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Research Article

Analysis of Corneal Biomechanical Properties Dependence on Topometric and Biometric Parameters

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Abstract

To assess the dependence of biomechanical parameters on the initial biometric, keratometric and tomographic parameters of the cornea in healthy patients with different refractions, a retrospective study was performed, which included 173 eyes of 173 healthy patients with different refractions. The study analyzed the correlation between indicators of corneal stiffness, biomechanically compensated intraocular pressure, measured using Pentacam HR and Corvis ST (OCULUS Optikgeräte GmbH; Wetzlar, Germany), true keratometry, anteroposterior eyeball size, corneal thickness in the central optical zone and the age of the patient.

As a result of the study, a significant direct dependence of the corneal stiffness parameter was noted, first of all, on the corneal thickness in the central optical zone ($p = 0.0000$), on the level of biomechanically compensated intraocular pressure ($p = 0.0056$), as well as a reliable inverse dependence on keratometry ($p = 0.0465$), but there was no influence on the patient's age ($p = 0.382$) and the anteroposterior eyeball size ($p = 0.851$).

Keywords: Amplitude of Corneal Deformation; Corneal Stiffness; Corneal Biomechanical Properties

Today all new approaches are being undertaking in development of a method allowing to not only reveal of corneal ectatic process at the earliest stages, but also to predict the disease development. Assessment of corneal biomechanical properties allows to measure intraocular pressure more accurately, which also has a significant influence on corneal response to deformation [1-3]. The Ocular Response Analyzer (ORA, Reichert Inc., Depew, NY), which is a modified non-contact tonometer that provides more accurate IOP measurements by understanding corneal compensation properties, was the first clinical tool to assess corneal biomechanical properties *in vivo* [4-6]. New opportunities for corneal biomechanics assessment were provided by Corvis ST system, which is a non-contact tonometer with collimated airflow with fixed pressure, which uses Scheimpflug camera to monitor corneal deformation [7-10]. Integration of the obtained data on corneal biomechanical properties in combination with corneal topography and tomography results into perfect artificial intelligence algorithms allows improving the accuracy of disease detection and evaluation of the impact of the corneal surgery. This is made possible with Pentacam HR and Corvis ST (OCULUS Optikgeräte GmbH; Wetzlar, Germany). Ambrosio RJr., *et al.* [11] presented tomographic and biomechanical index TBI combining Scheimpflug analysis of corneal tomography and assessment of its biomechanical properties. The results of Pentacam HR and Corvis ST (OCULUS Optikgeräte GmbH; Wetzlar, Germany) were analyzed and combined by various artificial intelligence techniques. A combination of "random forest" and "leave-one-out-validation" proved to be the most effective technique. Accuracy of prediction and ectasia detection was ensured by comparing the results obtained with the Belin/Ambrosio total ectasia deviation (BAD-D) and Corvis Biomechanical Index (CBI). The study proved that the use of tomographic and biomechanical index provides higher accuracy of ectasia detection in comparison with other methods.

The aim of the study is to analyze the corneal topographic, tomographic and biomechanical parameters in healthy patients with different refractions as well as to determine the dependence of biomechanical parameters on the initial biometric, keratometric and tomographic criteria.

Materials and Methods

This prospective study included 173 patients with different refractions (173 eyes). Only one eye of each patient was randomly included in the analysis. The age and gender composition of the study group is presented in table 1.

Refraction	Number of patients, eyes	Men	Women	Age (M ± σ)
Myopia	130	76 (58%)	54 (42%)	29 ± 8,42
Hyperopia	13	7(54%)	6 (47%)	38 ± 9,13
Emmetropia	30	20 (67%)	10 (33%)	32,0 ± 7,3
Total	173	103 (60%)	70 (40%)	30,35 ± 8,59

Table 1: Demographic characteristics of the observation group, (M ± σ).

The mean age of the patients was 30.35 ± 8.59 (M ± σ), 18 to 45 years. Examination of the patients included visometry with determination of un- and best-corrected visual acuity (UCVA and BCVA), optical biometry with determination of anteroposterior eyeball size (APES), and examination of corneal topographic, tomographic, and biomechanical parameters using Pentacam HR and Corvis ST (OCULUS Optikgeräte GmbH; Wetzlar, Germany).

Corneal thickness in the central optical zone (CT), K1, K2 and their arithmetic mean Km, which are keratometric criteria of true corneal refraction (True Net Power) in the zone of 4.0 mm around the corneal apex, were determined using a Scheimpflug Analyser Pentacam HR of the eyeball anterior segment. The calculation of true corneal refraction is provided using the formula:

True Net Power = $(1,376 - 1) \times 1000/R_{ant} + (1,336 - 1,367) \times 1000/R_{post}$, where R_{ant} and R_{post} are curvature values of the anterior and the posterior surface, correspondingly.

Corneal biomechanical parameters were assessed using a noncontact fixed-pressure collimated airflow tonometer with Scheimpflug Corneal Formation Monitoring Corvis ST (OCULUS Optikgeräte GmbH; Wetzlar, Germany) [7,9,11]. The Scheimpflug camera takes more than 4300 frames per second to monitor corneal response to a metered airflow with a fixed profile that has a symmetrical configuration and a fixed maximum internal pressure of 25 kPa. The camera has a blue LED (455 nm, no UV) and provides 8.5 mm horizontally in a single scan. The recording measurement time is 30 ms, which allows 140 digital frames. Each image has 576 measurement points. This imaging system allows to monitor the actual process of corneal deformation dynamically during the examination. Algorithms for determining corneal deformation limits are applied to each frame. Recording begins with the cornea in its natural convex shape. The airflow induces the cornea to convex inward (entry phase) through applanation (first or entry applanation), moving into the concavity phase until its maximum is reached. There is a period of oscillation before the exit or return phase. The cornea undergoes a second applanation before regaining its natural shape. The time and corresponding airflow pressure at the first and second applanation and at the moments of applanation maximum are identified. Intraocular pressure is calculated based on the time of the first applanation event. The IOP value depends on corneal resistance. Corvis ST, being a non-contact tonometer, allows to determine IOP values using corneal thickness, its biomechanical response to the impulse and patient's age (biomechanically corrected IOP (bIOP) [8,12,13].

The corneal stiffness parameter at the first applanation (SPA_1) is calculated based on the difference between the strength of the airflow on the corneal surface and the bIOP. The corneal displacement at the moment of the first applanation is the deviation amplitude A_1.

$SPA_1 = (AP_1 - bIOP)/A_1$, where AP_1 is the force of airflow on corneal surface at the moment of first applanation, bIOP is biomechanically corrected IOP, A_1 is the amplitude of corneal deviation at the moment of first applanation [9].

Inclusion criteria for patients in the study were refraction stability within a year, no history of previous ophthalmic surgeries, as well as previous or concomitant glaucoma or hypotensive therapy.

The results of the study were processed using "Microsoft Excel" and "STATISTICA 10.0". Distribution type was assessed by Pearson criterion. The distribution was normal. We calculated arithmetic mean values (M), standard errors of arithmetic mean values (m), and standard deviation (σ). The significance of differences was assessed using Student's test (t). Differences were considered significant if the significance level (p) was more than 95.0% ($p \le 0.05$).

Results of the Study and their Discussion

Keratometric, pachymetric and biometric parameters of corneas in the study group are presented in table 2.

Refraction	Km, D	Anteroposterior dimension of the eye, mm	Corneal thickness in the central optical zone, µm	bIOP, mm Hg	SPA_1
Myopia (130 eyes)	42,32 ± 1,29	25,15 ± 1,17	551,18 ± 28,83	15,8 ± 2,2	127,70 ± 23,32
Hyperopia (14 eyes)	42,34 ± 1,65	23,00 ± 0,74	528,50 ± 61,96	15,57 ± 1,96	131,67 ± 24,50
Emmetropia (30 eyes)	41,18 ± 1,34	23,95 ± 0,87	563,80 ± 24,97	15,40 ± 1,78	126,22 ± 15,3
Total (174 eyes)	41,12 ± 1,37	24,76 ± 1,30	551,5 ± 33,34	15,74 ± 2,08	127,74 ± 21,90

Table 2: Keratometric, pachymetric and biometric characteristics of the observation group, M ± σ.

Patients with topographically regular corneas were examined; the Belin/Ambrosio total ectasia deviation index (BAD-D), derived from Pentacam HR, was 1.35 ± 0.24 (M ± σ) in the study group, less than 1.6, indicating no suspicion of a possible ectatic process in the cornea.

Correlation analysis showed reliable inverse weak dependence ($p = 0.046$) of the corneal stiffness parameter at the first applanation on the mean value of true keratometry (Km): $SPA_1 = 227.81 - 2.37 \times Km$, where SPA_1 – the corneal stiffness parameter at the first applanation (Figure 1). The correlation coefficient r x/y = -0.155. The obtained result indicates that flatter and more regular cornea is more biomechanically stable.

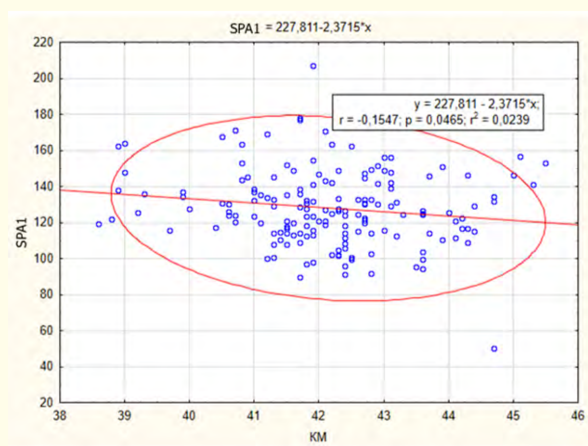

Figure 1: Correlation analysis of SPA_1 dependence on Km.

Correlation analysis also revealed a significant ($p = 0.00001$) direct dependence of the corneal stiffness parameter at the first applanation (SPA_1) on central corneal thickness (CT):

$SPA_1 = -26.37 + 0.279 \times CT$ (Figure 2). Correlation coefficient r x/y was equal to 0.37. The corneal stiffness parameter at the first applanation increased with corneal thickness (CT).

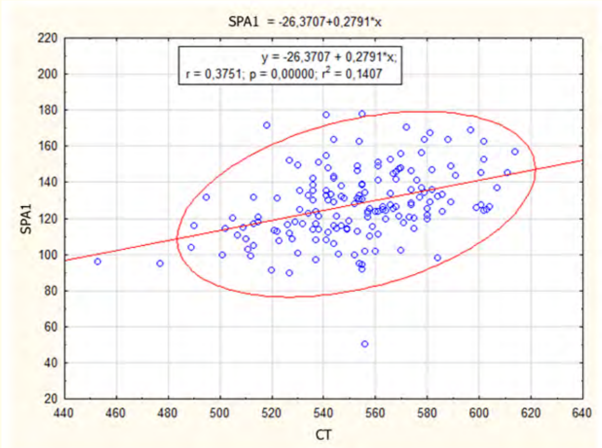

Figure 2: Correlation analysis of SPA_1 dependence on CT.

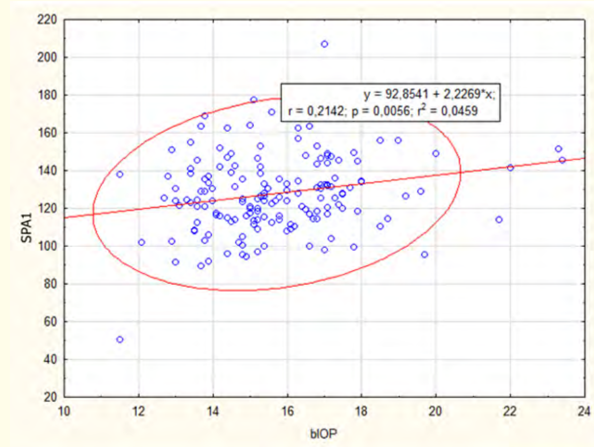

Figure 3: Correlation analysis of SPA_1 dependence on bIOP.

There was a direct correlation between the corneal stiffness parameter at the first applanation and the value of biomechanically compensated intraocular pressure (bIOP). The corneal stiffness parameter at the first applanation with the increase of IOP level: $SPA_1 = 92.85 + 2.23 \times bIOP$ (Figure 3).

The obtained results are in agreement with the literature data [9]. The correlation coefficient r x/y was 0.21; p = 0.005.

Based on multivariate regression analysis we established a correlation between the corneal stiffness parameter at the first applanation (SPA_1), central corneal thickness (CT) and biomechanically compensated IOP (bIOP), which was characterized by the formula:

$SPA_1 = -65.5108 + 0.2836 \times x + 2.3329 \times y$, where x is CT, mm, y is bIOP, mm Hg. Using the formula, we obtained a table for calculating the corneal stiffness parameter from the known values of CTR in 10 µm steps and bIOP in 1 mm Hg intervals (Table 3).

CT	bIOP												
	10,0	11,0	12,0	13,0	14,0	15,0	16,0	17,0	18,0	19,0	20,0	21,0	22,0
440	82,6	84,9	87,3	89,6	91,9	94,3	96,6	98,9	101,3	103,6	105,9	108,3	110,6
450	85,4	87,8	90,1	92,4	94,8	97,1	99,4	101,8	104,1	106,4	108,8	111,1	113,4
460	88,3	90,6	92,9	95,3	97,6	99,9	102,3	104,6	106,9	109,3	111,6	113,9	116,3
470	91,1	93,4	95,8	98,1	100,4	102,8	105,1	107,4	109,8	112,1	114,4	116,8	119,1
480	93,9	96,3	98,6	100,9	103,3	105,6	107,9	110,3	112,6	114,9	117,3	119,6	121,9
490	96,8	99,1	101,4	103,8	106,1	108,4	110,8	113,1	115,4	117,8	120,1	122,4	124,8
500	99,6	102,0	104,3	106,6	109,0	111,3	113,6	115,9	118,3	120,6	122,9	125,3	127,6
510	102,5	104,8	107,1	109,5	111,8	114,1	116,5	118,8	121,1	123,5	125,8	128,1	130,4
520	105,3	107,6	110,0	112,3	114,6	117,0	119,3	121,6	124,0	126,3	128,6	131,0	133,3
530	108,1	110,5	112,8	115,1	117,5	119,8	122,1	124,5	126,8	129,1	131,5	133,8	136,1
540	111,0	113,3	115,6	118,0	120,3	122,6	125,0	127,3	129,6	132,0	134,3	136,6	139,0
550	113,8	116,1	118,5	120,8	123,1	125,5	127,8	130,1	132,5	134,8	137,1	139,5	141,8
560	116,6	119,0	121,3	123,6	126,0	128,3	130,6	133,0	135,3	137,6	140,0	142,3	144,6

570	119,5	121,8	124,1	126,5	128,8	131,1	133,5	135,8	138,1	140,5	142,8	145,1	147,5
580	122,3	124,6	127,0	129,3	131,6	134,0	136,3	138,6	141,0	143,3	145,6	148,0	150,3
590	125,1	127,5	129,8	132,1	134,5	136,8	139,1	141,5	143,8	146,1	148,5	150,8	153,1
600	128,0	130,3	132,6	135,0	137,3	139,6	142,0	144,3	146,6	149,0	151,3	153,6	156,0
610	130,8	133,1	135,5	137,8	140,1	142,5	144,8	147,1	149,5	151,8	154,1	156,5	158,8
620	133,7	136,0	138,3	140,6	143,0	145,3	147,6	150,0	152,3	154,6	157,0	159,3	161,6
630	136,5	138,8	141,2	143,5	145,8	148,2	150,5	152,8	155,2	157,5	159,8	162,1	164,5
640	139,3	141,7	144,0	146,3	148,7	151,0	153,3	155,7	158,0	160,3	162,7	165,0	167,3

Table 3: Table of Corneal SPA_1 Calculation in Healthy Patients with CT and bIOP.

Studies of corneal stiffness in healthy individuals will be continued and verified for further comparative analysis with patients with keratoconus, a dystrophic corneal disease characterized by decreased visual acuity due to deformation and decreased corneal stiffness.

Conclusion

Reliable direct dependence of the corneal stiffness parameter, first of all, on the thickness of cornea in the central optical zone (p = 0,0000) and on the level of biomechanically compensated intraocular pressure (p = 0,0056), and also reliable inverse dependence on keratometry (p = 0,0465) were registered in healthy persons. The table on determination of corneal stiffness in healthy subjects depending on its thickness, keratometry values and the level of biomechanically compensated intraocular pressure will allow in practical work to make a quick comparative analysis with the results of keratoconus patients.

Conflict of Interest

There is no conflict of interest.

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