• Clinical Research •

Correlation between corneal biomechanical and tomographic parameters in cataract patients

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Abstract
● **AIM:** To investigate the relationship between preoperative corneal biomechanical properties and corneal tomographic properties in cataract patients.
● **METHODS:** The study consisted of 59 eyes of 30 participants who were diagnosed as cataract in Peking University Third Hospital between September 2019 and November 2019. Stepwise multivariable linear regression analysis was calculated to determine the relationship between corneal biomechanical parameters and tomographic parameters. The patients were classified into three groups of with the rule (WTR) astigmatism, against the rule astigmatism and oblique astigmatism. And the differences in corneal parameters among different groups were compared.
● **RESULTS:** There were significant differences in the first applanation time (A1T), the first applanation length (A1L), corneal velocity during the first applanation (Vin), the second applanation time (A2T), highest concavity (HC) radius, displacement amount (DA), DA ratio, stiffness parameter A1 (SPA1) and integrated radius (IR) between oblique astigmatism patients and the other two groups. Total corneal steep meridian (K2) was negatively associated with A1L, A1T and corneal velocity during the second applanation (Vout). Patients with higher anterior corneal curvature had lower HC radius and central corneal thickness (CCT; P=0.001 and 0.006, respectively), while the Ambrosio relational thickness to the horizontal profile (ARTh) was higher than those with lower anterior corneal curvature (P=0.009).
● **CONCLUSION:** The study reveals that the elasticity of corneal collagen fibers is greater, but the viscoelasticity of cornea is smaller in patients with oblique astigmatism. There is no significant difference in ARTh between patients with different types of astigmatism, that is, the corneal biomechanical specificity of oblique astigmatism group is probably not caused by corneal thickness. Moreover, we find patients with higher anterior corneal curvature has lower HC radius and CCT but higher ARTh than those with lower anterior corneal curvature.
● **KEYWORDS:** corneal biomechanical parameters; corneal tomography; cataract
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INTRODUCTION
The cornea, a biological soft tissue material with a complex biomechanical structure, has a specific thickness and surface tension. The biomechanical characteristics of the cornea are very complex which focus on the deformation and balance process of the cornea under external force. The examination of corneal biomechanical parameters is an essential means for the diagnosis and treatment of various ocular diseases. The Corneal Visualization Scheimpflug Technology (Corvis ST, Oculus, Wetzlar, Germany) was introduced as a new non-contact tonometer system with a high-speed Scheimpflug camera. The Corvis ST monitors the whole process of corneal deformation during a constant-pressure air puff *in vivo*, captures a series of horizontal images of the corneal and analyzes corneal biomechanics based on the real-time data[1-2]. *In vivo* measurement of corneal biomechanics is of significant importance in clinical evaluation and has been used in keratoconus[3], corneal surgery[4], corneal cross-linking[5], glaucoma[6], *etc*.

Corneal tomography is used to characterize the shape and features of the cornea. Traditional corneal topography could only map a large part of the anterior corneal surface instead of a complete pachymetric evaluation[7]. With the advancement of ophthalmic examination technology and the development of related research, the significance of corneal posterior surface astigmatism has been gradually recognized and widely accepted. Previous studies have reported that corneal posterior surface astigmatism is also an essential factor to be considered in astigmatism correction surgery and intraocular lens implantation, and its impact on total corneal astigmatism could reach an average of 0.3 to 0.8 D[8-9]. Corneal tomography, specifically, could obtain information from both anterior and posterior corneal surfaces, reconstruct three-dimensional images of the anterior segment, assess the whole cornea and detect microstructure changes in the cornea.

Cataract is one of the most common causes of worldwide visual impairment and vision loss[10]. With the development of cataract diagnosis and treatment entering the era of refraction, the goal of cataract surgery has gradually changed to refractive correction, and the position of precise preoperative ocular refractive examination has gradually improved[11]. Additionally, with the development of cataract surgery into micro-incision phacoemulsification surgery, surgically induced corneal changes after cataract surgery have gained more and more attention. Some previous studies have reported that the preoperative corneal elastic properties are correlated with the refractive results of corneal optical quality after cataract surgery. Denoyer *et al*[12] found that surgical-derived astigmatism was associated with preoperative corneal hysteresis. Additionally, as a critical step during the phacoemulsification surgery, the quality of watertight corneal incision could be affected by the weak and deformable corneas[13].

The purpose of this study was to investigate the relationship between preoperative corneal biomechanical properties and corneal tomographic properties in cataract patients and further study the relationship between corneal morphology and function.

PARTICIPANTS AND METHODS

Ethical Approval The research was approved by the Ethics Committee of the Peking University Third Hospital Review Board (M2022809). Informed consent was written by each participant.

The study consisted of 59 eyes of 30 participants who were diagnosed with cataract at Peking University Third Hospital between September 2019 and November 2019. All examination dates were collected during preoperative examinations. Inclusion criteria were age-related cataract patients aged 60 years or older, with best corrected visual acuity of 20/40 or above, scheduled to undergo cataract surgery, normal fundus examination findings of the optic disc and retinal nerve fibre layer, normal visual fields, and exclusion of other types of cataract such as metabolic, comorbid, and pharmacological cataract. Exclusion criteria included any history of ocular surgery, ocular trauma or ocular disease (*e.g.*, glaucoma, uveitis and myopia), systemic disease (*e.g.*, diabetes, hypertension, and coagulopathy), wearing soft contact lenses within 2wk or rigid gas permeable lenses within 4wk.

Each patient underwent a comprehensive ocular examination. The following parameters were recorded: central corneal thickness (CCT), anterior chamber depth (ACD), corneal volume (CV), intraocular pressure measured by non-contact tonometer (IOPnct), biomechanical-corrected IOP (bIOP), white to white (WTW), tear meniscus height (TMH) and tear film break up time (BUT). Scheimpflug-based corneal tomography was performed using the Pentacam HR, and the Corvis ST was used to assess corneal biomechanical parameters. Both measurements were performed under the same light condition by experienced examiners. And the biomechanical parameters concerned in this study included time from start to the first and second applanation (A1T and A2T), length of the flattened cornea at the first and second applanation (A1L and A2L), corneal velocity during the first and second applanation (Vin and Vout), time from start to the highest concavity (HC time), radius of curvature at the highest concavity (HC radius), the amount of corneal displacement at the highest degree of concavity (displacement amount, DA), distance between the two peaks of the cornea at the highest concavity (peaks distance, PD), stiffness parameter A1 (SPA1), integrated radius (IR), the Ambrosio relational thickness to the horizontal profile (ARTh), ratio of deformation amplitude at the corneal apex to deformation amplitude at points 2-mm peripheral to apex at highest concavity (DA ratio) and the Corvis biomechanical index (CBI).

Statistical Analysis Data were analyzed with IBM SPSS Statistic 25.0. The continuous variables were presented in the form of mean±standard deviation (SD). A one-way analysis of variance (ANOVA) was used to analyze the differences in corneal parameters among different groups. The Spearman correlation test was applied to analyses the correlation between parameters. Stepwise multivariable linear regression analysis was calculated to determine the relationship between corneal biomechanical and tomographic parameters. The correlation coefficients 0.00–0.19, 0.20–0.39, 0.40–0.59, 0.60–0.79, and 0.80–1.0 indicated a very weak correlation between the two variables, weak correlation, moderate correlation, strong correlation, and very strong correlation, respectively. A P-value of <0.05 was considered statistically significant.

RESULTS

The study included 59 cataract eyes (30 right eyes and 29 left eye) of 30 patients (14 males and 16 females), as only 1 female reported a unilateral cataract. The mean age of our participants was 72.3±14.0y (range 35 to 90y). The mean values of corneal morphological and biomechanical parameters are displayed in Table 1.

Comparison of Corneal Parameters in Different Anterior Corneal Astigmatism Groups According to types of anterior corneal astigmatism, the patients were classified into three groups with the rule (WTR) astigmatism (*n*=25), against the rule (ATR) astigmatism (*n*=23) and oblique astigmatism (*n*=11). Corneal biomechanical and morphological parameters in different groups were compared with the results shown in Figure 1. When comparing corneal parameters among the three groups, there were significant differences in IOPnct (*P*=0.020), A1T (*P*=0.026), Vin (*P*=0.007), A2T (*P*<0.001), PD (*P*=0.023), DA (*P*=0.021) and bIOP (*P*=0.038). Other parameters showed no statistically significant differences.

In multiple comparisons, IOPnct was higher in oblique astigmatism compared to WTR astigmatism and ATR astigmatism (*P*=0.008, *P*=0.016; Figure 1E). A1T in the oblique astigmatism group was significantly longer than both WTR astigmatism and ATR astigmatism patients (*P*=0.009, *P*=0.022; Figure 1F). In comparison, patients with oblique astigmatism had shorter A2T than the other two groups (*P*<0.001, *P*=0.003; Figure 1I). Vin in oblique astigmatism patients was significantly lower than in the other two groups (*P*=0.002, *P*=0.031; Figure 1H). There was a significant difference between oblique astigmatism and WTR astigmatism in A1L and PD (*P*=0.03; Figure 1G; *P*=0.006; Figure 1M). The difference in HC radius was significant between oblique astigmatism and ATR astigmatism (*P*=0.048; Figure 1N). DA in oblique astigmatism patients was significantly lower than in the other two groups (*P*=0.013, *P*=0.009; Figure 1O). Besides, SPA1 was significantly higher, and IR significantly lower, in oblique astigmatism than the other two groups (SPA1: *P*=0.028, *P*=0.005; Figure 1P; IR: *P*=0.005, *P*=0.009; Figure 1Q). DA ratio also differed significantly among groups with oblique astigmatism lower than WTR astigmatism and ATR astigmatism (*P*=0.022, *P*=0.005; Figure 1S). Also, bIOP was higher in oblique astigmatism compared to WTR astigmatism and ATR astigmatism (*P*=0.017, *P*=0.022; Figure 1U). There was a statistically significant difference in BUT between WTR astigmatism and ATR astigmatism (*P*=0.024; Figure 1W).

Comparison of Corneal Parameters in Different Posterior Corneal Astigmatism and Total Corneal Astigmatism Groups The patients were also classified into three groups according to types of posterior corneal astigmatism and total corneal astigmatism, respectively (Figures 2, 3). When comparing corneal parameters in different posterior corneal astigmatism groups, only SPA1 showed a statistically significant difference among groups with WTR astigmatism higher than ATR astigmatism and oblique astigmatism (*P*=0.007, *P*=0.012; Figure 2P).

Table 1 Baseline characteristics of the study

Parameters	Mean±SD	Range
CCT (μm)	548.42±22.878	502-600
CV (mL)	59.2030±3.4231	51.0-66.6
WTW (mm)	11.2360±0.4400	10.1-12.1
ACD (mm)	2.4337±0.4265	1.70-3.55
IOPnct (mm Hg)	15.6270±4.1174	9.00-27.50
A1T (ms)	7.0122±0.4126	6.40-8.23
A1L (mm)	2.2944±0.3624	1.22-2.90
Vin (m/s)	0.1559±0.0208	0.10-0.18
A2T (ms)	21.0929±0.5077	19.76-21.97
A2L (mm)	1.8919±0.3808	1.02-2.97
Vout (m/s)	-0.2920±0.0430	-0.42 to -0.20
HC time (ms)	16.5447±0.5959	15.02-18.25
PD (mm)	5.2781±0.3612	4.23-5.87
HC radius (mm)	6.9256±0.7911	5.42-8.67
DA (mm)	1.1995±0.1402	0.89-1.43
SPA1	116.0450±21.0379	72.7-157.0
IR (mm^{-1})	8.1590±1.0730	5.7-11.0
ARTh	577.2400±142.4976	369.3-962.6
DA ratio	3.9640±0.3638	3.2-4.7
CBI	0.0734±0.0784	0.00-0.37
bIOP (mm Hg)	13.5930±3.5561	7.40-23.50
TMH (mm)	0.0211±0.0674	0.09-0.43
BUT (s)	6.4132±4.3665	1.53-20.46

SD: Standard deviation; CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: Anterior chamber depth; IOPnct: Intraocular pressure measured by non-contact tonometer; bIOP: Biomechanical-corrected intraocular pressure; TMH: Tear meniscus height; BUT: Tear film break up time; A1T: The first applanation time; A2T: The second applanation time; A1L: The first applanation length; A2L: The second applanation length; Vin: Corneal velocity during the first applanation; Vout: Corneal velocity during the second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index.

While in different total corneal astigmatism groups, there was a tendency in the same direction with anterior corneal astigmatism groups in PD (ATR astigmatism <WTR astigmatism, *P*=0.016; Figure 3M) and BUT (ATR astigmatism <WTR astigmatism, *P*=0.042; Figure 3W). There was also a statistically significant difference in WTW between WTR astigmatism and oblique astigmatism (*P*=0.032; Figure 3C). Both A2T and IR were higher in WTR astigmatism compared to oblique astigmatism (*P*=0.042; Figure 3I; *P*=0.033; Figure 3Q). TMH in oblique astigmatism was significantly lower than in WTR astigmatism (*P*=0.009; Figure 3V).

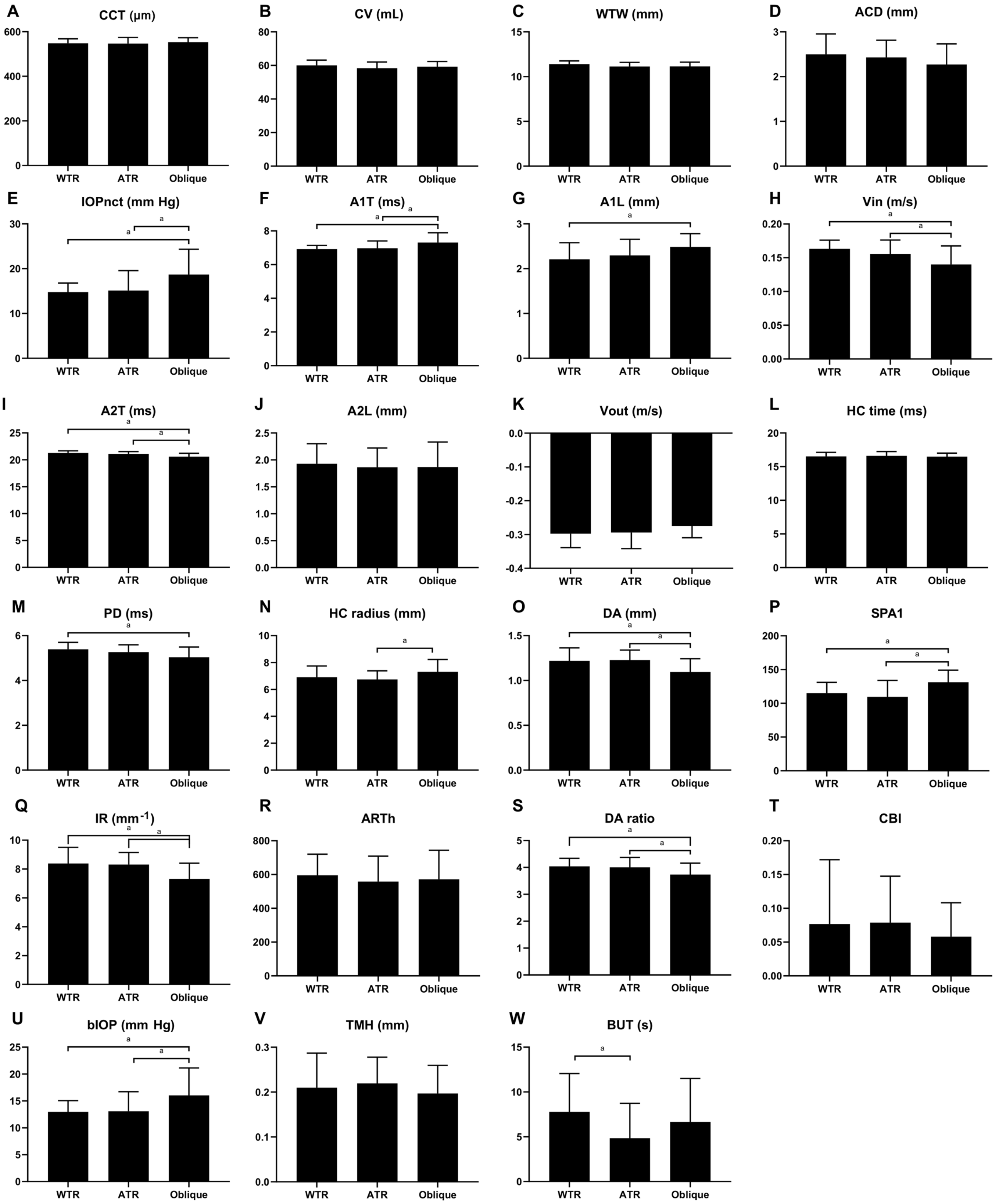

Figure 1 Comparison of corneal parameters in different anterior corneal astigmatism groups There was a statistically significant difference in IOPnct, A1T, A1L, Vin, A2T, PD, HC radius, DA, bIOP, SPA1, IR, DA ratio and BUT. CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: Anterior chamber depth; IOPnct: Intraocular pressure measured by non-contact tonometer; bIOP: Biomechanical-corrected IOP; TMH: Tear meniscus height; BUT: Tear film break up time; A1T: The first applanation time; A2T: The second applanation time; A1L: The first applanation length; A2L: The second applanation length; Vin: Corneal velocity during the first applanation; Vout: Corneal velocity during the second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index. [a]$P<0.05$.

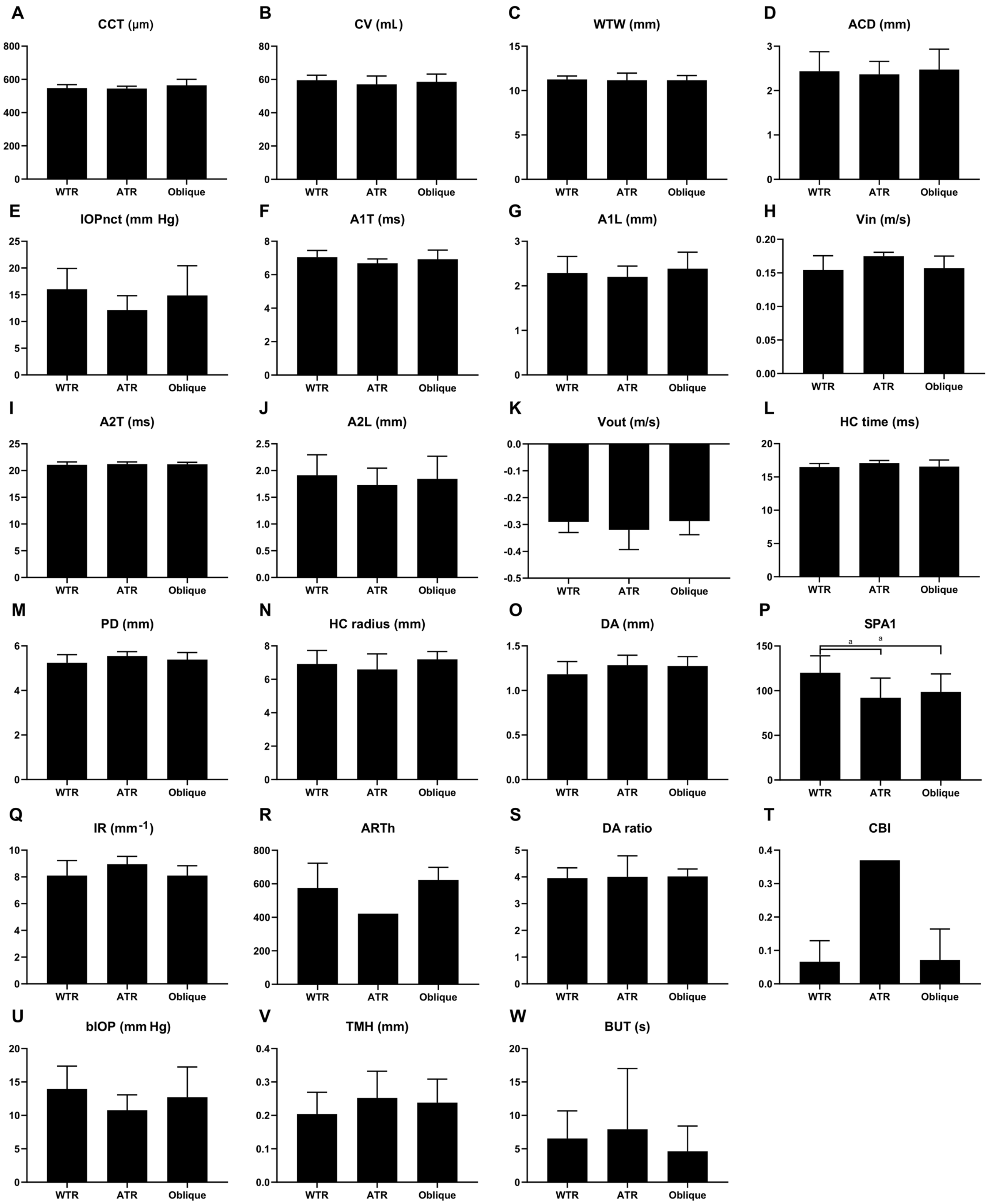

Figure 2 Comparison of corneal parameters in different posterior corneal astigmatism groups There was a statistically significant difference in SPA1. CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: Anterior chamber depth; IOPnct: Intraocular pressure measured by non-contact tonometer; bIOP: Biomechanical-corrected IOP; TMH: Tear meniscus height; BUT: Tear film break up time; A1T: The first applanation time; A2T: The second applanation time; A1L: The first applanation length; A2L: The second applanation length; Vin: Corneal velocity during the first applanation; Vout: Corneal velocity during the second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index. [a]P<0.05.

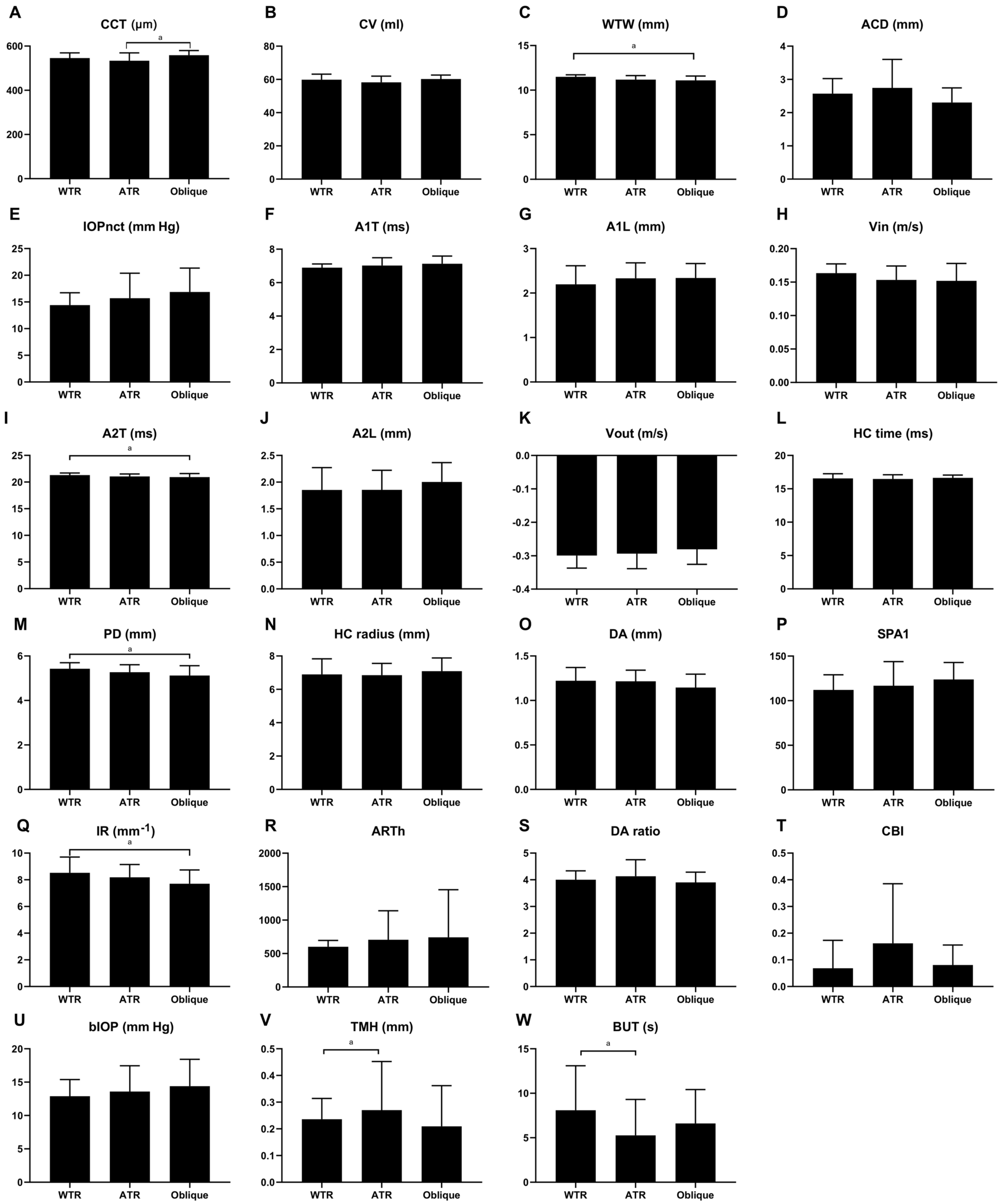

Figure 3 Comparison of corneal parameters in different total corneal astigmatism groups There was a statistically significant difference in A2T, PD, IR, BUT, CCT, TMH and WTW. CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: Anterior chamber depth; IOPnct: Intraocular pressure measured by non-contact tonometer; bIOP: Biomechanical-corrected IOP; TMH: Tear meniscus height; BUT: Tear film break up time; A1T: The first applanation time; A2T: The second applanation time; A1L: The first applanation length; A2L: The second applanation length; Vin: Corneal velocity during the first applanation; Vout: Corneal velocity during the second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index. [a]$P<0.05$.

Correlation Analysis Between Corneal Parameters and Corneal Curvature Spearman correlation analysis was conducted for relations among different variables (Table 2). The patients' A2T, PD, DA, IR and DA ratio were positively correlated with age (*r*=0.283, *P*=0.030; *r*=0.272, *P*=0.037; *r*=0.393, *P*=0.002; *r*=0.295, *P*=0.024; *r*=0.318, *P*=0.020;), and there was a negative correlation between age and A1T (*r*= -0.370, *P*=0.004). Anterior corneal curvature K1 was negatively correlated with HC radius, ARTh and TMH (*r*=-0.271, *P*=0.038; *r*=-0.382, *P*=0.005; *r*=-0.346, *P*=0.010), while the anterior corneal curvature K2 was positively correlated with CBI (*r*=0.309, *P*=0.034) and negatively correlated with HC radius and ARTh (*r*=-0.384, *P*=0.003; *r*=-0.466, *P*<0.001). Posterior corneal curvature K1 showed a positive correlation with HC radius, ARTh and TMH (*r*=0.282, *P*=0.030; *r*=0.516, *P*<0.001; *r*=0.330, *P*=0.014), but a negative correlation with CBI (*r*=-0.431, *P*=0.002). Posterior corneal curvature K2 showed a positive correlation with HC radius, ARTh, and TMH (*r*=0.409, *P*=0.001; *r*=0.510, *P*<0.001; *r*=0.276, *P*=0.042), but a negative correlation with IR and CBI (*r*= -0.263, *P*=0.044; *r*=-0.490, *P*<0.001). Total corneal curvature K1 showed a negative correlation with ARTh and TMH (*r*= -0.3.27, *P*=0.018; *r*=-0.332, *P*=0.013). Total corneal curvature K2 was positively correlated with HC time, DA and CBI (*r*=0.266, *P*=0.042; *r*=0.272, *P*=0.037; *r*=0.320, *P*=0.028), but negatively correlated with ARTh and HC radius (*r*=-0.460, *P*=0.001; *r*=-0.430, *P*=0.001). And bIOP showed a positive correlation with A1T, A1L, Vout and SPA1 (*r*=0.917, *P*<0.001; *r*=0.289, *P*=0.027; *r*=0.446, *P*<0.001; *r*=0.625, *P*<0.001), but a negative correlation with Vin, A2T, PD, DA, IR and DA ratio (*r*=-0.754, *P*<0.001; *r*=-0.789, *P*<0.001; *r*=-0.684, *P*<0.001; *r*=-0.669, *P*<0.001; *r*=-0.557, *P*<0.001; *r*=-0.654, *P*<0.001). CCT was positively correlated with A1T, Vout, and SPA1 (*r*=0.302, *P*=0.028; *r*=0.292, *P*=0.034; *r*=0.322, *P*=0.020), but negatively correlated with PD, DA and IR (*r*=-0.292, *P*=0.034; *r*=-0.347, *P*=0.011; *r*=-0.381, *P*=0.005). CV showed a positive correlation with A1T, A1L, A2L, Vout, HC radius and SPA1 (*r*=0.307, *P*=0.018; *r*=0.258, *P*=0.048; *r*=0.436, *P*=0.001; *r*=0.389, *P*=0.002; *r*=0.287, *P*=0.027; *r*=0.302, *P*=0.021), but a negative correlation with IR and PD (*r*=-0.366, *P*=0.004; *r*= -0.290, *P*=0.026). WTW showed a positive correlation with Vin, A2T, PD, DA and BUT (*r*=0.356, *P*=0.021; *r*=0.427, *P*=0.005; *r*=0.451, *P*=0.003; *r*=0.341, *P*=0.027; *r*=0.448, *P*=0.004), but a negative correlation with A1T and Vout (*r*= -0.501, *P*=0.001; *r*=-0.334, *P*=0.031). ACD was positively correlated with Vin, PD, DA and BUT (*r*=0.328, *P*=0.017; *r*=0.390, *P*=0.004; *r*=0.392, *P*=0.004; *r*=0.386, *P*=0.006), but negatively correlated with Vout and SPA1 (*r*=-0.442, *P*=0.001; *r*=-0.344, *P*=0.014).

Univariate Regression and Multivariate Regression Table 3 describes the coefficient (*β*) and *P* value for univariate linear regression analysis on the relationship of age, corneal curvature, bIOP, CCT, CV, WTW and ACD with corneal biomechanical parameters.

The multivariable regression analysis demonstrated that age was positively associated with A1T (*β*=0.164, *P*=0.001) and SPA1 (*β*=0.557, *P*=0.005) but negatively associated with Vin (*β*=0.-0.276, *P*=0.017) and IR (*β*=-0.394, *P*=0.048). Posterior K1 was negatively associated with Vin (*β*=-0.476, *P*=0.043). Posterior K2 was negatively associated with CBI (*β*=-0.785, *P*=0.010). Total K2 was negatively associated with A1L (*β*= -2.842, *P*=0.046). Additionally, bIOP were positively related to A1T (*β*=1.005, *P*<0.001), Vout (*β*=0.598, *P*=0.031) and SPA1 (*β*=1.007, *P*<0.001), while negatively related to Vin (*β*=-1.116, *P*<0.001), A2T (*β*=-0.775, *P*<0.001), PD (*β*=-0.571, *P*=0.003), DA (*β*=-0.609, *P*=0.022), IR (*β*=-1.137, *P*<0.001) and DA ratio (*β*=-1.125, *P*<0.001). WTW was positively associated with PD (*β*=0.332, *P*=0.033).

DISCUSSION

The cornea is located in the front 1/6 of the eyeball and has a large diopter, accounting for 70% of the total diopter of the whole eye. The cornea is a viscoelastic tissue with non-linear, anisotropic and other biomechanical properties. The biomechanical integrity and stability of its tissue structure are crucial for imaging[14]. The present study aimed to investigate the relationship between preoperative corneal biomechanical properties and corneal tomographic properties in cataract patients.

When grouped according to types of anterior corneal astigmatism, we found patients in the oblique astigmatism group had higher A1T, IOPnct, bIOP and SPA1 but lower Vin, A2T, DA and IR than WTR astigmatism and ATR astigmatism. A1L and HC radius in oblique astigmatism were higher compared to WTR astigmatism, while PD was lower than in WTR astigmatism. Besides, BUT was higher in WTR astigmatism compared to ATR astigmatism. While in different total corneal astigmatism groups, there was a tendency in the same direction with anterior corneal astigmatism groups in A2T, PD, IR and BUT. As for patients with different posterior corneal astigmatism, only SPA1 showed a statistically significant difference among groups with WTR astigmatism higher than ATR astigmatism and oblique astigmatism.

During the first flattening, A1T indicates the time from the initial state to the flattened state. A1L is the length of the flattened anterior cornea under the air pressure pulse. Vin is the instantaneous speed of the corneal vertex downward movement of the first flattened state, which is a vector index. Correspondingly, in the second flattening, A2T is the time when the cornea returns from maximum deformation to the

Table 2 Correlation analysis between corneal parameters and corneal curvature

Parameters	Age	Anterior K1	Anterior K2	Posterior K1	Posterior K2	Total K1	Total K2	bIOP (mm Hg)	CCT (μm)	CV (mL)	WTW (mm)	ACD (mm)
A1T (ms)												
r	-0.370[b]	0.121	0.085	-0.224	-0.141	0.097	0.066	0.917[b]	0.302[a]	0.307[a]	-0.501[b]	-0.224
P	0.004	0.360	0.523	0.088	0.288	0.466	0.620	<0.001	0.028	0.018	0.001	0.111
A1L (mm)												
r	-0.084	-0.172	-0.217	0.144	0.137	-0.199	-0.215	0.289[a]	0.151	0.258[a]	-0.152	-0.102
P	0.526	0.193	0.099	0.276	0.302	0.132	0.102	0.027	0.281	0.048	0.336	0.471
Vin (m/s)												
r	0.229	0.046	0.104	-0.032	-0.107	0.064	0.104	-0.754[b]	-0.098	-0.094	0.356[a]	0.328[a]
P	0.081	0.730	0.432	0.807	0.418	0.633	0.432	<0.001	0.485	0.479	0.021	0.017
A2T (ms)												
r	0.283[a]	-0.043	-0.089	0.170	0.079	-0.006	-0.058	-0.789[b]	-0.196	-0.086	0.427[b]	0.140
P	0.030	0.746	0.505	0.198	0.551	0.966	0.664	<0.001	0.160	0.515	0.005	0.322
A2L (mm)												
r	-0.183	0.023	-0.074	-0.075	-0.066	0.000	-0.101	0.236	0.223	0.436[b]	-0.087	-0.226
P	0.166	0.864	0.578	0.572	0.621	0.999	0.444	0.072	0.109	0.001	0.582	0.107
Vout (m/s)												
r	-0.155	-0.059	-0.158	0.044	0.165	-0.065	-0.168	0.446[b]	0.292[a]	0.389[b]	-0.334[a]	-0.442[b]
P	0.242	0.659	0.233	0.741	0.212	0.623	0.204	<0.001	0.034	0.002	0.031	0.001
HC time (ms)												
r	0.185	0.197	0.249	-0.157	-0.138	0.223	0.266[a]	-0.254	0.002	0.100	-0.035	-0.136
P	0.160	0.135	0.058	0.234	0.296	0.090	0.042	0.053	0.986	0.449	0.826	0.336
PD (mm)												
r	0.272[a]	-0.156	-0.025	0.137	-0.017	-0.131	0.016	-0.684[b]	-0.292[a]	-0.290[a]	0.451[b]	0.390[b]
P	0.037	0.239	0.854	0.299	0.897	0.324	0.905	<0.001	0.034	0.026	0.003	0.004
HC radius (mm)												
r	-0.159	-0.271[a]	-0.384[b]	0.282[a]	0.409[b]	-0.235	-0.430[b]	0.050	0.265	0.287[a]	0.181	-0.143
P	0.228	0.038	0.003	0.030	0.001	0.073	0.001	0.708	0.055	0.027	0.252	0.312
DA (mm)												
r	0.393[b]	0.147	0.251	-0.090	-0.211	0.162	0.272[a]	-0.669[b]	-0.347[a]	-0.243	0.341[a]	0.392[b]
P	0.002	0.265	0.055	0.499	0.109	0.219	0.037	<0.001	0.011	0.063	0.027	0.004
SPA1												
r	-0.163	0.050	-0.045	-0.033	-0.024	0.013	-0.040	0.625[b]	0.322[a]	0.302[a]	-0.251	-0.344[a]
P	0.222	0.712	0.739	0.806	0.856	0.922	0.766	<0.001	0.020	0.021	0.114	0.014
IR (mm^{-1})												
r	0.295[a]	0.140	0.233	-0.131	-0.263[a]	0.140	0.257[a]	-0.557[b]	-0.381[b]	-0.366[b]	0.158	0.263
P	0.024	0.292	0.076	0.321	0.044	0.289	0.050	<0.001	0.005	0.004	0.318	0.060
ARTh												
r	-0.020	-0.382[b]	-0.466[b]	0.516[b]	0.510[b]	-0.327[a]	-0.460[b]	-0.221	0.123	0.049	0.315	-0.016
P	0.891	0.005	<0.001	<0.001	<0.001	0.018	0.001	0.116	0.409	0.731	0.062	0.919
DA ratio												
r	0.318[a]	0.188	0.223	-0.079	-0.206	0.185	0.222	-0.654[b]	-0.270	-0.168	0.321[a]	0.261
P	0.020	0.177	0.109	0.575	0.140	0.184	0.111	<0.001	0.055	0.230	0.050	0.080
CBI												
r	0.073	0.237	0.309[a]	-0.431[b]	-0.490[b]	0.207	0.320[a]	-0.079	-0.146	0.046	-0.121	-0.170
P	0.625	0.108	0.034	0.002	<0.001	0.162	0.028	0.598	0.339	0.759	0.496	0.293
TMH (mm)												
r	-0.199	-0.346[b]	-0.248	0.330[a]	0.276[a]	-0.332[a]	-0.204	0.019	-0.209	-0.226	0.042	0.160
P	0.145	0.010	0.068	0.014	0.042	0.013	0.136	0.889	0.150	0.098	0.799	0.277
BUT (s)												
r	-0.262	-0.126	-0.038	0.064	-0.081	-0.151	-0.060	-0.202	0.030	0.096	0.448[b]	0.386[b]
P	0.051	0.355	0.779	0.637	0.555	0.266	0.662	0.135	0.837	0.482	0.004	0.006

CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: anterior chamber depth; bIOP: biomechanical-corrected IOP; TMH: Tear meniscus height; BUT: Tear film break up time; A1T: The first applanation time; A2T: The second applanation time; A1L: The first applanation length; A2L: The second applanation length; Vin: Corneal velocity during the first applanation; Vout: Corneal velocity during the second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index; K1: Flat meridian; K2: Steep meridian. [a]$P<0.05$, [b]$P<0.01$.

Table 3 Univariate regression on the relationship of age, corneal curvature, bIOP, CCT, CV, WTW and ACD with corneal biomechanical parameters

Parameters	Age	Anterior K1	Anterior K2	Posterior K1	Posterior K2	Total K1	Total K2	bIOP (mm Hg)	CCT (μm)	CV (mL)	WTW (mm)	ACD (mm)
A1T (ms)												
β	-0.120	0.103	0.108	-0.241	-0.147	0.070	0.090	0.959	0.222	0.283	-0.472	-0.162
P	0.365	0.438	0.418	0.066	0.265	0.599	0.499	<0.001[b]	0.111	0.030[a]	0.002[b]	0.253
A1L (mm)												
β	0.015	-0.173	-0.218	0.160	0.115	-0.199	-0.217	0.290	0.220	0.293	-0.214	-0.178
P	0.908	0.189	0.098	0.226	0.387	0.131	0.099	0.026[a]	0.114	0.024[a]	0.173	0.206
Vin (m/s)												
β	0.024	-0.021	0.047	0.021	-0.041	0.018	0.054	-0.838	-0.104	-0.124	0.345	0.262
P	0.856	0.875	0.724	0.872	0.757	0.891	0.685	<0.001[b]	0.460	0.349	0.025[a]	0.061
A2T (ms)												
β	0.058	-0.035	-0.068	0.153	0.049	0.004	-0.048	0.010	-0.096	-0.062	0.409	0.127
P	0.664	0.265	0.609	0.248	0.714	0.975	0.717	<0.001[b]	0.496	0.639	0.007[b]	0.370
A2L (mm)												
β	-0.067	0.022	-0.081	-0.036	-0.044	0.015	-0.102	0.229	0.191	0.404	-0.092	-0.318
P	0.612	0.871	0.543	0.788	0.739	0.910	0.441	0.081	0.172	0.002[b]	0.563	0.022[a]
Vout (m/s)												
β	-0.025	-0.044	-0.194	0.093	0.168	-0.049	-0.186	0.403	0.305	0.419	-0.378	-0.375
P	0.849	0.739	0.142	0.484	0.202	0.711	0.158	0.002[b]	0.026[a]	0.001[b]	0.014[a]	0.006[b]
HC time (ms)												
β	0.176	0.097	0.157	0.050	0.041	0.128	0.189	-0.267	0.086	0.150	-0.004	-0.290
P	0.183	0.463	0.234	0.706	0.756	0.334	0.151	0.041[a]	0.541	0.257	0.980	0.037[a]
PD (mm)												
β	0.059	-0.274	-0.114	0.213	0.058	-0.243	-0.075	-0.729	-0.272	-0.303	0.466	0.334
P	0.655	0.036[a]	0.391	0.106	0.661	0.064	0.572	<0.001[b]	0.049[a]	0.020[a]	0.002[b]	0.015[a]
HCradius (mm)												
β	-0.139	-0.214	-0.434	0.325	0.414	-0.200	-0.456	0.056	0.340	0.269	0.204	-0.093
P	0.295	0.104	0.001[b]	0.012[a]	0.001[b]	0.129	<0.001[b]	0.672	0.013[a]	0.040[a]	0.195	0.513
DA (mm)												
β	0.265	0.127	0.275	-0.070	-0.162	0.149	0.293	-0.718	-0.293	-0.260	0.326	0.311
P	0.043[a]	0.338	0.035[a]	0.600	0.219	0.262	0.025[a]	<0.001[b]	0.033[a]	0.046[a]	0.035[a]	0.025[a]
SPA1												
β	-0.023	0.027	-0.069	-0.052	-0.064	-0.002	-0.071	0.645	0.258	0.333	-0.215	-0.275
P	0.866	0.838	0.607	0.696	0.636	0.990	0.598	<0.001[b]	0.065	0.011[a]	0.177	0.051
IR (mm^{-1})												
β	0.110	0.099	0.271	-0.126	-0.260	0.114	0.294	-0.601	-0.398	-0.374	0.133	0.239
P	0.408	0.455	0.038[a]	0.340	0.047[a]	0.392	0.024[a]	<0.001[b]	0.003[b]	0.004[b]	0.403	0.088
ARTh												
β	-0.022	-0.383	-0.478	0.537	0.501	-0.343	-0.470	-0.217	0.140	-0.021	0.259	-0.092
P	0.875	0.005[b]	<0.001[b]	<0.001[b]	<0.001[b]	0.013[a]	<0.001[b]	0.122	0.349	0.882	0.127	0.549
DA ratio												
β	0.198	0.171	0.233	-0.121	-0.222	0.191	0.232	-0.671	-0.260	-0.189	0.312	0.199
P	0.156	0.222	0.093	0.387	0.110	0.171	0.094	<0.001[b]	0.066	0.175	0.057	0.184
CBI												
β	0.104	-0.161	0.267	-0.351	-0.555	-0.170	0.319	-0.076	-0.085	0.148	-0.089	-0.500
P	0.485	0.278	0.070	0.016[a]	<0.001[b]	0.252	0.029[a]	0.613	0.579	0.322	0.618	0.762
TMH (mm)												
β	-0.120	0.103	0.108	-0.241	-0.147	0.070	0.090	0.959	0.222	0.283	-0.472	-0.162
P	0.365	0.438	0.418	0.066	0.265	0.599	0.499	<0.001[b]	0.111	0.030[a]	0.002[b]	0.253
BUT (s)												
β	0.015	-0.173	-0.218	0.160	0.115	-0.199	-0.217	0.290	0.220	0.293	-0.214	-0.178
P	0.908	0.189	0.098	0.226	0.387	0.131	0.099	0.026[a]	0.114	0.024[a]	0.173	0.206

K1: Flat meridian; K2: Steep meridian; CCT: Central corneal thickness; CV: Corneal volume; WTW: White to white; ACD: Anterior chamber depth; bIOP: Biomechanical-corrected IOP; TMH: Tear meniscus height; BUT: Tear film break up time; A1T and A2T: The first and second applanation time; A1L and A2L: The first and second applanation length; Vin and Vout: Corneal velocity during the first and second applanation; HC: Highest concavity; DA: Displacement amount; PD: Peaks distance; SPA1: Stiffness parameter A1; IR: Integrated radius; ARTh: The Ambrosio relational thickness to the horizontal profile; CBI: Corvis Biomechanical Index. [a]$P<0.05$; [b]$P<0.01$.

central level. A2L is the length of the flattened corneal when turning from the concave surface to the convex surface. Vout is the relevant instantaneous speed of corneal vertex upward movement. The forces involved during the second flattening include the intrinsic viscoelasticity of the cornea, IOP, and the decreasing airflow. Generally, the first and second applanation may be related to collagen fiber elasticity and corneal viscoelasticity, respectively[15-16]. Previous studies have figured out that A1T and A2T are connected to the calculation of IOP, while local corneal fluctuations may affect the results of A1L and A2L[17]. Additionally, some studies have pointed out that A2T and Vout may be indicators of the cornea's total viscoelasticity[1,18-19]. Oblique astigmatism has longer A1T, longer A1L, smaller Vin and shorter A2T, which may indicate that the elasticity of corneal collagen fibers is greater, but the viscoelasticity of the cornea is smaller.

HC time is the time from the initial state to the maximum depression. HC-radius is the central curvature radius of the corneal anterior surface at the largest concavity. The softer the cornea is, the easier it is to deform; that is, the smaller the HC radius[20]. PD is the horizontal length between the highest points of the undeformed parts on both sides of the cornea at the maximum depression state. DA is the vertical displacement from the highest point (corneal apex) of the initial corneal state to the lowest point of the cornea in the maximum depression state, that is, the deformation amplitude of the cornea. DA is considered to characterize the degree of corneal stiffness and thickness[21]. Previous studies have pointed out that DA is one of the most repeatable and reproducible parameters. The higher the DA value, the greater the corneal deformation and the smaller the deformation resistance, indicating that the cornea is softer or thinner[22]. Smaller DA and PD and larger HC radius show that the resistance to corneal deformation in oblique astigmatism is greater and prone to deformation is less; in other words, the cornea is harder or thicker. However, there was no significant difference in CCT among the three groups, so the factor causing greater deformation resistance of oblique astigmatism might be that the cornea is harder.

Vinciguerra screening parameters are newly developed. Various ocular biomechanical and ocular parameters are combined by logistic regression, which provides more information for evaluating ocular indexes[23]. Same with DA, SPA1 is an index used to assess corneal stiffness and can quantify resistance to corneal deformation. SPA1 refers to the ratio of the pressure load of the cornea to the displacement between the vertex of the undeformed cornea and the deflection during the first applanation[24]. SPA1 plays an essential role in evaluating corneal stiffness and internal corneal biomechanics because it considers confounding factors, including intraocular pressure and eye movements. Previous studies have confirmed that the higher the SPA1 value, the higher the corneal stiffness[25]. IR refers to the area under the inverse concave radius curve versus time curve, and it is the reciprocal of the radius of curvature during the concave phase of the deformation[26]. ARTh is the quotient of corneal thickness at the thinnest point in the horizontal meridian direction. ARTh is not only related to the corneal thickness of peripheral and central but also the increasing rate of corneal thickness toward the periphery. ARTh is small when the peripheral cornea is thick, and the central cornea is thin in the horizontal meridian direction and a faster thickness increase toward the periphery. The DA ratio is the deformation amplitude of the corneal apex divided by the average deformation amplitude of two points 2 mm on both sides of the apex. It is reported that DA ratio is related to anterior corneal tomography parameters and central corneal thickness[27-28]. Larger DA ratios are associated with worse corneal resistance to deformation[29]. CBI is calculated by CST parameters such as SPA1, DA ratio, DA and ARTh, combining dynamic corneal response parameters and corneal horizontal thickness profile[23]. Its value fluctuates between 0 and 1. The closer CBI is to 1, the weaker corneal biomechanics[23-24]. Consistent with the above results, SPA1 of the oblique astigmatism group is larger, indicating that its stiffness is higher. A smaller DA ratio is related to better resistance to corneal deformation. There was no significant difference in ARTh between the three groups; that is, the corneal biomechanical specificity of the oblique astigmatism group is probably not caused by corneal thickness.

Studies have shown that the posterior surface of the cornea acts as a minus lens in the corneal refractive system, constantly applying horizontal refractive power or ATR refractive power[8-9]. Previous studies have shown that the morphology of the posterior surface of the cornea is relatively unchanged in the elderly. Still, the anterior surface astigmatism will change from WTR to ATR with age[30-31]. The possible reasons include the reduction of upper eyelid compression on the upper cornea, the weakening of the role of the internal rectus muscle, the decrease of corneal basal nerve fibers, stromal cells and endothelial cells, the thickening of the corneal stromal collagen fiber bundle, the reduction of the gap between fibers, the changes of corneal internal structure and IOP, and the thinning of corneal thickness[32]. A recent study indicated that both anterior and posterior corneal vertical powers would reduce in the elderly while the anterior corneal horizontal power would increase, but there was no significant oblique rotation along the steep meridian in oblique astigmatism[33]. Naeser *et al*[30] also figured out that the astigmatic power of the 45-degree meridian was unchanged in the elderly. Therefore, the author speculates that oblique astigmatism is not the intermediate state of the transformation between WTR and ATR but a relatively independent astigmatism type, which is more stable and shows the biomechanical characteristics of the cornea that can better resist deformation. In other words, WTR and ATR are more unstable in the process of changing with age, so they are more prone to deformation and have a greater degree of deformation. The multivariable regression analyses in the study demonstrated that age was positively associated with A1T and SPA1 and negatively associated with Vin and IR. Posterior K1 was negatively associated with Vin. Posterior K2 was negatively associated with CBI. Total K2 was negatively associated with A1L. A1T, Vout and SPA1 were positively related to bIOP, while Vin, A2T, PD, DA, IR and DA ratio were negatively related to bIOP. WTW was positively associated with PD.

Age has been found to be associated with various Corvis ST parameters in previous studies, such as HC time, A1T, A1T, IR, DA and DA ratio[34-35]. This could be explained by the increase of glycosylation-induced cross-linked fibers in the corneal stroma with age, resulting in stiffer cornea in the elderly[1]. On the other hand, some other studies reported no association between age and corneal biomechanical properties. The greater the corneal curvature, the steeper the cornea, and the greater force required to flatten it. At the same time, the greater the corneal curvature, the lower the corneal viscoelasticity itself. The simultaneous action of the two factors makes A1L and Vin smaller under the same pressure pulse.

CCT is the vertical distance between the anterior and posterior surface vertices of the cornea. The bIOP value was calculated by finite element simulations, and the influence of dynamic corneal response parameters, CCT and age were taken into account. Some studies have indicated that the variation in corneal deformation may be affected not only by the corneal structure but also by the IOP of the eye and corneal biomechanics[2]. Consistent with previous studies, both IOP and CCT are confirmed to be associated with a number of corneal biomechanical parameters, including A1T, Vin, A2T, Vout, DA, and PD[1,35-36]. Additionally, corneal astigmatism may be related to IOP values in patients prior to the cataract surgery[37]. To our best knowledge, this article is the first one to comprehensively investigate the relationship between preoperative corneal biomechanical properties and corneal tomographic properties in cataract patients.

In conclusion, the study investigated the relationship between corneal biomechanical properties and corneal tomographic properties and revealed that the elasticity of corneal collagen fibers is greater, but the viscoelasticity of cornea is smaller in patients with oblique astigmatism. There was no significant difference in ARTh between patients with different types of astigmatism, which means the corneal biomechanical specificity of the oblique astigmatism group is probably not caused by corneal thickness. Moreover, we found patients with higher anterior corneal curvature had lower HC radius and CCT but higher ARTh than those with lower anterior corneal curvature.

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REFERENCES

1 Yu AY, Shao H, Pan AP, *et al*. Corneal biomechanical properties in myopic eyes evaluated *via* Scheimpflug imaging. *BMC Ophthalmol* 2020;20(1):279.

2 Hon Y, Lam AK. Corneal deformation measurement using Scheimpflug noncontact tonometry. *Optom Vis Sci* 2013;90(1):e1-8.

3 Yang K, Xu L, Fan Q, *et al*. Repeatability and comparison of new Corvis ST parameters in normal and keratoconus eyes. *Sci Rep* 2019;9(1):15379.

4 Ziaei M, Gokul A, Vellara H, *et al*. Measurement of *in vivo* biomechanical changes attributable to epithelial removal in keratoconus using a noncontact tonometer. *Cornea* 2020;39(8):946-951.

5 Jabbarvand M, Moravvej Z, Shahraki K, *et al*. Corneal biomechanical outcome of collagen cross-linking in keratoconic patients evaluated by Corvis ST. *Eur J Ophthalmol* 2021;31(4):1577-1583.

6 Jung Y, Park HL, Oh S, *et al*. Corneal biomechanical responses detected using corvis st in primary open angle glaucoma and normal tension glaucoma. *Medicine* (*Baltimore*) 2020;99(7):e19126.

7 Kanclerz P, Khoramnia R, Wang XG. Current developments in corneal topography and tomography. *Diagnostics* 2021;11(8):1466.

8 Koch DD, Ali SF, Weikert MP, *et al*. Contribution of posterior corneal astigmatism to total corneal astigmatism. *J Cataract Refract Surg* 2012;38(12):2080-2087.

9 Hosny M, Badawy A, Khazbak L, *et al*. Contribution of posterior corneal astigmatism to total corneal astigmatism in a sample of Egyptian population. *Clin Ophthalmol* 2020;14:3325-3330.

10 GBD 2019 Blindness and Vision Impairment Collaborators, Vision Loss Expert Group of the Global Burden of Disease Study. Causes of blindness and vision impairment in 2020 and trends over 30 years, and prevalence of avoidable blindness in relation to VISION 2020: the Right to Sight: an analysis for the Global Burden of Disease Study. *Lancet Glob Health* 2021;9(2):e144-e160.

11 Xu JY, Li C, Wang LJ, *et al*. Influence of measurement differences of anterior chamber depth and axial length on lens thickness evaluation in cataract patients: a comparison of two tests. *BMC Ophthalmol* 2020;20(1):481.

12 Denoyer A, Ricaud X, van Went C, *et al*. Influence of corneal biomechanical properties on surgically induced astigmatism in cataract surgery. *J Cataract Refract Surg* 2013;39(8):1204-1210.

13 Miao A, Tang YT, Zhu XJ, *et al*. Associations between anterior segment biometry and high axial myopia in 3438 cataractous eyes in the Chinese population. *BMC Ophthalmol* 2022;22(1):71.

14 Espana EM, Birk DE. Composition, structure and function of the corneal stroma. *Exp Eye Res* 2020;198:108137.

15 Liu MX, Zhu KY, Li DL, *et al*. Corneal biomechanical characteristics in myopes and emmetropes measured by corvis ST: a meta-analysis. *Am J Ophthalmol* 2024;264:154-161.

16 Wallace HB, Misra SL, Li SS, *et al*. Biomechanical changes in the cornea following cataract surgery: a prospective assessment with the Corneal Visualisation Scheimpflug Technology. *Clin Exp Ophthalmol* 2019;47(4):461-468.

17 Wei YJ, Xu LX, Song H. Application of Corvis ST to evaluate the effect of femtosecond laser-assisted cataract surgery on corneal biomechanics. *Exp Ther Med* 2017;14(2):1626-1632.

18 Lee R, Chang RT, Wong IY, *et al*. Assessment of corneal biomechanical parameters in myopes and emmetropes using the Corvis ST. *Clin Exp Optom* 2016;99(2):157-162.

19 Miki A, Maeda N, Ikuno Y, *et al*. Factors associated with corneal deformation responses measured with a dynamic scheimpflug analyzer. *Invest Ophthalmol Vis Sci* 2017;58(1):538-544.

20 Wang JY, Li Y, Jin YM, *et al*. Corneal biomechanical properties in myopic eyes measured by a dynamic scheimpflug analyzer. *J Ophthalmol* 2015;2015:161869.

21 Dorronsoro C, Pascual D, Pérez-Merino P, *et al*. Dynamic OCT measurement of corneal deformation by an air puff in normal and cross-linked corneas. *Biomed Opt Express* 2012;3(3):473-487.

22 Ye C, Yu M, Lai G, *et al*. Variability of corneal deformation response in normal and keratoconic eyes. *Optom Vis Sci* 2015;92(7):e149-e153.

23 Vinciguerra R, Ambrósio R Jr, Elsheikh A, *et al*. Detection of keratoconus with a new biomechanical index. *J Refract Surg* 2016;32(12):803-810.

24 Ambrósio R Jr, Lopes BT, Faria-Correia F, *et al*. Integration of scheimpflug-based corneal tomography and biomechanical assessments for enhancing ectasia detection. *J Refract Surg* 2017;33(7):434-443.

25 Hirasawa K, Nakakura S, Nakao Y, *et al*. Changes in corneal biomechanics and intraocular pressure following cataract surgery. *Am J Ophthalmol* 2018;195:26-35.

26 Koh S, Inoue R, Ambrósio R Jr, *et al*. Correlation between corneal biomechanical indices and the severity of keratoconus. *Cornea* 2020;39(2):215-221.

27 Tian L, Huang YF, Wang LQ, *et al*. Corneal biomechanical assessment using corneal visualization scheimpflug technology in keratoconic and normal eyes. *J Ophthalmol* 2014;2014:147516.

28 Bak-Nielsen S, Pedersen IB, Ivarsen A, *et al*. Dynamic Scheimpflug-based assessment of keratoconus and the effects of corneal cross-linking. *J Refract Surg* 2014;30(6):408-414.

29 Wei Q, Ding H, Nie K, *et al*. Long-term clinical outcomes of small-incision femtosecond laser-assisted intracorneal concave lenticule implantation in patients with keratoconus. *J Ophthalmol* 2022;2022:9774448.

30 Naeser K, Savini G, Bregnhøj JF. Age-related changes in with-the-rule and oblique corneal astigmatism. *Acta Ophthalmol* 2018;96(6):600-606.

31 Mongkolareepong N, Mekhasingharak N, Pimpha O. Factors associated with corneal astigmatism change after ptosis surgery. *Int J Ophthalmol* 2022;15(4):576-580.

32 Namba H, Sugano A, Murakami T, *et al*. Age-related changes in astigmatism and potential causes. *Cornea* 2020;39(Suppl 1):S34-S38.

33 Hayashi K, Sasaki H, Hirata A, *et al*. Comparison of long-term astigmatic changes following cataract surgery among types of corneal astigmatism. *Br J Ophthalmol* 2023;107(7):920-926.

34 Vellara HR, Ali NQ, Gokul A, *et al*. Quantitative analysis of corneal energy dissipation and corneal and orbital deformation in response to an air-pulse in healthy eyes. *Invest Ophthalmol Vis Sci* 2015;56(11):6941-6947.

35 Wang W, He M, He H, *et al*. Corneal biomechanical metrics of healthy Chinese adults using Corvis ST. *Cont Lens Anterior Eye* 2017;40(2):97-103.

36 Guo YH, Guo LL, Yang WQ, *et al*. Age-related analysis of corneal biomechanical parameters in healthy Chinese individuals. *Sci Rep* 2024;14:21713.

37 Pniakowska Z, Jurowski P. Influence of preoperative astigmatism on corneal biomechanics and accurate intraocular pressure measurement after micro-incision phacoemulsification. *Int J Ophthalmol* 2019;12(4):587-591.