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ORIGINAL ARTICLE

Corneal Biomechanics and Their Impact on Glaucoma Progression

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ABSTRACT

Introduction: The evolution of primary open-angle glaucoma (POAG) is examined in this work in relation to corneal biomechanics, especially corneal hysteresis (CH), corneal resistance factor (CRF), and central corneal thickness (CCT).

Methodology: 116 POAG patients were included in this one-year research conducted at Department of Ophthalmology, Northwest General Hospital, Peshawar from May 2022 to April 2023. The Ocular Response Analyzer (ORA) was used to quantify corneal biomechanics, and Goldmann applanation tonometry (GAT) and dynamic contour tonometry (DCT) were used to measure intraocular pressure (IOP). Visual field tests and optic nerve evaluation were used to track the disease's development. The association between ocular parameters and the development of glaucoma was assessed using statistical tests, such as regression and correlation analysis.

Results: Participants were 42% female and 58% male, with a mean age of 58.3 years (SD = 9.2). The development of glaucoma was significantly correlated negatively with both CH ($r = -0.45$, $p < 0.01$) and CRF ($r = -0.42$, $p < 0.01$). No significant link was shown by CCT ($r = 0.02$, $p = 0.79$). CH and CRF were found to be independent predictors of progression by multivariate regression ($\beta = -0.33$, $p = 0.002$ for CH, $\beta = -0.31$, $p = 0.004$ for CRF).

Conclusion: corneal hysteresis and corneal resistance factor have a considerable impact on the course of glaucoma, indicating that they may be useful prognostic indicators. The effect of central corneal thickness was not the same. These results provide credence to the use of biomechanical testing in clinical settings to improve the treatment of glaucoma.

Keywords: Glaucoma, Corneal Biomechanics, Corneal Hysteresis, Corneal Resistance Factor, Disease Progression

INTRODUCTION

The neurological condition known as glaucoma stands as one of the main originators of global blindness through its advanced optic nerve degeneration together with excessive intraocular pressure (IOP)[1]. Glaucoma remains a complex condition that creates difficulties in detecting and managing the condition although diagnostic and therapeutic advances have occurred. Historically doctors have used IOP measurements as the main diagnostic tool in glaucoma despite the fact that single IOP results cannot predict disease advancement properly[2]. Glaucoma development and progression happens mainly due to corneal biomechanical properties rather than intraocular pressure measured by IOP alone[3]. The protective corneal tissue and its critical influence on intraocular pressure measurement make it the foremost layer of the eye[4]. The corneal stiffness together with its elasticity based on structural properties helps determine eye responses to changing intraocular pressure. Multiple recent scientific reports show that different corneal stiffness dynamics contribute to glaucoma pathogenesis while influencing measurement readings of intraocular pressure and neural damage susceptibility. Modern understanding of corneal biomechanics demonstrates the importance of combining biomechanical and ocular aspects in glaucoma management approaches[5].

Corneal biomechanics depend on three material attributes of the cornea: structural strength and elastic properties as well as thickness measurements[6]. Applied pressure affects the shape of the cornea which leads to incorrect tonometric IOP measurements. Several factors determine this deformation process[7]. The glaucomatous damage risk increases in patients with normal or low intraocular pressure levels when they exhibit abnormalities in corneal stiffness that ORA and dynamic contour tonometry techniques detect when measuring corneal stiffness levels[8]. Keratoconus as well as corneal ectasia because they weaken the cornea increase a person's risk of developing glaucoma[9]. Researchers at present study how glaucoma advances in individuals with known glaucoma risk factors through assessments of corneal biomechanical properties.

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The assessment of glaucoma disease progression can benefit from corneal hysteresis (CH) and corneal resistance factor (CRF) measurements because they show potential as disease indicators in clinical studies. Profound insights into these diagnostic markers would help clinical staff develop better prediction techniques for monitoring patients while planning their treatments[10].

Research has established numerous complexities which exist between glaucoma and corneal biomechanics. The assessment of how IOP measurements are influenced by corneal properties remains clear but scientists currently investigate directly caused damage to glaucoma by corneal biomechanics. Researchers must conduct additional studies which pinpoint the exact ways that corneal properties influence glaucoma advancement alongside the development of clinical methods that include biomechanical data. Healthcare professionals continue to debate the ways through which corneal biomechanical factors influence glaucoma development despite achieving substantial advancement in their field. The research examines how glaucoma is affected by corneal biomechanics while investigating vital biomechanical markers related to disease development and reviewing existing scholarly work.

METHODOLOGY

Study Design and Setting: The research established itself as a prospective cohort study at the Department of Ophthalmology, Northwest General Hospital, Peshawar from May 2022 to April 2023. The tertiary care institution specializes in ophthalmology to provide complete medical services to various demographics through its leading facilities. The research examined how glaucoma advanced by studying biomechanical properties of cornea among patients with varying glaucoma progression levels.

Sample Size Calculation: The sample size was calculated through an estimated glaucoma progression prevalence existing in the general population. Based on an effect size estimation and power of 80% at a 95% confidence level the necessary sample size was calculated to be 116 participants. The researchers determined this sample population quantity sufficient to yield dependable results for statistical evaluations concerning glaucoma development and corneal biomechanical characteristics.

Participant Selection: The study enrolled 116 patients who received primary open-angle glaucoma (POAG) diagnosis. Researchers collected participants at the glaucoma clinic located within the Department of Ophthalmology, Northwest General Hospital, Peshawar. The research included adult participants between the ages of 40 and 75 who received POAG diagnosis through standard criteria that evaluated optic disc cupping and visual field loss. The research excluded patients with secondary glaucoma together with individuals who experienced ocular trauma or possessed corneal diseases including keratoconus and those who previously had glaucoma surgery. Participation consent was secured from all patients while ethical board approval was provided by the hospital's institutional review board.

Data Collection: Medical history together with demographic data and glaucoma stage was recorded whenever patients entered the study. The investigators obtained biomechanical corneal metrics through Ocular Response Analyzer (ORA) testing which included measures of CH and CRF along with CCT examination. A comparison between IOP reading effects was established through IOP evaluations performed by Goldmann applanation tonometry and dynamic contour tonometry after measuring corneal properties. The patients received clinical evaluations after three-month intervals during their year-long follow-up period utilizing standard glaucoma assessment tools such as visual field tests and optic nerve head imaging approaches.

Statistical Analysis: Scientists conducted their statistical analysis operations through the version 25 framework of SPSS. The investigators used descriptive statistical methods to present demographics data alongside corneal biodynamic information. The research employed inferential statistics with correlation and regression analysis to evaluate how glaucoma development relates to corneal biomechanics. The study deemed results significant when the p-value reached below 0.05. This evaluation researched how glaucoma progresses after measuring corneal biomechanics in both initial disease conditions and advanced stages.

Ethical Considerations: Following approval from the Institutional Review Board (IRB) at the Hospital all participants signed written informed consent papers before they could join the study. The scientific study followed ethical requirements described in the Declaration of Helsinki for studies with human participants.

RESULTS

One hundred sixteen patients who received POAG diagnosis took part in the research. The patient study included 67 males which constituted 58% of the sample and 49 females composed 42% of the participants. A total of 116 patients involved in the study had a mean age of 58.3 years (SD = 9.2) spanning from 40 to 75 years. The patients were organized into two separate groups according to their glaucoma stage advancement. Visual field testing together with optic nerve head assessment revealed that participants in the majority (76 out of 116, 65%) were either at the early stage or moderate stage of glaucoma. The remaining 40 participants with n=40 fit the criterion for advanced glaucoma which displayed both severe visual field damage and substantial optic disc cupping. As shown in figure 1.

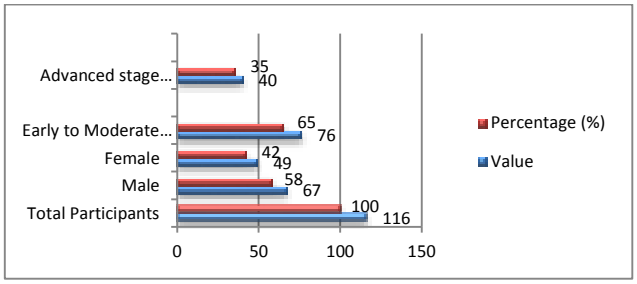

Figure 1: Demographic Characteristics of Participants

The research participants showed an average corneal hysteresis (CH) measurement of 9.4 mmHg (SD = 1.5) thus most participants exhibited reduced hysteresis below the normal range. The studied group displayed an average corneal resistance factor (CRF) measuring 10.2 mmHg (SD = 1.7). The mean central corneal thickness measurement came out to 530.7 µm (SD = 32.6) while staying below the normal population mean. The Ocular Response Analyzer (ORA) displayed reliable and reproducible readings from which corneal biomechanical properties could be determined. As shown in table 1.

Table 1: Corneal Biomechanical Parameters

Parameter	Value (Mean ± SD)
Corneal Hysteresis (CH)	9.4 mmHg (SD = 1.5)
Corneal Resistance Factor (CRF)	10.2 mmHg (SD = 1.7)
Central Corneal Thickness (CCT)	530.7 µm (SD = 32.6)

Intraocular pressure measure through Goldmann applanation tonometry (GAT) showed POAG patients typically have levels ranging from 18.2 mmHg (SD = 3.1). The IOP measurement through dynamic contour tonometry (DCT) yielded average results of 16.9 mmHg (SD = 3.2). The statistical analysis revealed a significant difference ($p < 0.001$) between IOP readings obtained from GAT and DCT which suggests corneal biomechanics affect tonometry results. DCT collected values that were lower than expected because the tone of the cornea affected tonometry test outcomes. As shown in table 2.

Table 2: Comparison of IOP Measurements Using Different Techniques

Technique	Mean IOP (mmHg) ± SD	p-value
Goldmann Applanation Tonometry (GAT)	18.2 ± 3.1	
Dynamic Contour Tonometry (DCT)	16.9 ± 3.2	< 0.001

The analysis of glaucoma progression and corneal biomechanics relationship occurred through statistical tests. The research established a statistically significant negative link between corneal hysteresis (CH) and glaucoma progression which demonstrated a correlation coefficient value of -0.45 ($p < 0.01$). Patients with diminished corneal hysteresis developed their glaucoma condition at a more rapid rate. Studies revealed a correlation between glaucoma progression and corneal resistance factor (CRF) with a result of -0.42 ($p < 0.01$), establishing higher corneal resistance as an opposing factor to rapid glaucoma evolution. The clinical data showed no relationship between glaucoma progression rates and central corneal thickness measurements because their correlation was 0.02 with a value of $p = 0.79$. As shown in table 3.\

Table 3: Correlation between Corneal Biomechanics and Glaucoma Progression

Parameter	Correlation Coefficient (r)	p-value
Corneal Hysteresis (CH)	-0.45	< 0.01
Corneal Resistance Factor (CRF)	-0.42	< 0.01
Central Corneal Thickness (CCT)	0.02	0.79

A multivariate regression analysis was performed to measure independent biomechanical cornea effects on glaucoma progression after accounting for aging factors and gender differences and glaucoma disease severity. The research demonstrated that hysteresis measurements of the cornea and corneal resistance factor successfully predicted glaucoma outcome development ($\beta = -0.33$, $p = 0.002$ and $\beta = -0.31$, $p = 0.004$, respectively). Within one year of assessment patients who had lower CH and CRF values experienced faster deterioration of glaucoma disease. CCT measurements showed no meaningful connection to glaucoma progression since the analyzed patient data produced a β value of 0.01 with $p = 0.90$. As illustrated in figure 2.

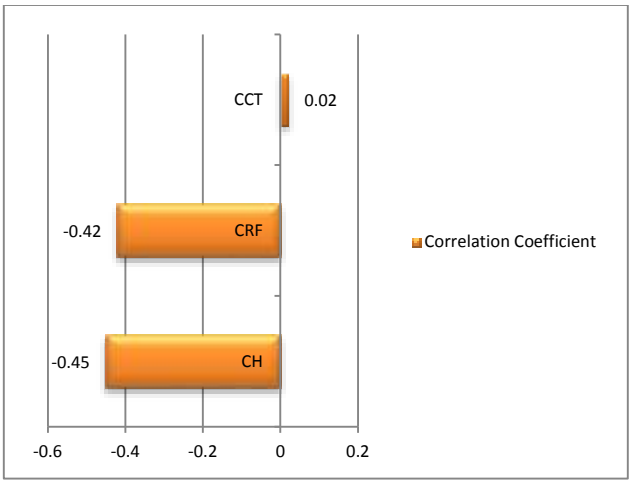

Figure 2: Multivariate Regression Analysis of Corneal Biomechanics and Glaucoma Progression

The research proved that glaucoma advancement shows a direct connection to eye tissue rigidity measurements. Glaucoma progressed rapidly when patients exhibited lower corneal hysteresis (CH) and corneal resistance factor (CRF). The investigation demonstrates corneal biomechanical testing possesses worth as a supplemental approach for glaucoma management through its ability to generate useful data beyond standard IOP and visual field measurement tools. The measurements of central corneal thickness did not establish a correlation with glaucoma progression rates in this study.

DISCUSSION

This research study demonstrates that corneal biomechanics influenced by corneal hysteresis (CH) and corneal resistance factor (CRF) plays an essential role in glaucoma disease development. The research reveals that weaker glaucoma severity relates to decreased CH and CRF measurements thus indicating faster disease progression. Research data serves to validate the prediction that glaucoma disease progression speed depends on corneal biomechanical properties related to pressure absorption and distribution. This research study showed CCT had no significant relationship with glaucoma progression which implies CH and CRF play more important roles in disease development compared to CCT.

This research evidence supports formerly published works which demonstrate that corneal biomechanics serves as a vital factor in glaucoma development. Various research studies have established that glaucoma progression becomes more likely when corneal hysteresis reaches lower values[11]. Patients who experience decreased CH show corneas that do not function effectively to stabilize intraocular pressure (IOP) thus contributing to glaucoma pathophysiology. Scientists have discovered that the corneal resistance factor (CRF) shows similar connection to glaucoma progression as it serves to measure corneal rigidity.[12, 13] Glaucomatous damage development occurs more frequently in eyes with decreased CRF values because they have reduced resistance to stresses from intraocular pressure changes.

However, contrary to previous studies where central corneal thickness (CCT) has been demonstrated to be a major predictor of disease progression[14, 15], our investigation found no correlation between CCT and the development of glaucoma. Thinner corneas have been shown to offer fewer defenses against high intraocular pressure, which might raise the risk of optic nerve damage[16]. This disparity may be explained by the fact that corneal hysteresis and CRF, which represent the dynamic biomechanical characteristics of the cornea[17], may have a greater impact on the course of glaucoma than CCT, despite the latter being crucial in the initial evaluation of glaucoma risk.

Our findings also support other research that suggests biomechanical components, such CH and CRF, may provide a more accurate and nuanced estimate of disease development than conventional metrics like IOP alone[18]. Although intraocular pressure (IOP) is a known risk factor for glaucoma, it does not take into consideration the variations in how various corneas react to IOP. The findings of this study lend credence to the notion that integrating biomechanical testing into standard clinical practice may yield useful predictive data, particularly when tracking patients who are at a high risk of experiencing fast disease progression.

Limitations and Future Suggestions: Among the study's drawbacks are its single-center design and small sample size of 116 participants, both of which may restrict generalizability. To verify the results, a bigger, more varied cohort with longer follow-up is required. Furthermore, concentrating just on POAG without contrasting other forms of glaucoma may restrict the data' generalizability. In order to better comprehend their involvement in the evolution of the illness, future research should employ genetic biomarkers, integrate sophisticated imaging techniques, and investigate the processes that relate corneal biomechanics to glaucoma damage.

CONCLUSION

The evolution of glaucoma is significantly influenced by corneal biomechanics, namely corneal hysteresis and corneal resistance factor, as this study demonstrates. Faster disease development was linked to lower levels of these measures, indicating that they may be useful prognostic indicators. The therapy of glaucoma may be improved by integrating corneal biomechanics testing into standard clinical practice, even if central corneal thickness did not demonstrate a significant link. Longer follow-up times and bigger, more varied populations are required for future studies to validate these results and investigate the underlying processes.

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