Effect of Biomechanical Properties on Myopia: a Study of New Corneal Biomechanical Parameters

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Abstract

**Background:** To assess the corneal stress-strain index (SSI), which is a marker for material stiffness and corneal biomechanical parameters, in myopic eyes.

**Methods:** A total of 1054 myopic patients were included in this study. Corneal visualisation Scheimpflug technology was used to measure the SSI. Corneal biomechanics were assessed using the first and second applanation times (A1-and A2-times); maximum deflection amplitude (DefAmx); deflection area (HCDefArea); the highest concavity peak distance (HC-PD), time (HC-time), and deflection amplitude (HC-DefA); integrated radius (IR); whole eye movement (WEM); stiffness parameter (SP-A1); biomechanically corrected intraocular pressure (BIOP); and Corvis biomechanical index (CBI). Scheimpflug tomography was used to obtain the mean keratometry (Km) and central corneal thickness (CCT). According to the spherical equivalent (SE) (low myopia: SE ≥ -3.00D and high myopia: SE ≤ -6.00D), the suitable patients were divided into two groups.

**Results:** The mean SSI value was 0.854±0.004. The SSI had a positive correlation with A1-time (r=0.272), HC-time (r=0.218), WEM (r=0.288), SP-A1 (r=0.316), CBI (r=0.199), CCT (r=0.125), BIOP (r=0.230), and SE (r=0.313) (all p-values<0.01). The SSI had a negative correlation with HCDefA (r=-0.721), HCDefArea (r=-0.665), HC-PD (r=-0.597), IR (r=-0.555), DefAmx (r=-0.564), and Km (r=-0.103) (all p-values<0.01). There were significant differences in SSI (t=8.960, p<0.01) and IR (t=-3.509, p<0.01) between the low and high myopia groups.

**Conclusions:** In different grades of myopia, the SSI values were lower in eyes with higher SEs. It indicates that the mechanical strength of the cornea may be compromised in high myopia. The SSI was positively correlated with the spherical equivalent, and it may provide a new way to study the mechanism of myopia.

1 Background

Quantification of corneal biomechanics has helped us to understand the changes in corneal shape and structure after refractive surgery[1, 2]. The corneal stiffness is a recently described index with clinical significance for the detection in patients who are at risk of ectasia development [3, 4]. Previous studies have shown that the biomechanical properties of the cornea are correlated with many factors such as central corneal thickness (CCT) and intraocular pressure (IOP) [5, 6]. Eliasy et al.[7] used finite element models of human ocular globes with wide ranges of geometries. The models were subjected to different levels of IOP and the action of external air puff produced by a non-contact tonometer. The algorithm was assessed using clinical data obtained from two large datasets of healthy participants and produced a material stiffness parameter—stress-strain index:SSI:that showed no significant correlation with both CCT and IOP. However, the distribution characteristics and influencing factors of SSI in myopic patients have not been reported. In this study, we aimed to determine the normative values in myopic patients and the effect of SSI on myopia and to assess its possible correlation with other corneal biomechanical parameters.

2 Methods

2.1 Subjects

This was a retrospective clinical study of 1054 myopic participants (464 women and 590 men) who were scheduled to undergo corneal refractive surgery at Tianjin Eye Hospital, Tianjin Medical University between March 2019 and November 2019. Data from a single representative eye per participant (right eye) were used for the analysis.

According to the spherical equivalent (SE; low myopia: SE ≥ -3.00 D and high myopia: SE ≤ -6.00 D), suitable patients were divided into two groups. The study protocol followed the tenets of the Declaration of Helsinki and was approved by the ethics committee of Tianjin Eye Hospital. Written informed consent was obtained from all participants before enrolment. Inclusion criteria included: stable refraction for at least 2 years and the absence of ocular inflammation. Patients were asked to refrain from using soft contact lenses for at least 2 weeks and rigid contact lenses for at least 4 weeks. Exclusion criteria included: history of ophthalmic surgery, ocular trauma, keratoconus, glaucoma, diabetes, systemic connective tissue disease and abnormal immune function.

2.2 Methods

All the participants underwent comprehensive eye examinations, including uncorrected visual acuity and best corrected visual acuity measurements, subjective refraction, non-contact tonometry, and slit lamp examinations. Corneal thicknesses and mean curvatures were obtained using Scheimpflug imaging (Pentacam, Oculus, Germany). Corneal biomechanical parameters were obtained using the corneal visualisation Scheimpflug technology (Corvis ST) analyzer (Oculus, Germany).
2.3 Corvis ST and SSI

The Corvis ST (software version 1.6r2015) is a non-contact tonometer that enables quantitative and qualitative (visual) assessments of corneal dynamic response to an air pulse using an ultra-high speed Scheimpflug camera that captures 4330 images and covers 8 mm of the central cornea in a single horizontal meridian (Figure 1). The new software used in the current study measures dynamic corneal response (DCR) parameters including first applanation (A1) parameters (A1-time, A1-length and A1-velocity), second applanation (A2) parameters (A2-time, A2-length and A2-velocity), highest concavity (HC) parameters (HC-time, HC-radius, HC deformation amplitude [DA], and HC peak distance [PD]), maximum deflection amplitude (DefAmax), deflection area (HCDefArea), uncorrected IOP, corneal stiffness parameter (SP-A1), biomechanically corrected intraocular pressure (biOP), Corvis biomechanical index (CBI), and SSI.

An in-built software using the least squares method was used to estimate the value of SSI according to numerical modelling using CCT, biOP, and SP-HC as input and output parameters [7]. It fits data via a regression equation to prior numerical analysis results.

\[
SSI = \frac{1}{1 + e^{-a_1 + a_2 C_1 + a_3 C_2 + a_4 + a_5 C_1 C_2 + a_6 + a_7 + a_8 C_2 + a_9 C_1 + \ln (SP - HC)}}
\]

where \(C_1 = \frac{CCT}{545}\) and \(C_2 = \frac{biOP}{20}\). \(\ln (SP - HC)\) the natural logarithm of the SP at HC, and a1-a9 constants are determined by fitting the equation to the numerical input and output values. The ssi was considered as 1.0 for the average experimental behaviour obtained for corneal tissue with age=50 years[8]. Higher values of SSI are indicative of higher tissue stiffness and vice versa.

2.4 Statistical analyses

The statistical analyses were performed using SPSS version 26.0 software (IBM, Corp, Armonk, NY, USA). Descriptive statistical results included means, standard deviations, and minimum and maximum values of parameters. The 95% confidence interval (CI) of the overall mean of the parameters was calculated. Normality of all data samples was checked using the Kolmogorov-Smirnov test. Pearson bivariate correlation statistical analysis was used to obtain the linear fit of the correlation among variables. Stepwise multivariate linear regression analysis was applied to assess the correlation between SSI and other corneal properties; \(p < 0.05\) was considered to be statistically significant.

3 Results

3.1 Baseline characteristics

Data were collected from 1054 patients. The right eyes were used for the analysis. The characteristics of the participants are summarised in Table 1. The mean age and SE of the participants were 23.9±5.96 years and -5.03±2.03D, respectively.

Table 1. Characteristics of the participants included in the study

| Parameters       | Mean ±SD   | Range     |
|------------------|------------|-----------|
| Age (years)      | 23.9±5.96  | 17-45     |
| MRSE (D)         | -5.36±2.07 | -0.5-14.25|
| Spherical (D)    | -5.03±2.03 | -0.5-13.50|
| Cylinder (D)     | -0.66±0.48 | 0-1.75    |
| CCT (microns)    | 553.4±29.9 | 482-654   |
| Km (D)           | 43.14±1.35 | 39.0-46.75|
| IOPnct (mmHg)    | 16.39±2.37 | 9.5-27.5  |

CCT, central corneal thickness; Km, mean keratometry; MRSE, manifest refraction spherical equivalent; IOPnct, intraocular pressure with non-contact tonometry; SD: standard deviation

Values are presented as means (standard deviations) or as ranges.

3.2 Biomechanical parameters

The mean values of DCR parameters in eyes with corresponding standard deviations and 95% CIs are shown in Table 2.

Table 2: Distribution of normative values of Corvis ST parameters
Corvis ST: corneal visualisation Scheimpflug technology; SD: standard deviation; CI: confidence interval; A1-and A2-times: time reaching the first and second applanation; HC-time: highest concavity-time; A1 and A2DefA: displacement of corneal apex at the first or second applanation or at the moment of highest concavity after whole eye motion is removed; HCDefA: amplitude at the highest concavity; HCDefArea: deflection area at the highest concavity; DefAmax: maximum deflection amplitude; DAmax: maximum deformation amplitude; PD: peak distance; WEM: whole eye movement; SP-A1: stiffness parameter; IR: integrated radius; ARTh: ambrosio relational thickness horizontal; CBI: Corvis biomechanical index; SSI: stress-strain index; CCT: central corneal thickness; bIOP: biomechanically corrected intraocular pressure.

Values are presented as means (standard deviations) with 95% confidence intervals.

### 3.3 Correlations of SSI with other biomechanical parameters

#### 3.3.1 Correlation between baseline characteristics and SSI

No statistically significant correlations were observed between SSI and sex ($p>0.05$). The SSI was negatively correlated with mean keratometry (Km) ($r=-0.103$, $p<0.01$) and positively correlated with SE ($r=0.313$, $p<0.01$) (Figure 2), CCT ($r=0.125$, $p<0.01$), age ($r=0.198$, $p<0.01$), and bIOP ($r=0.23$, $p<0.01$) (Table 3).

Table 3: Correlations between SSI and characteristics of the participants

| Parameters                  | Mean±SD  | 95% CI          |
|-----------------------------|----------|-----------------|
| A1-time (ms)                | 7.208±0.289 | 7.194, 7.223   |
| A2-time (ms)                | 21.968±0.373 | 21.949, 21.987 |
| HC-time (ms)                | 17.032±0.401 | 17.011, 17.052 |
| A1DefA (mm)                 | 0.097±0.006 | 0.096, 0.097    |
| A2DefA (mm)                 | 0.109±0.011 | 0.108, 0.109    |
| HCDefA (mm)                 | 0.941±0.096 | 0.936, 0.946    |
| HCDefArea (mm²)             | 3.521±0.501 | 3.495, 3.547    |
| DefAmax (mm)                | 0.953±0.095 | 0.948, 0.957    |
| DAmax (mm)                  | 4.349±0.424 | 4.328, 4.372    |
| PD (mm)                     | 5.181±0.251 | 5.169, 5.194    |
| WEM (mm)                    | 0.201±0.065 | 0.258, 0.265    |
| SP-A1                       | 107.866±14.927 | 107.091, 108.640 |
| ARTh                        | 581.715±112.10 | 575.918, 587.512 |
| IR                          | 7.902±0.977 | 7.852, 7.951    |
| CBI                         | 0.221±0.187 | 0.212, 0.230    |
| SSI                         | 0.854±0.133 | 0.847, 0.860    |
| CCT (μm)                    | 554±32.75  | 576, 587        |
| bIOP (mmHg)                 | 16±2.06    | 15.9, 16.1      |
### Parameters

| Parameters        | SSI |   |
|------------------|-----|---|
|                  |     | r | p  |
| Age (years)      | 0.198 | 0.01 |
| MRSE (D)         | 0.313 | 0.01 |
| CCT (microns)    | 0.125 | 0.01 |
| Km (D)           | -0.103 | 0.01 |
| bIOP (mmHg)      | 0.230 | 0.01 |

SSI: stress-strain index; MRSE: manifest refraction spherical equivalent; CCT: central corneal thickness; Km: mean keratometry; BIOP: biomechanically corrected intraocular pressure

Statistical significance has been defined as p < 0.05.

### 3.3.2 Comparison of parameters in low and high myopia

There were no significant differences in age, CCT, BIOP, SP, ambrosio relational thickness horizontal (ARTh), and CBI between the low and high myopia groups. There was a significant difference in SSI ($t=8.960$, $p=0.01$) and integrated radius (IR) ($t=-3.509$, $p=0.01$) (Figure 3, Table 4).

Table 4: Comparison of the parameters in low and high myopia

| Group             | Number | Age (years) | CCT (microns) | SP-A1        | DAmx (mm) | IR (mm) | ARTh (mm) | CBI (mm) | SSI       |
|-------------------|--------|-------------|---------------|--------------|------------|---------|-----------|----------|-----------|
| Low myopia        | 161    | 23.2±6.12   | 553±32.9      | 4.272±        | 7.663±     | 589.402±| 0.214±    | 0.920±0.138|
|                   |        |             |               | 16±2.07      | 108.520±15.699|        |          |          |
| High myopia       | 506    | 24.0±5.56   | 551±29.3      | 4.360±        | 7.953±     | 577.718±| 0.224±    | 0.813±0.129|
|                   |        |             |               | 16±1.98      | 107.787±14.884|        |          |          |
| $t$               | -1.616 | 0.770       | -1.354        | 0.538        | -2.328     | -3.509  | 1.190     | -0.609    | 8.960     |
| $p$               | 0.107  | 0.441       | 0.176         | 0.590        | 0.020      | 0.01    | 0.234     | 0.543     | 0.01      |

CCT: central corneal thickness; BIOP: biomechanically corrected intraocular pressure; SP-A1: stiffness parameter; DAmx: maximum deformation amplitude; IR: integrated radius; ARTh: ambrosio relational thickness horizontal; CBI: Corvis biomechanical index; SSI: stress-strain index

Statistical significance has been defined as p < 0.05.

### 3.3.3 Regression analysis of SSI and baseline characteristics

Multiple linear stepwise regression analysis was performed with SSI as the dependent variable and SE, Km, CCT, bIOP, and age as independent variables (Table 5). The following regression equation was obtained:

$$SSI=0.768+0.021SE+0.02bIOP+0.006AGE-0.013KM+0.001CCT$$

Table 5: Multiple linear stepwise regression analysis with SSI as the dependent variable
β | t | p | 95% CI
---|---|---|---
Constant | 0.768 | 6.429 | <0.01 | 0.534, 1.002
MRSE (D) | 0.021 | 14.114 | <0.01 | 0.018, 0.024
bIOP | 0.020 | 12.752 | <0.01 | 0.017, 0.023
Age (year) | 0.006 | 11.352 | <0.01 | 0.005, 0.007
Km (D) | -0.013 | -5.680 | <0.01 | -0.018, -0.009
CCT (µm) | 0.001 | 5.558 | <0.01 | 0.000, 0.001

CI: confidence interval; MRSE: manifest refraction spherical equivalent; bIOP: biomechanically corrected intraocular pressure; Km: mean keratometry CCT: central corneal thickness; SSI: stress-strain index

Values are presented 95% confidence intervals, and statistical significance has been defined as p < 0.05.

### 3.3.4 Correlation between corneal biomechanical parameters and SSI

A1-time, HC-time, A2DefA, WEM, SP-A1, ARTh, CBI, IR, and bIOP were weak positively correlated with SSI. DAmax, A2-time, and A2DefA were weakly negatively correlated with SSI. HCDefA, HCDefArea, PD, IR, and DefAmax were strongly negatively correlated with SSI. No significant correlation was found between A1DefA and SSI (Table 6, Figure 4).

| Parameters | r   | p  |
|------------|-----|----|
| A1-time (ms) | 0.272 | <0.01 |
| A2-time (ms) | -0.323 | <0.01 |
| HC-time (ms) | 0.218 | <0.01 |
| A1DefA (mm) | -0.007 | 0.798 |
| A2DefA (mm) | 0.081 | <0.01 |
| HCDefA (mm) | -0.721 | <0.01 |
| HCDefArea (mm²) | -0.665 | <0.01 |
| DefAmax (mm) | -0.564 | <0.01 |
| DAmax (mm) | -0.388 | <0.01 |
| PD (mm) | -0.597 | <0.01 |
| WEM (mm) | 0.288 | <0.01 |
| SP-A1 | 0.316 | <0.01 |
| ARTh | 0.113 | <0.01 |
| IR | -0.555 | <0.01 |
| CBI | 0.199 | <0.01 |
| bIOP | 0.230 | <0.01 |

SSI: stress-strain index; Corvis ST: corneal visualization Scheimpflug technology; A1-and A2-times: time reaching the first and second applanation; HC-time: highest concavity-time; A1 and A2DefA: displacement of corneal apex at the first or second applanation or at the moment of highest concavity after whole eye motion is removed; HCDefA: amplitude at the highest concavity; HCDefArea: deflection area at the highest concavity; DefAmax: maximum deflection amplitude; DAmax: maximum deformation amplitude; PD: peak distance; WEM: whole eye movement; SP-A1: stiffness parameter; IR: integrated radius; ARTh: ambrosio relational thickness horizontal; CBI: Corvis biomechanical index; bIOP: biomechanically corrected intraocular pressure
4 Discussion

Myopia is a public health problem [9] with a high prevalence, especially in the Far East[10]. The onset and progression of myopia has been associated with genetic and environmental factors [11, 12]. Previous studies have noted that myopia is correlated with an increase in corneal curvature and a decrease in corneal thickness[13]. Animal studies have shown a change in the length of the eye and shape of the anterior cornea during the process of myopia modelling [14, 15]. It is also known that high myopes have lower corneal hysteresis than emmetropes [16]. However, it is difficult to detect the ocular biomechanical properties in vivo [17]. The Corvis ST provides information on corneal deformation parameters by visualising the dynamic reaction of the cornea to a single puff of air [18].

In our study, one of the new Corvis ST parameters—SSI, was evaluated in myopic eyes. We demonstrated that the SSI was positively correlated with SE (r=0.313, p<0.01) (Figure 1). When comparing eyes with low and high myopia, there were no significant differences in CCT, bIOP, SP, ARTh, and CBI, although there was a significant difference in SSI (t=8.960, p<0.01) and IR (t=-3.509, p<0.01) (Figure 2, Table 4) values. The results showed that the SSI of high myopia was lower than that of low myopia, suggesting that the biomechanical properties of the cornea changed and corneal hardness decreased with an increase in the SE.

Inmaculada Bueno-Gimeno et al. used ocular response analyser and suggested that corneal biomechanical properties appear to be compromised in myopia from an early age, especially in high myopia [19]. Another study showed a weak although significant correlation between corneal hysteresis (CH) and refractive error, with CH being lower in both moderate and high myopia than in emmetropia and low myopia [20]. Wu et al. [21] reported a difference in corneal biomechanical properties between 835 low myopic eyes and 1027 high myopic eyes. Low CH and corneal resistance factor and high cornea-compensated and Goldmann-correlated IOPs were suggested to be associated with high myopia. However, the correlation of the biomechanics of myopia is controversial. Some studies reported no significant correlation between myopia and CH [22, 23]. The results of our study showed a strong negative correlation of SSI with HCDelArea (r=-0.721, p<0.01), HCDelAreaPD (r=-0.665, p<0.01), PD (r=-0.597, p<0.01), IR (r=-0.555, p<0.01), and DefAmax (r=-0.564, p<0.01) (Table 6, Figure 3). Wang et al. [24] found that eyes with high myopia had a larger corneal DA than eyes with mild-to-moderate myopia, and A2-time and HC-radius were positively correlated with SE. Eyes with high myopia also showed longer DA and smaller HC-radius. Similar results were reported by Miaohe et al. [5]. These findings are consistent with our results.

Previous studies have shown that the biomechanical properties of the cornea are correlated with CCT. Eyes with thick CCT exhibited strong corneal resistance to external force and are less prone to deformation [25]. Higher intraocular pressure may mask abnormal corneal biomechanical properties, resulting in apparently normal HCDA measurements [26]. The introduction of SSI resolved this issue because it estimates the material stiffness [27]. Eliasy et al. [7] used the numerical models in the SSI parametric study that covered wide variations in IOP, CCT, geometry and material parameters, which covered and slightly extended beyond the ranges reported in clinical studies. Through the consideration of a Corvis parameter—SP-HC, which is more strongly correlated with corneal stiffness than IOP, SSI is intended to be independent of intraocular pressure and corneal geometry. As a new index, it could help in the detection in patients with higher risk or susceptibility for ectasia development or progression after refractive surgery and could aid in surgery planning.

In this study, we observed a weak correlation among BIOP (r=0.23, p<0.01), CCT (r=0.125, p<0.01), and SSI (Table 3). It indicated that despite correction, the effect of corneal biomechanics cannot be completely independent of IOP and thickness, which is consistent with our clinical experience and previous studies. Effects of IOP and corneal biomechanics on eye behaviour are difficult to separate; IOP also affects the immediate corneal stiffness. It is generally believed that sex has no significant effect on corneal biomechanics [28]. Our study also suggested that the corneal biomechanical properties of myopia may have nothing to do with sex. Correlation between stress-strain behaviour and age was reported [8, 29], although this study found that there was no strong significant correlation between age (r =0.198, p<0.01) and SSI, which may be correlated with the concentration of the individual age included.

It is noteworthy that the mean CCT value measured by Corvis ST (553±29.96 um) was slightly lower than that measured by Pentacam corneal topography (554±31.04 um) (t=4.970, p<0.01). However, it has been shown that Corvis-ST CCT measurements have good repeatability [30].

The main limitation of the current study is lack of eye axis parameters and a control group with emmetropia, despite a large sample size with myopic participants, which will be improved and supplemented in future studies.

5 Conclusions
In conclusion, our study showed that there was a positive correlation between SSI and SE. It may provide a new way to study the mechanism of myopia. In different grades of myopia, the SSI values were lower in eyes with higher SE. This indicates that the mechanical strength of the cornea may be compromised in high myopia. Future studies can corroborate the findings of our study. A longitudinal study in progressive and stable myopic participants is warranted.

6 Abbreviations

A1-time: the first and applanation time; A2-time: the second applanation time; ARTh: ambrosio relational thickness horizontal; bIOP: biomechanically corrected intraocular pressure; CBI: Corvis biomechanical index; CH: corneal hysteresis; Corvis ST: corneal visualisation Scheimpflug technology; CCT: central corneal thickness; CI: confidence interval; DA: deformation amplitude; DCR: dynamic corneal response; DefAmax: maximum deflection amplitude; HCDefArea: deflection area; IR: integrated radius; Km: mean keratometry; IOP: intraocular pressure; PD: peak distance; SE: spherical equivalent; SP-A1: stiffness parameter; SP-HC: stiffness parameter at highest concavity; SSI: stress-strain index; WEM: whole eye movement

7 Declarations

7.1 Ethics approval and consent to participate

The study adhered to the tenets of the Declaration of Helsinki and was approved by the ethics committee at Tianjin Eye Hospital.

7.2 Consent for publication

Not applicable.

7.3 Availability of data and materials

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

7.4 Competing interests

The authors declare that they have no competing interests.

7.5 Funding

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7.6 Authors’ contributions

FH and YW contributed to the conception of the work. FH, PHW and MD.L performed data acquisition and analysis, as well as drafting of the manuscript. JN.M was also involved in data analysis. YW and Vishal Jhanji revised the manuscript and produced the final version. All authors reviewed and approved the final manuscript.

7.7 Acknowledgements

Not applicable.

8 References

1. Oner V, Tas M, Ozkaya E, Oruc Y: Effect of pathological myopia on biomechanical properties: a study by ocular response analyzer. Int J Ophthalmol 2015, 8(2):365-368.

2. MB, KT, CG, WS, KS K: Five-year results of Small Incision Lenticule Extraction (ReLEx SMILE). The British journal of ophthalmology 2016, 100(9):1192-1195.

3. Tian L, Ko MW, Wang LK, Zhang JY, Li TJ, Huang YF, Zheng YP: Assessment of ocular biomechanics using dynamic ultra-high-speed Scheimpflug imaging in keratoconic and normal eyes. J Refract Surg 2014, 30(11):785-791.

4. Qiu K, Zhang R, Wang G, Zhang M: Relationship of corneal hysteresis and optic nerve parameters in healthy myopic subjects. Scientific Reports 2017, 7(1):17538-17537.
5. He M, Wang W, Ding H, Zhong X: Corneal Biomechanical Properties in High Myopia Measured by Dynamic Scheimpflug Imaging Technology. *Optom Vis Sci* 2017, 94(12):1074-1080.

6. X J, J Y, SH L, XC D: Biomechanics of the sclera and effects on intraocular pressure. *International journal of ophthalmology* 2016, 9(12):1824-1831.

7. Xu H, Zong Y, Zhai R, Kong X, Jiang C, Sun X: Intereye and intraeye asymmetry analysis of retinal microvascular and neural structure parameters for diagnosis of primary open-angle glaucoma. *Eye (Lond)* 2019.

8. A E, B G, P R, M C, KM M: Characterization of age-related variation in corneal biomechanical properties. *Journal of the Royal Society, Interface* 2010, 7(51):1475-1485.

9. Holden BA, Frick TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, Wong TY, Naduvilath TJ, Resnikoff S: Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050. *Ophthalmology* 2016, 123(5):1036-1042.

10. Wei S, Sun Y, Li S, Hu J, Yang X, Lin C, Cao K, J D, Guo J, Li H *et al*: Refractive Errors in University Students in Central China: The Anyang University Students Eye Study. *Invest Ophthalmol Vis Sci* 2018, 59(11):4691-4700.

11. Hung GK, Mahadas K, Mohammad F: Eye growth and myopia development: Unifying theory and Matlab model. *Comput Biol Med* 2016, 70:106-118.

12. Lee MW, Kim JM, Shin YI, Jo YJ, Kim JY: Longitudinal Changes in Peripapillary Retinal Nerve Fiber Layer Thickness in High Myopia: A Prospective, Observational Study. *Ophthalmology* 2019, 126(4):522-528.

13. TW L, AK L, CS K: Corneal shapes of Chinese emmetropes and myopic astigmats aged 10 to 45 years. *Optometry and vision science: official publication of the American Academy of Optometry* 2013, 90(11):1259-1266.

14. Cohen Y, Belkin M, Yehezkel O, Avni I, Polat U: Light intensity modulates corneal power and refraction in the chick eye exposed to continuous light. *Vision Res* 2008, 48(21):2329-2335.

15. Rucker F, Britton S, Spatcher M, Hanowsky S: Blue Light Protects Against Temporal Frequency Sensitive Refractive Changes. *Invest Ophthalmol Vis Sci* 2015, 56(10):6121-6131.

16. Wong YZ, Lam AK: The roles of cornea and axial length in corneal hysteresis among emmetropes and high myopes: a pilot study. *Curr Eye Res* 2015, 40(3):282-289.

17. A E, KJ C, R V, O M, P V, R A, CJ R, A E: Ex-vivo experimental validation of biomechanically-corrected intraocular pressure measurements on human eyes using the CorVis ST. *Experimental eye research* 2018, 175:98-102.

18. Roberts CJ: Concepts and misconceptions in corneal biomechanics. *J Cataract Refract Surg* 2014, 40(6):862-869.

19. Bueno-Gimeno I, España-Gregori E, Gene-Sampedro A, Lanzagorta-Aresti A, Piñero-Llorens DP: Relationship among Corneal Biomechanics, Refractive Error, and Axial Length. *Optometry and Vision Science* 2014, 91(5):507-513.

20. Shen M, Fan F, Xue A, Wang J, Zhou X, Lu F: Biomechanical properties of the cornea in high myopia. *Vision Res* 2008, 48(21):2167-2171.

21. Ha A, Kim YK, Baek SU, Park KH, Jeoung JW: Optic Disc Microhemorrhage in Primary Open-Angle Glaucoma: Clinical Implications for Visual Field Progression. *Invest Ophthalmol Vis Sci* 2019, 60(6):1824-1832.

22. LL L, GG G, YH C, AF A, AK K, EL S, DT L, TS M: Cornea biomechanical characteristics and their correlates with refractive error in Singaporean children. *Investigative ophthalmology & visual science* 2008, 49(9):3852-3857.

23. K K, M H, FF F, KS S: Factors affecting corneal hysteresis in normal eyes. *Graefes archive for clinical and experimental ophthalmology = Albrecht von Graefes Archiv fur klinische und experimentelle Ophthalmologie* 2008, 246(10):1491-1494.

24. Wang J, Li Y, Jin Y, Yang X, Zhao C, Long Q: Corneal Biomechanical Properties in Myopic Eyes Measured by a Dynamic Scheimpflug Analyzer. *J Ophthalmol* 2015, 2015:161869.

25. SG Ç, SA K, B A-B, M T-Ç: Relationship among Corneal Biomechanics, Anterior Segment Parameters, and Geometric Corneal Parameters. *Journal of ophthalmology* 2016, 2016:8418613.

26. Ma J, Wang Y, Hao W, Jhanji V: Comparative analysis of biomechanically corrected intraocular pressure with corneal visualization Scheimpflug technology versus conventional noncontact intraocular pressure. *International ophthalmology* 2020, 40(1):117-124.

27. Vinciguerra R, Ambrosio RJ, Elsheikh A, Roberts CJ, Lopes B, Morenghi E, Azzolini C, Vinciguerra P: Detection of Keratoconus With a New Biomechanical Index. *J Refract Surg* 2016, 32(12):803-810.

28. Shah S, Laiquzzaman M, Yeung I, Pan X, Roberts C: The use of the Ocular Response Analyser to determine corneal hysteresis in eyes before and after excimer laser refractive surgery. *Cont Lens Anterior Eye* 2009, 32(3):123-128.

29. B G, SW J, PR R, RA A, EA E: Age-related variations in the biomechanical properties of human sclera. *Journal of the mechanical behavior of biomedical materials* 2012, 16:181-191.
30. Ali NQ, Patel DV, McGhee CN: Biomechanical responses of healthy and keratoconic corneas measured using a noncontact scheimpflug-based tonometer. *Invest Ophthalmol Vis Sci* 2014, 55(6):3651-3659.