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· Clinical Research ·

Corneal biomechanical data and biometric parameters measured with Scheimpflug-based devices on normal corneas

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Abstract
● AIM: To analyze the correlations between ocular biomechanical and biometric data of the eye, measured by Scheimpflug-based devices on healthy subjects.

● METHODS: Three consecutive measurements were carried out using the corneal visualization Scheimpflug technology (CorVis ST) device on healthy eyes and the 10 device-specific parameters were recorded. Pentacam HR-derived parameters (corneal curvature radii on the anterior and posterior surfaces; apical pachymetry; corneal volume; corneal aberration data; depth, volume and angle of the anterior chamber) and axial length (AL) from IOLMaster were correlated with the 10 specific CorVis ST parameters.

● RESULTS: Measurements were conducted in 43 eyes of 43 volunteers (age 61.24±15.72y). The 10 specific CorVis ST data showed significant relationships with corneal curvature radii both on the anterior and posterior surface, pachymetric data, root mean square (RMS) data of lower-order aberrations, and posterior RMS of higher-order aberrations and spherical aberration of the posterior cornea. Anterior chamber depth showed a significant relationship, but there were no significant correlations between corneal volume, anterior chamber volume, mean chamber angle or AL and the 10 specific CorVis ST parameters.

● CONCLUSION: CorVis ST-generated parameters are influenced by corneal curvature radii, some corneal RMS data, but corneal volume, anterior chamber volume, chamber angle and AL have no correlation with the biomechanical parameters. The parameters measured by CorVis ST seem to refer mostly to corneal properties of the eye.

● KEYWORDS: anterior segment parameters; biomechanics; corneal visualization Scheimpflug technology; Ocular Response Analyzer

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INTRODUCTION

The diagnostic techniques presently used in ophthalmological practice measure the static parameters of the anterior segment of the eye. There are currently two devices capable of *in vivo* measurements of the ocular biomechanical data since the cornea has been identified with viscoelastic properties[1]. One is the Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Depew, New York, USA), which is a dynamic bidirectional applanation device[2-3]. The other tool, called corneal visualization Scheimpflug technology (CorVis ST; Oculus Inc., Wetzlar, Germany), also uses a high-intensity air impulse for biomechanical measurements, but applies a high-speed Scheimpflug camera to detect changes of corneal shape. The CorVis ST and ORA also analyze corneal deformations due to a high-intensity air puff applanation, but the parameters obtained by these two devices cannot be compared with each other.

In the case of ORA, corneal hysteresis (CH) and corneal resistance factor (CRF) are the two main data, but now, it is possible to reach a more detailed analysis and new data set of the deformation signal waveform, aimed at further refining the evaluation of ocular biomechanical data. In the case of CorVis ST, several new parameters will probably appear regarding the deformation graph, and will perhaps yield some additional information and data about ocular biomechanics.

With these two devices, an emphasis has been placed on the biomechanical measurements of the cornea in the diagnosis of glaucoma[4] and in diagnosis and monitoring of keratectasia[5-6], refractive surgeries[7-8] and corneal collagen cross-linking therapies[9-10]. *In vivo* measurement of biomechanical data has a declared and important aim, namely to differentiate between normal and abnormal corneas. For example, Wang *et al*[11] demonstrated differences in CorVis ST data between normal and keratoconus group, moreover Long *et al*[12] showed differences in some specific CorVis ST parameters between normal and dry eyes.

A relatively small number of papers deal with the relationship between the anatomical parameters of the eye and biomechanical data. Some papers suggest that parameters of ORA are correlated with some anterior segment parameters[13-21]. Our aim was to investigate the relationship between the specific parameters determined by CorVis ST and anterior segment's anatomical and biometric data obtained by Scheimpflug imaging.

SUBJECTS AND METHODS

Our examinations were carried out on healthy eyes, with normal anterior and posterior eye segment examined at slit-lamp. Exclusion criteria were any anterior segment disease, any intraocular- or refractive surgery and contact lens wearing in the medical history. Besides, exclusion criteria were any type of glaucoma, or refractive error of more than ±0.5 D. All of the examinations were carried out at the Department of Ophthalmology, University of Debrecen, Debrecen, Hungary. All patients were informed about the course and the aim of the measurements. The protocol adhered to the tenets of the Declaration of Helsinki and was approved by the local Ethics Committee.

First, axial lengths (AL) were recorded with signal noise ratio >10.0 with an IOLMaster (software version 5.4.3.0002, Carl Zeiss Meditec, Jena, Germany), using the average of at least 5 measurements. Subsequently, corneal curvature radii (horizontal and vertical radii at the anterior and posterior surfaces), pachymetry (at the apex), corneal volume (CV) in a 10-mm diameter area, total root mean square (RMS) of the cornea, representing a summation of the corneal shape data, RMS of lower-order aberration (LOA) of the cornea, RMS of higher-order aberration (HOA) of the cornea and spherical aberration of the cornea (all aberrations on both the anterior and posterior corneal surfaces), anterior chamber depth (according to the definition of Pentacam software, epithelial chamber height), anterior chamber volume and mean anterior chamber angle were recorded by the high-resolution version of Pentacam (Pentacam HR, Oculus Optikgeräte GmbH, Wetzlar, Germany), using auto setting at 25 images/2s mode. Corneal aberrations were evaluated at 8.0 mm pupil setting based on the elevation data. These IOLMaster and Pentacam HR derived parameters were referred later as "biometric parameters".

Finally, three captures were taken for all eyes using the CorVis ST device (software version 1.00r24 rev. 772.). The CorVis ST, a non-contact tonometer and pachymeter, also measure 10 device-specific ocular biomechanical parameters using a metered, high-intensity air impulse. The Scheimpflug camera captures approximately 140 frames in an examination period of roughly 30ms. In all of the 140 snapshots, taken during the deformation process, the software identifies the anterior and posterior contour of the cornea and calculates these 10 specific data. The device measures the amplitude of corneal deformation and the time taken to reach this applanation. The CorVis ST also monitors the speed of the cornea during the first and second applanation phase, the distance of the two corneal apexes at highest concavity time (called the peak distance), the chord length (length of the flattened cornea in mm) and a radius value which represents the central concave curvature at higher concavity time. Altogether, 10 device-specific parameters, as well as corneal thickness (CT) and intraocular pressure (IOP) based on the first applanation are measured by the CorVis ST, referred later as biomechanical parameters (Figure 1). Patients were seated with their chin on the chinrest and forehead against the device. At accurate setting, the air-impulse automatically starts and the data are exported to a computer. The means of the three consecutive measurement data were used for further analyses in case of all parameters. The measurements were taken by the same investigator and at nearly the same time of day. During the time between the captures, the patients could move their heads from the chinrest.

Statistical Analysis Statistical analysis was performed using MedCalc for Windows, version 12.2.1 (MedCalc Software, Ostend, Belgium) and Microsoft Excel (Microsoft Corp., Redmond, WA, USA) software. Descriptive statistical results were written as mean±standard deviation (SD) and 95% confidence intervalls (95% CI) for the mean. Multiple regression analyses were performed with the 10 specific CorVis ST data as dependent variables and the anatomical parameters (Pentacam data and AL) as independent variables, as our aim was to study the effect of biometry on CorVis ST parameters. Multiple correlation coefficients were recorded and a *P* value below 0.05 was considered statistically significant. Sample size calculation showed that a minimum of 43 eyes were required for a correlation coefficient of 0.47 or above with type 1 error of 0.05 and type 2 error of 0.1.

RESULTS

Our measurements were conducted in 43 eyes of 43 volunteers (mean age: 61.24±15.72y; range: 22.2-87.3y; 16 males and 27 females). The mean IOP was 15.37±0.97 mm Hg (range: 14.0-17.0 mm Hg). The device-specific data obtained with CorVis ST, the corneal and anterior chamber data from Pentacam HR and AL from IOLMaster are shown in detail in Table 1.

The 10 specific CorVis ST data showed significant relationships with corneal curvature radii both on the anterior and posterior surface of the cornea, pachymetric data, RMS data

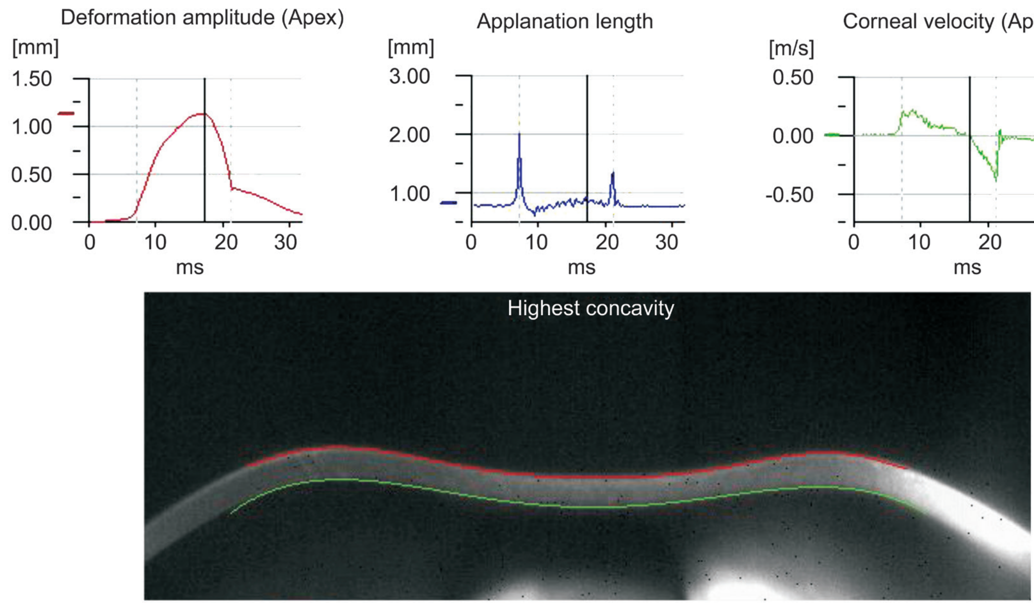

Figure 1 A demonstrative picture taken by the CorVis ST showing the highest concavity phase of a normal corneal biomechanical measurement.

of anterior and posterior cornea, RMS data of LOA on the anterior and posterior cornea, and posterior RMS HOA and spherical aberration of the posterior cornea. Anterior chamber depth showed significant relationships as well. There were no significant correlations between CV, the anterior chamber volume, the mean chamber angle or AL and the 10 specific CorVis ST parameters (Table 2).

DISCUSSION

As the measured biomechanical data characterize not only corneal biomechanics, but rather ocular metrics[22], a question is raised as to whether there are any relationships between the biomechanical data and any anatomical parameters of the eye.

The ORA, and more recently the CorVis ST, are capable of measuring ocular biomechanical data using an air impulse to deform the cornea. Our aim was to assess the relationship between the specific CorVis ST parameters and other biometric parameters of the eye, including the radius values of the corneal curvature, CT, CV, corneal aberrations, anterior chamber depth, anterior chamber volume, anterior chamber angle and also AL of the eye.

The central CT was positively correlated with CH and/or CRF in several previous studies[13-18,23-26]. In the present study, a significant correlation was found between the apical pachymetric data of Pentacam HR and the specific CorVis ST parameters.

Statistically significant correlation was observed between the CH/CRF of ORA and spur-to-spur distance[19]. The CH was found to correlate significantly with superior and inferior angle width in eyes with pigmentary glaucoma[20]. Corneal diameter had no significant association with CH and CRF in a large sample study[16], which was contrary to the findings of another study[17]. We do not have spur-to-spur or white-to-white data on the present patient group; therefore it is now an opened question whether CorVis ST parameters depend on sulcus or corneal diameter data or not.

The radius of the cornea was negatively correlated with CH and/or CRF; more specifically, the steeper the cornea was, the larger the CH and/or CRF were[13-16,18,21]. Other authors stated that corneal astigmatism was negatively correlated with CH and CRF[17], but in a study with a larger sample, this was not supported[16]. According to the data of Lanza *et al*[6], obtained by CorVis ST, corneal curvature would have a greater influence on corneal deformation than central CT, especially in diseased corneas. Other authors did not prove a keratometric association of these data[23-24]. Our data obtained with a CorVis ST device showed that significant correlation exists between the keratometric data and the CorVis ST parameters, so corneal curvature data may have a real influence on the measured data.

The CRF strongly correlated with corneal spherical-like aberrations, especially in keratoconus patients[27-29]. Weak, but significant, negative correlation was described between the CH/CRF and the anterior/posterior elevation[15,27]. The corneal biomechanical parameters of ORA showed a negative correlation with the anterior central elevation, a positive correlation with the Q value, but no significant correlations were found between CH/CRF and the corneal morphological index on the posterior corneal surface[27]. Zhang *et al*[27] suggested that higher biomechanical values might be related to central flattening and oblate corneal shape. In a recent study, high myopic eyes showed greater second applanation velocity on CorVis ST testing, than emmetropic eyes[30]. Moreover, in another study, it was found that highly myopic eyes presented longer deformation amlitude and smaller radius of the highest concavity data than do moderately myopic eyes, and the

Table 1 Descriptive statistical data obtained by CorVis ST and Pentacam HR in a healthy population *n*=43

Parameters	Mean	SD	95% CI
A1 length (mm)	1.75	0.19	1.69-1.81
A1 time (ms)	7.25	0.34	7.14-7.35
A1 velocity (m/s)	0.15	0.03	0.14-0.16
A2 length (mm)	1.88	0.36	1.77-1.99
A2 time (ms)	21.61	0.38	21.49-21.73
A2 velocity (m/s)	-0.34	0.07	-0.36- -0.32
Def. amp. max (mm)	1.07	0.11	1.04-1.11
HC time (ms)	16.92	0.43	16.78-17.05
Peak dist (mm)	3.28	0.81	3.02-3.53
Radius (mm)	7.82	0.92	7.54-8.10
Rh F (mm)	7.72	0.38	7.60-7.83
Rh B (mm)	6.47	0.42	6.34-6.60
Rv F (mm)	7.65	0.37	7.54-7.77
Rv B (mm)	6.22	0.27	6.13-6.30
Pachy apex (μm)	568.86	47.27	554.31-583.41
Cor. Vol. (mm^3)	61.28	5.65	59.54-63.02
RMS (CF) (μm)	5.69	4.09	4.42-6.96
RMS (CB) (μm)	1.94	0.87	1.67-2.21
RMS (cornea) (μm)	5.13	3.41	4.07-6.19
RMS LOA (CF) (μm)	5.42	3.88	4.21-6.63
RMS LOA (CB) (μm)	1.86	0.86	1.59-2.13
RMS LOA (cornea) (μm)	4.86	3.21	3.86-5.86
RMS HOA (CF) (μm)	1.67	1.37	1.24-2.10
RMS HOA (CB) (μm)	0.51	0.20	0.44-0.57
RMS HOA (cornea) (μm)	1.57	1.23	1.19-1.95
Z 4 0 (CF) (μm)	0.69	0.54	0.51-0.85
Z 4 0 (CB) (μm)	-0.32	0.13	-0.36- -0.28
Z 4 0 (cornea) (μm)	0.69	0.46	0.54-0.83
ACD (mm)	3.14	0.50	2.99-3.29
C. Volume (mm^3)	127.96	43.71	114.16-141.76
C. A. Mean (degree)	30.62	6.95	28.48-32.77
AL (mm)	23.26	1.47	22.77-23.76

SD: Standard deviation; CI: Confidence interval. A1 time: Time from starting until the first applanation; A1 length: Chord length of the first applanation; A1 velocity: Speed of the first applanation; A2 time: Time from starting until the second applanation; A2 length: Chord length of the second applanation; A2 velocity: Speed of the second applanation; Def. amp. max: Maximum amplitude at the apex (highest concavity); HC time: Time from starting of air-puff until highest concavity (HC) is reached; Peak dist: Distance of the two apex at HC; Radius: Central concave curvature of the cornea at the time of the HC; Rh: Horizontal radius of curvature of the cornea; Rv: Vertical radius of curvature of the cornea; F: Front (*i.e.* anterior surface of the cornea); B: Back (*i.e.* posterior surface of the cornea); Pachy apex: Corneal thickness at apex measured by Pentacam HR; Cor. Vol.: Corneal volume in a 10-mm diameter area; RMS: Root mean square; LOA: Lower order aberration; HOA: Higher-order aberration; Z 4 0: Spherical aberration; CF: Corneal front (*i.e.* anterior surface); CB: Corneal back (*i.e.* posterior surface); ACD: Anterior chamber depth (*i.e.* epithelial chamber height by Pentacam HR); C. Volume: Anterior chamber volume; C. A. Mean: Mean angle of the anterior chamber.

Table 2 Data of multiple regression analyses between the ten specific CorVis ST data as dependent variables and the anatomical parameters as independent variables

Parameters	Multiple correlation coefficient	*P*
Rh F (mm)	0.774	<0.001[a]
Rv F (mm)	0.837	<0.001[a]
Rh B (mm)	0.799	<0.001[a]
Rv B (mm)	0.755	<0.001[a]
Pachymetry (μm)	0.672	0.018[a]
CV (mm^3)	0.503	0.400
RMS cornea F (μm)	0.677	0.019[a]
RMS cornea B (μm)	0.788	<0.001[a]
RMS LOA cornea F (μm)	0.695	0.011[a]
RMS LOA cornea B (μm)	0.786	<0.001[a]
RMS HOA cornea F (μm)	0.517	0.370
RMS HOA cornea B (μm)	0.659	0.032[a]
Spherical aberration, cornea F (μm)	0.575	0.175
Spherical aberration, cornea B (μm)	0.671	0.023[a]
ACD (mm)	0.635	0.048[a]
Anterior chamber volume (mm^3)	0.609	0.110
Mean chamber angle (degree)	0.561	0.196
AL (IOLMaster) (mm)	0.585	0.255

Rh: Horizontal radius of curvature of the cornea; Rv: Vertical radius of curvature of the cornea; F: Front (*i.e.* anterior surface of the cornea); B: Back (*i.e.* posterior surface of the cornea); RMS: Root mean square; LOA: Lower order aberration; HOA: Higher-order aberration; ACD: Anterior chamber depth. [a]$P<0.05$.

eyes with longer AL tend to have less corneal stiffness and are easier to deform under stress[31]. Another study of Lanza *et al*[32] concluded that corneal deformation parameters were weakly correlated without statistical significance with corneal morphological parameters including central CT, CV, and simulated keratometric vaues or with spherical equivalent.

In our patients, posterior surface components of corneal RMS, corneal RMS LOA, corneal RMS HOA and spherical aberration obtained by Pentacam HR were significantly correlated with the parameters of CorVis ST. All posterior surface corneal data (corneal radii, corneal RMS, corneal RMS LOA, corneal RMS HOA, spherical aberration) were significantly correlated with CorVis ST parameters, according to our findings. Central CT and corneal RMS data are refers to shape properties of the cornea. We assume that these measurable parameters can therefore affect the corneal response to a high-pressure air-puff.

The Pentacam-derived CV and its distribution can be useful statistical data in the diagnosis of keratectasia[33]. Mannion *et al*[34] observed that CV was significantly decreased in keratoconus, particularly in the central and paracentral area. The correlations between the CV and the CH or CRF were significant in all examined zones of the normal eyes[15], and of myopic eyes[27]. In a large sample retrospective review by Hwang *el al*[16], the authors concluded that the CH was positively associated with CV, but the associations between CRF and CV were not significant. According to our present data, no significant relationship between CV and the CorVis ST parameters was observed.

In highly myopic eyes, CH and CRF were decreased, Altan *et al*[35] concluded that the biomechanical data of the cornea could change with increase of AL of the eye. In Chinese school children, lower CH had been associated with longer AL[25,36]. Chang *et al*[37] also studied children and found that the difference in the CH between the two eyes of each patient correlated significantly with the difference in the AL between the two eyes. The ORA parameters were also negatively associated with AL in a study by Narayanaswamy *et al*[18]. By contrast, other authors concluded that there were no significant associations between ORA measurements and AL in children[19,37]. Lim *et al*[21] also observed no significant correlation with AL. Regarding CorVis ST parameters, we did not find a significant relationship between AL and specific CorVis ST parameters.

The anterior chamber depth had no significant correlation with CH and CRF[16,24], although in other studies the anterior chamber depth was negatively correlated with CH, but there was no significant correlation with CRF[18,37]. Other authors judged that both CH and CRF had no correlation with anterior chamber depth[24]. Regarding our present data obtained with CorVis ST, it seems to be that there is a borderline, questionable relationship with anterior chamber depth, but no correlation regarding anterior chamber volume or mean chamber angle data.

In summary, CorVis ST-generated parameters characterizing ocular biomechanics seem to be influenced by corneal curvature radii on the anterior and posterior surface, corneal RMS data and, of course, CT. The CV, the anterior chamber volume, the mean chamber angle and AL had no correlation with the 10 specific CorVis ST data. According to our data, it seems that CorVis ST parameters are influenced by some anterior segment anatomical data, and it may have a potential role assessing these parameters in eyes with altered anterior segment (*i.e.* refractive errors, keratoconus, narrow angle glaucoma, *etc.*). Further studies are needed to evaluate which specific parameters are related to which anatomical data or to viscous or elastic properties of the cornea.

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