the mean ± standard deviation.

CCT, central corneal thickness; D, diopter; IOP, intraocular pressure; Ka, astigmatic keratometry; Km, mean keratometry; SE, spherical equivalent refraction.

Table 2. Mean and normal range of Corvis parameters among participants

|                   | Right eyes $^b$ | Left eyes $^b$ | Absolute variation $^b$ (95% range) | Relative variation $^c$ (95% range) |
|-------------------|----------------|---------------|--------------------------------------|-------------------------------------|
| T1, milliseconds  | 7.36 (6.60 to 8.12) | 7.34 (6.61 to 8.07) | ± 0.66                      | ± 9.0%                     |
| L1, mm            | 1.82 (1.37 to 2.23) | 1.83 (1.38 to 2.28) | ± 0.095                  | ± 5.2%                     |
| V1, m/s           | 0.12 (0.04 to 0.20) | 0.12 (0.04 to 0.20) | ± 0.65                  | ± 565%                    |
| T2, milliseconds  | 20.13 (19.19 to 21.07) | 20.15 (19.23 to 21.07) | ± 0.58                   | ± 2.9%                    |
| L2, mm            | 1.34 (0.26 to 2.42) | 1.38 (0.26 to 2.50) | ± 0.40                    | ± 29.4%                   |
| V2, m/s           | –0.67 (–1.00 to –0.34) | –0.67 (–1.06 to –0.28) | ± 1.45                  | ± 216%                    |
| T, milliseconds   | 16.84 (15.59 to 18.09) | 16.88 (15.70 to 18.06) | ± 1.29                  | ± 7.7%                    |
| DA, mm            | 1.05 (0.85 to 1.25) | 1.06 (0.86 to 1.26) | ± 0.19                    | ± 12.3%                   |
| PD, mm            | 4.60 (2.62 to 6.58) | 4.63 (2.66 to 6.58) | ± 2.56                  | ± 55.5%                   |
| R, mm             | 7.35 (4.63 to 10.07) | 7.35 (4.34 to 10.37) | ± 3.29                  | ± 44.8%                   |

$^b$Data are presented as the mean (95% range)

$^c$Calculated as: ± $\frac{1.96 \text{ SD of the mean difference (right–left)}}{\text{mean value of both eyes}} \times 100$

DA, deformation amplitude; L1, length of applanation 1; L2, length of applanation 2; PD, peak distance; R, radius; T, time of highest concavity; T1, time of applanation 1; T2, time of applanation 2; V1, velocity of applanation 1; V2, velocity of applanation 2.

Table 3. Linear regression analysis demonstrating association between selected demographic and ocular factors to each Corvis ST parameters at the first applanation moment

|       | T1        | L1        | V1        |
|-------|-----------|-----------|-----------|
|       | SC        | P-value $^a$ | SC        | P-value $^a$ | SC        | P-value $^a$ |
| Age   |           |           |           |           |           |           |
| Sex (male to female) |           |           | –0.091 | 0.021 $^b$ |           |           |
| SE    |           |           |           |           |           |           |
| Km    |           |           |           |           |           |           |
| Ka    |           |           |           |           |           |           |
| CCT   | 0.403     | < 0.001 $^b$ |           |           |           |           |
| IOP   | 0.964     | < 0.001 $^b$ |           |           | –0.328 | < 0.001 $^b$ |

$^a$Only factors with P-value < 0.05 in simple linear regression analysis are shown here

$^b$Denotes factors that remained significant after multiple stepwise linear regression analysis

CCT, central corneal thickness; IOP, intraocular pressure; Ka, astigmatic keratometry; Km, mean keratometry; L1, length of applanation 1; SC, standardized coefficient; SE, spherical equivalent refraction; T1, time of applanation 1; V1, velocity of applanation 1.
Table 4. Linear regression analysis demonstrating association between selected demographic and ocular factors to each Corvis ST parameters at the second applanation moment

|               | T2 SC | P-value<sup>a</sup> | L2 SC | P-value<sup>a</sup> | V2 SC | P-value<sup>a</sup> |
|---------------|-------|----------------------|-------|----------------------|-------|----------------------|
| Age           |       |                      |       |                      |       |                      |
| Sex (male to female) |       |                      |       |                      |       |                      |
| SE            | Km –0.092 | 0.021<sup>b</sup> | Ka –0.117 | 0.003<sup>b</sup> |       |                      |
| CCT           | 0.134 | 0.001<sup>b</sup> | 0.107 | 0.007<sup>b</sup> |       |                      |
| IOP           | –0.568 | < 0.001<sup>b</sup> |       |                      |       |                      |

<sup>a</sup>Only factors with P-value < 0.05 in simple linear regression analysis are shown here
<sup>b</sup>Denotes factors that remained significant after multiple stepwise linear regression analysis
CCT, central corneal thickness; IOP, intraocular pressure; Ka, astigmatic keratometry; Km, mean keratometry; L2, length of applanation 2; SC, standardized coefficient; SE, spherical equivalent refraction; T2, time of applanation 2; V2, velocity of applanation 2

Table 5. Linear regression analysis demonstrating an association between selected demographic and ocular factors to each Corvis ST parameters at the highest concavity moment

|               | T SC | P-value<sup>a</sup> | DA SC | P-value<sup>a</sup> | PD SC | P-value<sup>a</sup> | R SC | P-value<sup>a</sup> |
|---------------|------|----------------------|-------|----------------------|-------|----------------------|------|----------------------|
| Age           |      |                      |       |                      |       |                      |      |                      |
| Sex (male to female) | 0.125 | 0.001<sup>b</sup> |       |                      |       |                      |
| SE            | 0.086 | 0.028<sup>b</sup> |       |                      |       |                      |
| Km            |       |                      | Km 0.130 | 0.017<sup>b</sup> |       |                      |
| Ka            |       |                      | Ka 0.117 | 0.003<sup>b</sup> |       |                      |
| CCT           |       |                      | CCT –0.218 | < 0.001 |       |                      |
| IOP           | 0.135 | 0.001<sup>b</sup> | IOP –0.651 | < 0.001 |       |                      |
|               |       |                      | R 0.211 | < 0.001<sup>b</sup> |       |                      |

<sup>a</sup>Only factors with P < 0.05 in simple linear regression analysis are shown here
<sup>b</sup>Denotes factors that remained significant after multiple stepwise linear regression analysis
CCT, central corneal thickness; DA, deformation amplitude; IOP, intraocular pressure; Ka, astigmatic keratometry; Km, mean keratometry; PD, peak distance; R, radius; SC, standardized coefficient; SE, spherical equivalent refraction; T, time of highest concavity

Table 6. Mean and normal range of Corvis parameters categorized based on the intraocular pressure

| Intraocular Pressure, mm Hg<sup>a</sup> | T1, milliseconds<sup>a</sup> | V1, m/s<sup>a</sup> | T2, milliseconds<sup>a</sup> | T, milliseconds<sup>a</sup> | DA, mm<sup>a</sup> | PD, mm<sup>a</sup> | R, mm<sup>a</sup> |
|-----------------------------------------|-----------------------------|----------------------|-----------------------------|-----------------------------|-----------------|-----------------|-----------------|
| 10.00–12.99 (n = 30)                    | 6.78 (6.54 to 7.01)         | 0.114 (0.042 to 0.186) | 21.21 (20.75 to 21.68)     | 16.16 (15.47 to 16.86)     | 1.15 (1.04 to 1.26) | 5.46 (5.11 to 5.81) | 7.42 (5.53 to 11.31) |
| 13.00–15.99 (n = 230)                   | 7.06 (6.76 to 7.37)         | 0.130 (0.074 to 0.185) | 20.32 (19.43 to 21.20)     | 16.80 (15.48 to 18.11)     | 1.11 (0.942 to 1.28) | 4.77 (2.81 to 6.73) | 7.13 (4.29 to 9.97) |
| 16.00–18.99 (n = 252)                   | 7.39 (7.10 to 7.68)         | 0.117 (0.050 to 0.184) | 20.01 (19.34 to 20.69)     | 16.93 (15.74 to 18.12)     | 1.04 (0.908 to 1.17) | 4.49 (2.50 to 6.49) | 7.35 (4.75 to 9.95) |
| 19.00–22.00 (n = 104)                   | 7.80 (7.46 to 8.14)         | 0.080 (0.020 to 0.140) | 19.87 (19.27 to 20.48)     | 16.86 (15.82 to 17.91)     | 0.989 (0.764 to 1.21) | 4.36 (2.41 to 6.30) | 7.47 (6.09 to 8.86) |

<sup>a</sup>Data are presented as the mean (95% range); only analyses of right eyes are shown here
<sup>b</sup>Only parameters that have shown significant association with IOP are presented here
DA, deformation amplitude; PD, peak distance; R, radius; T, time of highest concavity; T1, time of applanation 1; T2, time of applanation 2; V1, velocity of applanation 1
Figure 1. Significant determinants of the selected Corvis ST parameters at the first applanation moment. CCT, central corneal thickness; IOP, intraocular pressure.

Figure 2. Significant determinants of the selected Corvis ST parameters at the second applanation moment. CCT, central corneal thickness; IOP, intraocular pressure; Km, mean keratometry; Ka, astigmatic keratometry.
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Figure 3. Significant determinants of the selected Corvis ST parameters at the highest concavity moment. CCT, central corneal thickness; IOP, intraocular pressure; SE, spherical equivalent refraction.

eyes) variations. For relative variation values < 10%, this parameter may be more informative because it incorporates the mean value as well; but for the relative variation > 10% (typically for those with small mean value), the relative variation measurements are exaggerated and useless. Absolute variation values may be more clinically useful for this class of Corvis ST parameters.

Several previous studies have evaluated Corvis ST parameters in normal and abnormal eyes. Hong et al reported that Corvis ST demonstrated excellent consistency in IOP measurement perhaps because it might be less affected by corneal properties.[5] Reznicek et al reported good repeatability and good accuracy of Corvis ST compared to standardized ultrasound pachymetry or Goldmann applanation tonometry for measuring CCT and IOP in healthy subjects, and in patients with ocular hypertension and glaucoma.[7] The results of our regression analysis of the factors associated with Corvis ST parameters closely parallels the findings of Huseynova et al.[1] In both studies, T1 and R were significantly associated with CCT, and T1, T2, and DA were correlated to IOP.[1] In both studies, T1 and R were significantly associated with CCT. Also, T1, T2, and DA were correlated with IOP.

In a recent study on healthy Brazilian patients, Valbon and colleagues[11] reported a normal range of Corvis ST parameters. Compared to our study, they enrolled fewer patients (n = 90), but with broader enrolment criteria (age range: 21 to 79
years). The mean values of Corvis ST parameters that were reported by Valbon et al were quite different compared to ours: T1 (8.32 vs 7.36 ms); T (18.38 vs 16.84 ms); T2 (23.80 vs 20.13 ms); L1 (2.07 vs 1.82 mm); L2 (2.37 vs 1.34 mm); DA (1.05 vs 1.05 mm); R (11.09 vs 7.35 mm); V1 (0.21 vs 0.12 m/s); and V2 (~0.33 vs ~0.67 m/s), respectively. However, these differences were not unexpected, because their study population enrolled older patients from a different ethnicity. Previous studies have established the role of ethnicity on CCT and IOP; the two fundamental determinants of Corvis ST parameters. The differences in Corvis ST values between the two studies further underscores the importance of using customized charts, based on underlying ocular and demographic factors, to improve accuracy of detecting abnormal cases in each particular population.

The present study has the advantage of including a large number of cases leading to more precise normative ranges, but it is limited due to its relatively strict enrolment criteria, which reduces the generalizability of the findings. In addition, we did not document the ethnicity. However, our sample was relatively homogenous with the majority of our patients consisting of those with Persian ethnicity. Our results should only be used for the population of refractive surgery candidates with similar age range, ethnicity, and refractive error.

In conclusion, this study has provided a reference normative database for Corvis ST parameters in Iranian refractive surgery candidates, which can be used with caution in selected patients who satisfy the enrolment criteria. Several demographic and ocular factors, and IOP in particular, essentially affected the Corvis ST parameters, and this issue should be considered when interpreting the results.

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Nil.

Conflicts of Interest

There are no conflicts of interest.

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