The Correlation between Biomechanical Properties of Normal Cornea with Tomographic Parameters of Pentacam

Hadi Ostadimoghaddam, PhD[1] • Mohammad Reza Sedaghat, MD[2]
Seyyed Hosein Hoseini Yazdi, MSc[3] • Hamed Niyazmand, MSc[4]

Abstract

Purpose: To investigate the correlation between corneal biomechanical properties and tomographic parameters of Pentacam

Methods: Corneal biomechanical properties and tomographic results of 36 normal subjects were measured by Ocular Response Analyzer (ORA) and Pentacam and the correlation between these two measurements were analyzed with Pearson correlation test with SPSS version16.

Results: Significant correlation was found between corneal hysteresis (CH) and central corneal thickness (CCT), depth and angle of the anterior chamber, corneal shape factor and corneal volume ($P<0.05$). Strong association between corneal resistance factor (CRF) and CCT was also found ($P<0.05$). Goldmann correlated intraocular pressure (IOPg) had significant positive relation with CCT and negatively correlated with corneal power in different areas ($P<0.05$). Corneal compensated intraocular pressure (IOPcc) had no significant correlation with CCT ($P>0.05$).

Conclusion: Corneal thickness had an effective role in determining biomechanical properties of this tissue. In addition, significant correlation between CH and corneal volume was also found. Since corneal volume is a three dimensional parameter, it can play a more effective role than corneal thickness, the two dimensional parameter, in determining biomechanical properties of cornea.

Keywords: Corneal Hysteresis, Corneal Resistance Factor, Pentacam, Ocular Response Analyzer

1. Associate Professor of Optometry, Department of Optometry, School of Paramedical Sciences, Mashhad University of Medical Sciences, Mashhad, Iran
2. Associate Professor of Ophthalmology, Khatam-al-Anbia Hospital, Mashhad University of Medical Sciences, Mashhad, Iran
3. Research Assistant, Department of Optometry, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran
4. Research Assistant, Department of Optometry, School of Paramedical, Mashhad University of Medical Sciences, Mashhad, Iran

Correspondence to: *Hamed Niyazmand, MSc*
Research Assistant, Department of Optometry, School of Paramedical, Mashhad University of Medical Sciences, Mashhad, Iran,
Email: hamed_optometry@yahoo.com

Introduction

The human cornea is a viscoelastic tissue[1] that can be described by 2 principal properties: (1) a static resistance component [characterized by the corneal resistance factor (CRF)], for which deformation is proportional to applied force, and (2) a dynamic resistance component [characterized by corneal hysteresis (CH)], for which the relationship between deformation and applied force depends on time.[2] These properties of the cornea have been assessed by Ocular Response Analyzer (ORA) in different studies. Whereas CH may reflect mostly corneal viscosity, CRF may predominantly be related to the elastic properties of the cornea.[3] CH represents the viscoelastic status of the cornea and can show the corneal biomechanical rigidity as well. Therefore, knowing the CH and CRF values is helpful before conducting refractive surgeries, measuring intraocular pressure (IOP) and diagnosing corneal pathologies such as keratoconus, keratoglobus and Fuchs' dystrophy.[4]

By measuring CH and CRF, two other parameters named corneal compensated IOP (IOPcc) and Goldmann correlated IOP (IOPg) can also be calculated by ORA. As IOP measurement after refractive surgery with conventional tonometers could artificially show lower results due to corneal changes, measuring IOPcc is important in assessing IOP after refractive surgeries[3]; since this parameter partially compensates for corneal properties and as a result it can be a more accurate indicator of the true IOP.[2]

Moreover, different studies have investigated the role of other corneal parameters or ocular conditions on determining biomechanical properties of cornea. The relationship between central corneal thickness (CCT) and CH has been proven in previous studies;[5-7] but there was no correlation between CH and keratometry results, sex, age and spherical equivalent.[7] The influence of ocular refraction on CH has been investigated and indicated that high myopic patients have lower CH than normal group.[8]

Other studies have reported the decrease in CH after LASIK.[2]

Luce[4] the inventor of the ORA, indicated that corneal biomechanical properties are a function of more than variations in corneal thickness. Furthermore, to know which parameters of the cornea and anterior segment might contribute to findings by ORA is of great importance for controlling the confounding factors in different corneal biomechanical studies. Therefore, we designed this study to investigate how the association of anterior segment and corneal refractive parameters measured by rotating Scheimpflug camera (Pentacam HR, Oculus Inc, Germany) is with biomechanical properties of the cornea measured by ORA in normal patients.

Methods

Right eyes of 36 subjects including 12 males and 24 females with the age range of 20 to 30 years were examined. There was no history of any ocular pathology and surgery, trauma or use of contact lenses in the eyes being tested. Subjects were excluded from the study if corneal ectasia was diagnosed with retinoscopy, keratometry and slit-lamp examination or forme fruste keratoconus was diagnosed after conducting corneal topography. All patients signed an informed consent in accordance with the tenets of the Declaration of Helsinki.

The examination was started first by corneal tomography with Pentacam HR (Oculus Inc, Germany). The patient was seated with his or her chin on a chinrest and forehead against the forehead strap and asked to fixate ahead on a blue light target. To reduce operator-dependent variables, the Pentacam's automatic release mode was used. In this mode, the instrument automatically determines when correct focus and alignment with the corneal apex have been achieved and then performs a scan in less than 2 seconds, the rotating camera captures up to 50 slit images of the anterior segment, while minute eye movements are captured by the second camera and corrected simultaneously.[9] Different indices reliability and repeatability of Pentacam in measuring such factors as anterior corneal curvature, anterior chamber and peripheral corneal thickness have been reported in other studies.[10,11]

After that, biomechanical status of the same eyes was measured by Ocular

Response Analyzer (ORA; Reichert Corp, Buffalo, NY, USA).

The patients were seated in front of the machine and was asked to fixate on a red light target. A fully automated alignment system positioned an air tube to a precise position relative to the apex of the cornea. Once aligned, a 25-millisecond air pulse applied pressure to the cornea. The air pulse causes the cornea to move inward, past applanation and into a slight concavity before returning to normal curvature.[5] Then two pressures are measurable through ORA signal. P_1 is the pressure at the first applanation event as the cornea moves inward under the increasing force of air pulse (inward applanation). P_1 is similar to the air-pulse system usually used in noncontact tonometry to measure IOP. P_2 is the pressure corresponding to the second applanation event as the cornea returns to its normal curvature under the decreasing force of the air pulse (outward applanation). Due to the dynamic nature of the measurement process, viscous damping in the cornea causes energy absorption and results in two different pressure values at the inward and outward events, with the second outward applanation pressure always lower than the first inward applanation pressure. The ORA produces two measurements of corneal biomechanical properties, CH and the CRF. CH represents the absolute difference between the applanation pressures P_1 and P_2, and the CRF is derived from the formula $(P_1 - kP_2)$, where k is a constant. The constant k was determined from an empirical analysis of the relationship between both P_1 and P_2 and CCT in order to develop a corneal parameter more strongly associated with CCT than CH.[12]

In addition the average of P_1 and P_2 provides the IOPg. IOPcc is another IOP given, which is less affected by corneal properties and not correlated with CCT as the manufacturer stated. IOPcc is derived from the difference between P_1 and P_2 using the formula $(P_1 - 0.43P_2)$.[13] The ORA produces repeatable measurements of corneal biomechanical properties and IOP measurements.[14]

Four measurements were obtained with each instrument and then results were averaged. The results of Pentacam and ORA were analyzed with SPSS 16 by Pearson correlation test at statistical significance of P<0.05.

Results

Thirty-six subjects (67% females and 33% males) with the mean age of 22.8 years were studied. No significant correlation was found between CH, CRF, IOPg and IOPcc with age and sex (P>0.05).

Correlation between corneal hysteresis and corneal tomographic parameters

The mean CH value was 10.07±1.50 mmHg in our normal subjects. There was significant positive correlation between CH value and CCT (P=0.001, r=+0.51), superior corneal thickness (P= 0.008, r=+0.43), inferior corneal thickness (P=0.005, r=+0.46) and central corneal elevation (P=0.03, r=+0.35) (Table 1). The positive association of CH with corneal volume was also significant (P=0.004, r=+0.46) (Figure 1). On the other hand, significant negative correlation was observed between CH value and volume (P=0.001, r=-0.52), depth (P=0.01, r=-0.39) and angle (P=0.007, r=-0.44) of the anterior chamber. Shape factor (Q) was related negatively with CH value (P=0.02, r=-0.38) such that the more negative the shape factor was; the higher CH values resulted and as the shape factor got closer to zero, lower CH values was the result. There was not significant correlation between CH and other corneal tomographic parameters (P>0.05).

Correlation between corneal resistance factor and corneal tomographic parameters

The mean CRF value was 9.67±1.50 mmHg in our normal subjects. There was significant positive correlation between CRF and central, superior and inferior corneal thickness (Table 2). On the other hand, CRF had significant negative correlation with superior and inferior corneal power (P=0.004, r=-0.47; P=0.009, r=-0.42; respectively). There was not significant correlation between CRF and other corneal tomographic parameters (P>0.05).

Correlation between Goldmann correlated intraocular pressure and corneal tomographic parameters

The mean IOPg value in our normal subjects was 13.99±3.38 mmHg. There was significant positive correlation of IOPg with central and

thinnest corneal thickness (P=0.007, r=+0.44; P=0.008, r=+0.43 respectively), superior corneal thickness (P=0.005, r=+0.45), minimum posterior power (P=0.000, r=+0.58) and maximum posterior power (P=0.02, r=+0.38).

IOPg had significant negative correlation with central corneal power (P=0.001, r=-0.53), inferior and superior corneal power (P=0.007, r=-0.44; P=0.005, r=-0.45, respectively). No significant correlation was observed between IOPg and other corneal tomographic parameters (P>0.05).

Correlation between corneal compensated intraocular pressure and corneal tomographic parameters

There was significant correlation of IOPcc with anterior chamber volume (P=0.002, r=+0.51), anterior chamber depth (P=0.01, r=+0.40) (Table 3). No significant correlation was observed between IOPcc and other corneal tomographic parameters (P>0.05).
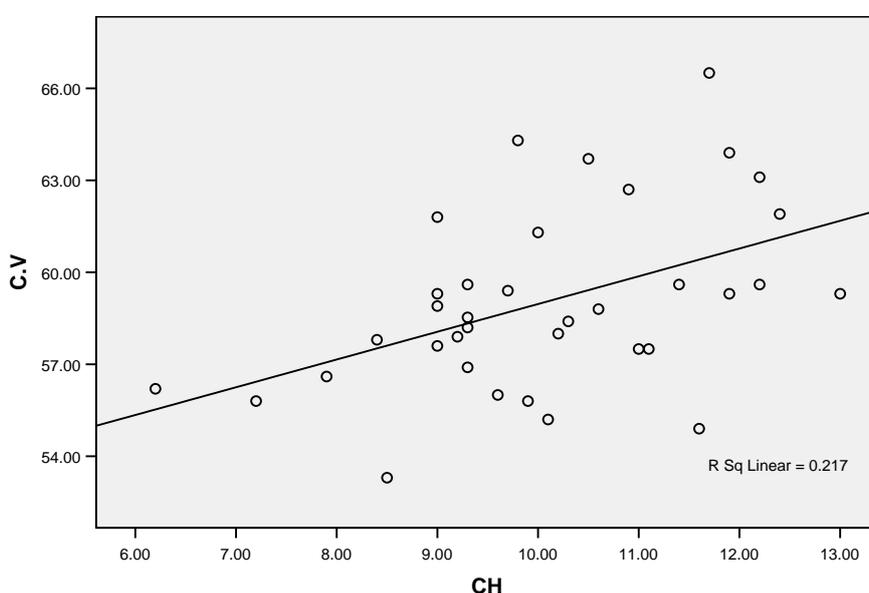

Figure1. The corneal hysteresis value versus corneal volume
C.V: Corneal volume (mm^3), CH: Corneal hysteresis (mmHg)

Table 1. Significant correlations between corneal hysteresis and corneal tomographic parameters

	P	Pearson correlation
Shape factor(Q)	0.02	-0.38
Central corneal thickness	0.001	+0.51
Thinnest corneal thickness	0.002	+0.50
Central corneal elevation	0.03	+0.35
Corneal volume	0.004	+0.46
Anterior chamber volume	0.001	-0.52
Anterior chamber depth	0.01	-0.39
Anterior chamber angle	0.007	-0.44
Superior corneal thickness	0.008	+0.43

Table 2. Significant correlations between corneal resistance factor and corneal tomographic parameters

	P	Pearson correlation
Central corneal thickness	0.000	+0.71
Thinnest corneal thickness	0.000	+0.50
Inferior corneal power	0.009	-0.42
Superior corneal power	0.004	-0.47
anterior chamber angle	0.02	-0.38
Superior corneal thickness	0.000	+0.65
Inferior corneal thickness	0.000	+0.59

Table 3. Significant correlations between corneal compensated intraocular pressure and corneal tomographic parameters

	P	Pearson correlation
Min and Max anterior power	0.02	-0.40
Anterior chamber volume	0.002	+0.51
Anterior chamber depth	0.01	+0.40
Central corneal power	0.01	-0.41
Central corneal elevation	0.03	-0.37

Discussion

The considerable overlap of CH values between normal and diseased corneas presents major challenges when using the ORA as a diagnostic aid.[15,16] Indeed, known or unknown factors, unless controlled for, could confound the interpretation of CH values.[16] So this study was designed to investigate if corneal and anterior segment parameters have any correlations with ORA measurements.

Emphasizing the difference between the inward and outward applanation pressures, CH describes the damping nature of the cornea[5] and is a positive measure of the cornea's biomechanical properties. Normal CH values are between 8 mmHg and 15 mmHg.[17] In Shah et al[6] study the mean CH and CRF values were 10.7±2.0 mmHg and 10.3±2.0 mmHg, respectively. Similarly we found CH and CRF values to be 10.07±1.50 mmHg and 9.60±1.50 mmHg, respectively. Other studies reported similar results for CH value.[18]

Being in line with the results of other studies[5,6,22] we found that CH positively correlated with CCT. In fact, as CCT increased the overall resistance to deformation of the cornea was also increased; thus resulted in higher levels of CH. Since 90% of corneal thickness is consisted of stromal layer, corneal stroma plays an important role in determining biomechanical and refractive properties of the cornea.[19] Generally, the thickness of the cornea can be an important factor in determining corneal biomechanical properties. The normal human corneal stroma is characterized by two preferred collagen fibril orientations orthogonal to each other which corneal biomechanical properties are strongly depended on them such that alteration of the regular orthogonal arrangement of the fibrils in keratoconus may be related to the biomechanical instability of the tissue.[20] Other studies have found that the specific architecture of the most anterior part of the corneal stroma (100-120 µm) is responsible for the stability of the corneal shape.[21]

However, the results in this study revealed a stronger positive correlation of CRF than CH with CCT. Touboul et al[5] also noticed that CRF had a strong positive correlation with

15

CCT measured with ultrasonography in the normal group; CH had a lower correlation. On the other hand Shah et al[6,22] found that hysteresis and CRF measured by the ORA have a positive but moderate correlation to CCT; the higher the CCT the higher the hysteresis (visco-elasticity) and CRF (elasticity). In agreement with Touboul et al[5] conclusion we also believe that corneal thickness has an important role in the damping process and more so in the elastic properties of cornea.

Despite the correlation observed between CCT with CH and CRF in our study, Broman et al[23] reported that eyes with the same CCT produced varying levels of CH, implying that other unidentified factors may be influencing corneal biomechanics. Indeed, the moderate levels of correlation found in our study between these variables suggests that other unknown biomechanical factors must also contribute towards the characteristics of CH.[18,24] As our results indicated, one of these factors might be corneal volume. Results of our study showed positive correlation between CH and corneal volume. We did not find any significant correlation between CRF and corneal volume, however. Pathel[25] also demonstrated that corneal volume was a slightly improved predictor for CH but not CRF, suggesting that CH may reflect a more composite effect of corneal thickness and contour variation. Since corneal volume is a three dimensional parameter, it can play a more effective role than corneal thickness, the two dimensional parameter, in determining biomechanical properties of cornea. Other studies noticed the important role of corneal volume in detecting keratoconus.[26,27] Fallah Tafti et al[27] suggested that Pentacam derived parameters like corneal volume distribution and percentage increase in volume can be helpful in differentiation of mild and moderate forms of keratoconus from normal corneas.

Our results revealed the negative relationship between CH and corneal shape factor; so that the more negative shape factor values correspond with the higher values of CH and as it gets closer to zero, lower values of CH result. Considering this relationship, myopic patients might have different CH than hyperopic patients. Although CH and CRF were not related to spherical equivalent in Montard et al[7] study, but CH was significantly lower in high myopia patients compared to that in normal subjects in Shen et al study.[8] We didn't find significant correlation between CRF and the shape factor in our study, however (P=0.19).

We found that CH was negatively related to angle, volume and depth of the anterior chamber. Chang et al[28] reported lower levels of CH to be associated with deeper anterior chamber depth. In Fontes et al[29] study, subjects with mild keratoconus had statistically higher anterior chamber depth combined with lower levels of CH compared with controls. Other studies have reported the relationship of CH with corneal diameter.[7] Therefore it might be assumed that longer distance between corneal apex to limbus corresponds with lower corneal dynamic resistance.

According to the results of our study, IOPg had a negative correlation with dioptric power of all parts of anterior cornea, and a positive correlation with corneal thickness and power in posterior of cornea that should be investigated in future studies.

Finally we found no significant association between IOPcc and CCT. In fact as our results show IOPcc has the minimal influence from other confounding corneal factors and in those significant correlations, the correlation coefficient is not such strong. This indicates that IOPcc can be an independent measure of IOP from other corneal factors.[30]

Conclusion

Our results revealed that the greater the amounts of CCT and corneal volume were, and the lesser the amount of shape factor, anterior chamber volume, angle and depth were, the stiffer cornea with higher CH was resulted. Since corneal volume is a three dimensional parameter, it can play a more effective role than corneal thickness, the two dimensional parameter, in determining biomechanical properties of cornea. Future studies are required for further investigation on the influence of corneal volume on biomechanical properties of this tissue.

References

1. Dupps WJ Jr, Wilson SE. Biomechanics and wound healing in the cornea. Exp Eye Res 2006;83(4):709-20.
2. Ortiz D, Piñero D, Shabayek MH, et al. Corneal biomechanical properties in normal, post-laser in situ keratomileusis, and keratoconic eyes. J Cataract Refract Surg 2007;33(8):1371-5.
3. Pepose JS, Feigenbaum SK, Qazi MA, et al. Changes in corneal biomechanics and intraocular pressure following LASIK using static, dynamic, and noncontact tonometry. Am J Ophthalmol 2007;143(1):39-47.
4. Luce DA. Determining in vivo biomechanical properties of the cornea with an ocular response analyzer. J Refract Cataract Surg 2005;31(1):156-62.
5. Touboul D, Roberts C, Kérautret J, et al. Correlations between corneal hysteresis, intraocular pressure, and corneal central pachymetry. J Cataract Refract Surg 2008;34(4):616-22.
6. Shah S, Laiquzzaman M, Cunliffe I, Mantry S. The use of the Reichert ocular response analyser to establish the relationship between ocular hysteresis, corneal resistance factor and central corneal thickness in normal eyes. Cont Lens Anterior Eye 2006;29(5):257-62.
7. Montard R, Kopito R, Touzeau O, et al. [Ocular response analyzer: feasibility study and correlation with normal eyes]. J Fr Ophtalmol 2007;30(10):978-84.
8. Shen M, Fan F, Xue A, et al. Biomechanical properties of the cornea in high myopia. Vision Res 2008;48(21):2167-71.
9. Al-Mezaine HS, Al-Amro SA, Kangave D, et al. Comparison between central corneal thickness measurements by oculus pentacam and ultrasonic pachymetry. Int Ophthalmol 2008;28(5):333-8.
10. Kawamorita T, Uozato H, Kamiya K, et al. Repeatability, reproducibility, and agreement characteristics of rotating Scheimpflug photography and scanning-slit corneal topography for corneal power measurement. J Cataract Refract Surg 2009;35(1):127-33.
11. Shankar H, Taranath D, Santhirathelagan CT, Pesudovs K. Anterior segment biometry with the Pentacam: comprehensive assessment of repeatability of automated measurements. J Cataract Refract Surg 2008;34(1):103-13.
12. Kotecha A. What biomechanical properties of the cornea are relevant for the clinician? Surv Ophthalmol 2007;52 Suppl 2:S109-14.
13. Medeiros FA, Weinreb RN. Evaluation of the influence of corneal biomechanical properties on intraocular pressure measurements using the ocular response analyzer. J Glaucoma 2006;15(5):364-70.
14. Moreno-Montañés J, Maldonado MJ, García N, et al. Reproducibility and clinical relevance of the ocular response analyzer in nonoperated eyes: corneal biomechanical and tonometric implications. Invest Ophthalmol Vis Sci 2008;49(3):968-74.
15. Dupps WJ Jr. Hysteresis: new mechanospeak for the ophthalmologist. J Cataract Refract Surg 2007;33(9):1499-501.
16. McMonnies CW. Assessing corneal hysteresis using the ocular response analyzer. Optom Vis Sci 2011 Dec 22. [Epub ahead of print]
17. Liu J, Roberts CJ. Influence of corneal biomechanical properties on intraocular pressure measurement: quantitative analysis. J Cataract Refract Surg 2005;31(1):146-55.
18. Kamiya K, Hagishima M, Fujimura F, Shimizu K. Factors affecting corneal hysteresis in normal eyes. Graefes Arch Clin Exp Ophthalmol 2008;246(10):1491-4.
19. Tripathi RC, Tripathi BJ. Anatomy of the human eye and adenexa. In: Dawson H, ed, The eye. Vegetative physiology and biochemistry, Academic Press, Florida, USA, 1984:1-102.
20. Daxer A, Fratzl P. Collagen fibril orientation in the human cornea stroma and its implication in keratoconus. Invest Ophthalmol Vis Sci 1997;38(1):121-9.
21. Müller L, Pels E, Vrensen GF. The specific architecture of the anterior stroma accounts for maintenance of corneal curvature. Br J Ophthalmol 2001;85(4):437-43.

22. Shah S, Laiquzzaman M, Mantry S, Cunliffe I. Ocular response analyser to assess hysteresis and corneal resistance factor in low tension, open angle glaucoma and ocular hypertension. Clin Experiment Ophthalmol 2008;36(6):508-13.
23. Broman AT, Congdon NG, Bandeen-Roche K, Quigley HA. Influence of corneal structure, corneal responsiveness, and other ocular parameters on tonometric measurement of intraocular pressure. J Glaucoma 2007;16(7):581-8.
24. Kirwan C, O'Keefe M. Corneal hysteresis using the Reichert ocular response analyser: findings pre- and post-LASIK and LASEK. Acta Ophthalmol 2008;86(2):215-8.
25. Patel HD. Biomechanical aspects of the anterior segment in human myopia. PhD thesis, School of Life and Health Sciences, Aston University, Birmingham, United Kingdom. 2010.
26. Ambrósio R Jr, Alonso RS, Luz A, Coca Velarde LG. Corneal-thickness spatial profile and corneal-volume distribution: tomographic indices to detect keratoconus. J Cataract Refract Surg 2006;32(11):1851-9.
27. Fallah Tafti MR, Heidarian Sh, Kiarudi MY, et al. The role of corneal volume distribution and percentage increase in volume in detection of mild and moderate keratoconus. Iranian Journal of Ophthalmology 2010;22(4):49-58.
28. Chang PY, Chang SW, Wang JY. Assessment of corneal biomechanical properties and intraocular pressure with Ocular Response Analyzer in childhood myopia. Br J Ophthalmol 2010;94(7):877-81.
29. Fontes BM, Ambrósio R Jr, Jardim D, et al. Corneal biomechanical metrics and anterior segment parameters in mild keratoconus. Ophthalmology 2010;117(4):673-9.
30. Lam A, Chen D, Chiu R, Chui WS. Comparison of IOP measurements between ORA and GAT in normal Chinese. Optom Vis Sci 2007;84(9):909-14.