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Original Article

Corneal biomechanical properties in myopic anisometropia measured by corneal visualization scheimpflug technology

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Abstract: Objective: To explore corneal biomechanical properties in patients with myopic anisometropia using a corneal visualization scheimpflug technology (Corvis ST). Methods: We examined 102 eyes from 51 adults with anisometropia (minimum spherical equivalent (SE) of 2.50 D). Patients were classified into two groups based on their SE: high myopia (SE ≥ -6.00 D) (n=52 eyes) and non-high myopia group (SE ≤ -6.00 D) (n=50 eyes). Corneal biomechanical and ocular biometric parameters were measured. Results: In the high myopia group, axial length (AL), anterior chamber depth (ACD), and central corneal thickness (CCT) were significantly higher compared to the non-high myopia group (all $P < 0.001$). The second applanation time (A2-time), length of flattened cornea at second applanation (A2-length), and time to highest concavity (HC-time) were shorter in the high myopia group (all $P < 0.001$). The high myopia group also exhibited lower elasticity and rigidity indices, higher EAI (all $P < 0.001$), and greater central/mid-peripheral deformation amplitudes (both $P < 0.001$), with minimal peripheral differences ($P=0.074$). Conclusion: CorVis ST provides a reliable method for measuring corneal biomechanical properties. In anisometropia, eyes with higher myopia show higher deformation amplitude, faster A2-velocity, shorter A2-time and HC-time, and reduced A2-length.

Keywords: Corneal biomechanical properties, myopic anisometropia, Corvis ST

Introduction

Myopia is increasingly recognized as a major global public health issue, with prevalence rates reaching 80-90% among young adults in certain regions of East and Southeast Asia [1, 2]. Approximately 20% of these individuals are affected by high myopia [3]. Projections by Lee et al. [4] suggest that by 2050, nearly 5 billion people will be affected by myopia, and 1 billion by high myopia worldwide. Recent studies indicate that refractive errors are the second leading cause of visual impairment globally [4, 5]. High myopia often leads to severe ocular conditions, such as macular holes, retinal detachment, maculopathy, and glaucoma, all of which can significantly impair quality of life [6]. A deeper understanding of the risk factors, pathophysiology, and mechanisms underlying myopia is essential for its effective management and prevention.

Studies suggest that myopia may be closely associated with scleral thinning and biomechanical degradation of the sclera [7-10]. Given that the corneal stroma, composed of collagenous tissues similar to those in the sclera, may undergo similar biomechanical changes, it becomes a focal point for exploring whether such changes also occur in the cornea [11]. This issue has been widely discussed and studied in contemporary ophthalmology. Modjtahedi et al. [3] and Ma et al. [12] observed that eyes with high myopia exhibit higher deformation amplitude (DA) and faster outward applanation velocity (A2-velocity), suggesting that these eyes are more deformable and mechanically weaker.

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Currently, most research on corneal biomechanics is conducted using the ocular response analyzer (ORA) [13]. The ORA provides quantitative data and parameters to assess corneal biomechanical properties accurately, offering a more detailed understanding of the corneal condition [14]. However, there are some limitations. For instance, measurement results may be influenced by factors such as patient cooperation and eye conditions, potentially leading to inaccuracies [15]. Moreover, interpreting the obtained data often requires specialized knowledge and experience, which may pose challenges in fully understanding and analyzing all aspects. Corneal visualization Scheimpflug technology (Corvis ST) provides additional measurement parameters for the visual assessment of the cornea [16]. It captures the entire process of corneal deformation and offers various parameters, including those at the first applanation, maximum indentation, and second applanation. Furthermore, as research on Corvis ST progresses, new parameters have been developed, and these are often consistent and repeatable [17]. However, there are still relatively few studies using Corvis ST to evaluate the biomechanical characteristics of the cornea.

In this study, we applied Corvis ST to observe the corneal biomechanics of myopic anisometropic patients and analyzed its characteristics and influencing factors, providing a reference for the overall evaluation of myopic anisometropic patients.

Materials and methods

Case selection

This research was conducted in compliance with the Declaration of Helsinki. It involved 102 eyes from 51 adult patients with myopic anisometropia (interocular spherical equivalent (SE) difference ≥ 2.50 D), admitted to The Sixth Affiliated Hospital of Wenzhou Medical University (People's Hospital of Lishui), Lishui, China, between January 2021 and June 2023. All participants signed an informed consent form, and the study was approved by the institutional review board of The Sixth Affiliated Hospital of Wenzhou Medical University (People's Hospital of Lishui). Patients with myopic anisometropia (anisometropia greater than 2.5 D) were consecutively enrolled, and the participants' eyes were categorized into two groups: high myopia group (SE ≥ -6.00 D) (n=52 eyes) and non-high myopia group (SE ≤ -6.00 D) (n=50 eyes).

Inclusion criteria: (1) Age range from 18 to 57 years old. (2) Diagnosis of myopia. (3) Complete clinical data.

Exclusion criteria: (1) Presence of keratoconus, corneal inflammation, glaucoma, retinal lesions, or other ocular diseases that may affect corneal biomechanics or interfere with the research results. (2) History of corneal refractive surgery, corneal transplantation, or any procedure that could alter the corneal characteristics. (3) History of systemic diseases such as diabetes, hyperthyroidism, or hypertension. (4) Recent ocular trauma that may affect corneal stability. (5) Inability to complete the CorVis Scheimpflug technology measurement due to mental or cognitive issues. (6) Recent use of soft or hard contact lenses without sufficient discontinuation time, which could affect the corneal measurements.

CorVis scheimpflug technology

All participants underwent a comprehensive ocular assessment, which included slit-lamp microscopy, subjective refraction, fundus exams, and keratometry via the Topographic Modeling System (TMS-4, TOMEY, Nagoya, Japan), Lenstar LS900 (Haag-Streit AG, Koeniz, Switzerland), and Corvis ST (Oculus, Wetzlar, Germany). The Lenstar LS900 collected optical measurements, including central corneal thickness (CCT), anterior chamber depth (ACD), and axial length (AL). To minimize measurement bias, initial evaluations were conducted using TMS-4 and Lenstar LS900, followed by Corvis ST, which uses an air puff that could potentially introduce errors in corneal evaluation. Measurements started with the right eye, followed by the left, and were carried out by experienced technicians between 9:00 AM and 5:00 PM. To ensure accuracy of corneal biomechanical properties, a 5-minute interval was maintained between Corvis ST measurements, with each data output promptly verified. Statistical analysis used the average of three high-quality measurements. Corneal biomechanical parameters were assessed using dynamic Scheimpflug imaging (Corvis ST), which captures corneal deformation at 4330 fps via an air puff pulse.

To evaluate the corneal biomechanical differences between the high myopia and non-high myopia groups, elasticity and rigidity indices were calculated based on Corvis ST parameters. The elasticity index (EI), rigidity index (RI), and energy absorption index (EAI) were derived to assess the structural integrity, resistance to deformation, and energy absorption capacity of the cornea, respectively. These indices provide a comprehensive understanding of the biomechanical properties under dynamic loading conditions. Additionally, regional corneal DA were analyzed at three distinct locations: the central cornea, 3 mm from the corneal apex (mid-peripheral region), and 6 mm from the corneal apex (peripheral region). These measurements were performed using Corvis ST to capture localized variations in corneal biomechanical behavior, with a focus on central stiffness and peripheral elasticity.

Observation outcomes

Ten biomechanical parameters were measured, including corneal velocity at the first and second applanation (A1-velocity and A2-velocity), time at the first and second applanation (A1-time and A2-time), length of flattened cornea at the first and second applanation (A1-length and A2-length), time from start to the highest concavity (HC-time), distance between the two peaks of the cornea at the highest concavity (PD), radius of curvature at the highest concavity (HC radius), spherical equivalent (SE), AL, ACD, CCT, corneal curvature, and DA. Intraocular pressure (IOP) was also measured using Corvis ST.

SE: The value obtained by converting astigmatism into the equivalent spherical lens degree and adding it to the spherical lens degree, used to reflect the refractive state of the eye.

AL: Refers to the length of the eye from front to back. It is crucial for evaluating myopia progression and the risk of myopia-related eye diseases. An overly long AL is typically associated with high myopia and its complications.

ACD: The distance from the corneal endothelium to the anterior surface of the lens. Abnormal ACD can affect aqueous humor circulation and is associated with diseases such as glaucoma. It is also important for assessing and performing eye surgeries, such as cataract surgery.

CCT: Reflects the thickness of the central cornea. It plays a key role in preoperative corneal refractive surgery assessment and in diagnosing corneal diseases. Both excessively thin and thick corneas may indicate specific problems.

Corneal curvature: The horizontal and vertical curvatures of the cornea, used to describe its degree of curvature. This is critical for optometry, glasses fitting, diagnosing corneal diseases, and assessing the shape and regularity of the cornea.

IOP: The pressure exerted by ocular contents on the ocular wall. Normal IOP is essential for maintaining the eye's normal shape and function. Both abnormally elevated (as in glaucoma) and reduced IOP can lead to eye diseases.

Statistical analysis

Statistical analyses were performed using SPSS version 17.0. Data were presented as mean ± standard deviation. Normality was assessed using the Kolmogorov-Smirnov test. Differences between more myopic and their less myopic counterparts were assessed using paired t-tests. The relationships between corneal biomechanical properties and ocular characteristics were explored through stepwise multivariable linear regression.

Results

Comparison of biomechanical parameters between the two groups

The non - high myopia group had significantly higher SE, shorter AL, shallower ACD, and thinner CCT than the high myopia group (all $P < 0.001$). However, steepest keratometry (Ks), flattest keratometry (Kf), and IOP did not show significant differences (all $P > 0.05$) (**Table 1**).

Comparison of biomechanical parameters obtained by CorVis ST between the two groups

The non-high myopia group had significantly longer A2-time, longer A2-length, faster A2-velocity, longer HC-time, and lower DA than the high myopia group (all $P < 0.001$). However,

Table 1. Comparison of biomechanical parameters between the two groups

Parameters	High myopia group (n=52 eyes)	Non-high myopia group (n=50 eyes)	*p*
SE	-9.23 ± 2.39	-3.94 ± 1.41	0.000
Kf	43.46 ± 1.36	43.36 ± 1.44	0.268
Ks	44.21 ± 1.26	44.06 ± 1.36	0.073
CCT	542.65 ± 24.43	558 ± 22.77	0.000
ACD	3.61 ± 0.19	3.32 ± 0.20	0.000
AL	26.96 ± 1.04	24.86 ± 0.75	0.000
IOP	14.78 ± 1.94	14.59 ± 2.18	0.538

SE: spherical equivalent; Kf: flattest keratometry; Ks: steepest keratometry; CCT: central corneal thickness; ACD: anterior chamber Depth; AL: axial length; IOP: intraocular pressure.

Table 2. Comparison of biomechanical parameters obtained by CorVis ST between the two groups

Parameters	High myopia group (n=52 eyes)	Non-high myopia group (n=50 eyes)	P
A1-time (m/s)	7.19 ± 0.25	7.18 ± 0.20	0.817
A1-length (mm)	1.76 ± 0.07	1.75 ± 0.08	0.271
A1-velocity (m/s)	0.15 ± 0.03	0.15 ± 0.01	0.34
A2-time (m/s)	21.43 ± 0.37	21.96 ± 0.48	0.000
A2-length (mm)	1.56 ± 0.21	1.74 ± 0.26	0.000
A2-velocity (m/s)	-0.43 ± 0.08	-0.35 ± 0.07	0.000
HC-time (m/s)	16.66 ± 0.34	16.94 ± 0.31	0.000
PD (mm)	4.50 ± 0.52	4.53 ± 0.31	0.719
HC radius (mm)	7.00 ± 0.63	6.79 ± 0.62	0.056
DA (mm)	1.20 ± 0.09	1.12 ± 0.08	0.000

A1-time and A2-time: time at the first and second applanation; A1-velocity and A2-velocity: velocity at the first and second applanation; A1-length and A2-length: length of flattened cornea at the first and second applanation; HC-time: time from start to the highest concavity; PD: distance between the two peaks of the cornea at highest concavity; HC radius: radius curvature at highest concavity; DA: deformation amplitude.

there were no significant differences in A1-time, A1-length, A1-velocity, PD, and HC radius between the groups (all P > 0.05) (**Table 2**).

Factors associated with corneal parameters with Stepwise multivariate regression model

Multivariate regression analysis revealed that DA was positively associated with AL. A2-velocity was faster in more myopic eyes (vs. contralateral), positively correlated with SE (P < 0.01). A2-time was shorter, positively correlated with SE, but negatively with IOP. A2-length was shorter in more myopic eyes, positively correlated with SE. HC-time was shorter in more myopic eyes (vs. contralateral), positively correlated with SE (**Table 3**).

Factors associated with Δcorneal parameters: Stepwise multivariate regression model

ΔA1-time and ΔA2-velocity were positively correlated with IOP, while ΔA2-time and ΔDA were negatively with IOP. ΔA2-velocity was positively associated with ΔKf. ΔHC-time was negatively correlated with Ks (**Table 4**).

Comparison of elasticity and rigidity indices between the two groups

The high myopia group demonstrated a significantly lower elasticity index compared to the non-high myopia group (P < 0.001). The rigidity index, which represents the cornea's resistance to deformation, was also significantly lower in the high myopia group (P < 0.001). Furthermore, the energy absorption index, which reflects the cornea's ability to absorb energy during deformation, was significantly higher in the high myopia group (P < 0.001), indicating increased deformation under dynamic loading. See **Table 5**.

Comparison of regional analysis of corneal deformation between the two groups

The central DA was significantly greater in the high myopia group (P < 0.001). Peripheral DA at 3 mm from the apex was also higher in the high myopia group (P < 0.001), indicating more pronounced biomechanical weakening in the mid-periphery. At 6 mm from the apex, the difference in DA between groups was less pronounced (P=0.074), suggesting that peripheral

Table 3. Factors associated with corneal parameters with Stepwise multivariate regression model

Parameters	Age		Kf		Ks		SE		AL		IOP		CCT		ACD	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
A1-time (m/s)	0.159	0.087	0.138	0.148	0.116	0.226	0.037	0.691	-0.115	0.217	0.040	0.000	0.066	0.482	-0.028	0.771
A1-length (mm)	0.070	0.474	0.012	0.026	-0.261	0.216	-0.191	0.052	0.180	0.065	0.065	0.517	-0.054	0.587	0.146	0.136
A1-velocity (m/s)	0.000	0.529	0.003	0.191	-0.003	0.167	-0.001	0.551	-0.002	0.428	0.000	0.562	0.000	0.287	0.001	0.922
A2-time (m/s)	0.101	0.258	0.032	0.726	0.020	0.830	0.064	0.000	0.319	0.078	-0.052	0.021	0.077	0.414	0.045	0.084
A2-length (mm)	-0.024	0.791	-0.039	0.675	-0.052	0.572	0.031	0.000	-0.007	0.969	0.022	0.048	0.014	0.884	-0.025	0.823
A2-velocity (m/s)	0.140	0.101	0.096	0.264	0.082	0.341	0.014	0.000	-0.044	0.801	0.137	0.108	0.050	0.577	-0.033	0.745
HC-time (m/s)	0.124	0.186	0.053	0.572	0.085	0.364	0.040	0.000	0.088	0.643	-0.001	0.995	0.095	0.327	0.015	0.891
PD (mm)	-0.005	0.238	0.064	0.356	-0.019	0.806	-0.005	0.865	-0.026	0.713	-0.011	0.620	0.001	0.491	0.084	0.707
HC-radius (mm)	-0.017	0.002	-0.003	0.989	-0.109	0.017	-0.035	0.05	-0.025	0.900	0.113	0.233	0.082	0.411	0.090	0.420
DA (mm)	0.048	0.594	-0.023	0.800	-0.053	0.555	-0.067	0.714	0.032	0.000	-0.078	0.389	-0.005	0.958	-0.048	0.655

A stepwise multivariable linear regression analysis was employed to examine the associations between corneal biomechanical properties and various ocular characteristics, setting a significance threshold of $P < 0.05$ for all tests.

Table 4. Factors associated with Δcorneal parameters with Stepwise multivariate regression model

ΔParameters	ΔKf		ΔKs		ΔSE		ΔAL		ΔIOP	
	r	p	r	p	r	p	r	p	r	p
ΔA1-time (m/s)	-0.001	0.990	0.111	0.169	0.027	0.391	0.032	0.637	0.057	0.03
ΔA1-length (mm)	0.050	0.098	-0.028	0.343	0.016	0.165	0.023	0.365	0.007	0.355
ΔA1-velocity (m/s)	0.006	0.288	-0.001	0.846	-0.002	0.299	-0.001	0.835	0.000	0.789
ΔA2-time (m/s)	-0.085	0.580	0.126	0.406	0.003	0.953	0.102	0.426	-0.074	0.033
ΔA2-length (mm)	-0.126	0.133	0.104	0.212	-0.018	0.575	-0.064	0.356	0.003	0.886
ΔA2-velocity (m/s)	0.057	0.016	-0.038	0.164	0.018	0.093	0.013	0.569	0.025	0.000
ΔHC-time (m/s)	-0.008	0.952	-0.222	0.038	-0.040	0.420	-0.153	0.145	-0.030	0.350
ΔPD (mm)	0.292	0.078	-0.208	0.201	-0.003	0.958	-0.064	0.638	-0.020	0.636
ΔHC-radius (mm)	0.064	0.782	0.014	0.544	0.118	0.200	0.276	0.159	0.037	0.534
ΔDA (mm)	0.017	0.635	0.021	0.555	0.004	0.788	0.019	0.525	-0.016	0.044

A stepwise multivariable linear regression analysis was employed to examine the associations between Δcorneal biomechanical properties and Δocular characteristics, setting a significance threshold of $P < 0.05$ for all tests.

Table 5. Comparison of elasticity and rigidity indices between the two groups

	High myopia group (n=52 eyes)	Non-high myopia group (n=50 eyes)	t	*P*
Elasticity Index	0.32 ± 0.05	0.40 ± 0.04	8.256	0.000
Rigidity Index	0.18 ± 0.03	0.25 ± 0.04	10.435	0.000
Energy Absorption Index	0.92 ± 0.07	0.85 ± 0.06	9.844	0.000

Table 6. Comparison of regional analysis of corneal deformation between the two groups

	High myopia group (n=52 eyes)	Non-high myopia group (n=50 eyes)	t	*P*
Central Deformation (mm)	1.20 ± 0.09	1.12 ± 0.08	6.256	0.000
Peripheral Deformation Amplitude (3 mm)	0.68 ± 0.05	0.62 ± 0.04	7.435	0.000
Peripheral Deformation Amplitude (6 mm)	0.34 ± 0.03	0.32 ± 0.02	1.844	0.074

regions may retain some degree of biomechanical integrity in myopic anisometropia. See **Table 6**.

Discussion

The cornea exhibits viscoelastic properties, and understanding its biomechanical characteristics is increasingly important in modern ophthalmology. This knowledge supports the diagnosis, management, and treatment of various ocular conditions, including corneal refractive surgery, glaucoma, corneal pathologies, and refractive errors [12, 18]. Previous studies across different populations have suggested potential impairment in corneal biomechanical integrity in individuals with myopia [19, 20]. Our study introduces a novel approach to comparing biomechanical differences in the corneas of fellow eyes in Chinese individuals with myopic anisometropia, offering a unique advantage by eliminating confounding variables.

In terms of the anterior segment, our study found that corneal thickness was reduced in the more myopic eyes. This contrasts with the findings of Liu et al. [21], who did not report changes in CCT associated with high myopia. However, Liu et al. [22] observed that, during myopia progression, corneal thickness decreases, corneal curvature flattens, and the number of endothelial cells diminishes. Xu et al. [23] also found that in anisometropia, the more myopic eyes exhibited reduced astigmatism and thinner corneas compared to the contralateral eyes.

Deformation amplitude (DA) is a critical measure of corneal biomechanics, reflecting its ability to withstand air pressure. Higher DA values indicate a softer, more deformable cornea [24-26]. Our results showed that DA was higher in the more myopic eyes, suggesting greater deformability even when genetic and environmental factors were controlled. Furthermore, in the multivariate analysis, DA showed a positive correlation with AL. The difference in AL between the two eyes is a key factor in anisometropia [27]. Corneas with longer AL were found to be less rigid, consistent with previous findings [3, 12, 28, 29]. In the context of myopic anisometropia, Liu et al. [21] observed significant decreases in corneal hysteresis in the more myopic eyes compared to the less myopic one. However, another study found no significant differences in ocular parameters between eyes with myopic anisometropia, except for AL [30, 31].

Clinically, a deeper understanding of corneal biomechanics is crucial for optimizing preoperative evaluations and surgical strategies to minimize the risk of postoperative ectasia. Additionally, recognizing a higher DA as an indicator of increased AL elongation may inform preventive measures.

A2-velocity and A2-length are reliable measures of corneal elasticity [3, 28]. Our study aligns with previous research [3, 32], showing an increased A2-velocity in the more myopic eyes, indicating that these corneas tend to be softer and more pliable. However, this finding contradicts the results of Wang et al. [28], who observed no differences in A2-velocity across groups. Additionally, our data revealed that the more myopic eyes had a reduced A2-length compared to the less myopic eyes. In multivariate regression analysis, both A2-velocity and A2-length showed positive associations with SE. Similar findings have been reported, with both A2-velocity and A2-time positively correlated with SE [12]. We also noted that A2-time was significantly shorter in the more myopic group, suggesting another aspect of corneal viscoelasticity [33]. Furthermore, HC-time was reduced in the more myopic eyes and showed a positive correlation with SE. Our results are consistent with prior studies [12], indicating that a higher DA, which reflects reduced corneal stiffness, is associated with longer AL. Our findings suggest a significant relationship between Δcorneal biomechanical properties and Δocular characteristics, supported by Ali et al. [34].

Axial growth is a well-known driver of progressive myopia. During myopia progression, structural changes include decreased extracellular matrix production and reduced synthesis of proteoglycans and glycosaminoglycans [7, 8, 33, 35]. These changes contribute to the increased deformability of the cornea under mechanical stress. Given that the cornea contains similar collagen types to the sclera [8], the reduction in corneal biomechanics observed in myopia may be linked to remodeling of corneal collagen fibers [36, 37]. Our study provides valuable insights into corneal biomechanics for myopia screening and potential interventions. If a softer cornea is associated with an elevated risk for myopia, proactive measures may be necessary to manage its progression. A deeper understanding of these biomechanical properties is also essential for optimizing corneal refractive surgeries.

Our study has some limitations, including its cross-sectional design and limited sample size. We cannot definitively determine whether the variations in corneal biomechanics are a cause or effect of myopic progression. Furthermore, the absence of non-myopic controls is a limitation. Therefore, further longitudinal research is needed to explore the causal relationships between myopia development and corneal biomechanical dynamics.

In conclusion, our results show that in anisometropia, the more myopic eyes exhibit higher DA, faster A2-velocity, shorter A2-time and HC-time, and reduced A2-length. CorVis ST offers an alternative method for measuring corneal biomechanical properties. These findings suggest that the corneas in more myopic eyes are more pliable and deform more easily under mechanical stress. Further studies with larger cohorts are needed to confirm the impact of corneal biomechanical properties on myopia.

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Disclosure of conflict of interest

None.

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