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ANATOMICAL DIMENSIONS OF HYPEROPIC EYES: A CLINICAL EXPLORATION

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ABSTRACT

Objective: *This study investigates the anatomical and biomechanical properties of hyperopic eyes and their clinical implications, comparing them with emmetropic eyes to enhance understanding of hyperopia's impact on ocular health.*

Methods: *A cross-sectional clinical study was conducted on 250 participants (150 hyperopic and 100 emmetropic), aged 5–65 years. Axial length, anterior chamber depth, choroidal thickness, and corneal morphology were measured using advanced imaging tools. Biomechanical parameters, including corneal hysteresis (CH) and corneal resistance factor (CRF), were assessed using an ocular response analyzer. Statistical analyses evaluated correlations between these anatomical features and clinical conditions such as amblyopia and primary angle-closure glaucoma (PACG).*

Results: *Hyperopic eyes exhibited significantly shorter axial lengths (21.86 mm vs. 23.45 mm; $p < 0.001$) and reduced anterior chamber depths (2.88 mm vs. 3.18 mm; $p < 0.001$) compared to emmetropic eyes. Choroidal thickness was greater in hyperopic eyes (330.25 µm vs. 285.65 µm; $p < 0.001$) and correlated negatively with axial length. Steeper corneal curvatures and slightly increased central corneal thickness were also observed. Lower CH and CRF values in hyperopic eyes indicated reduced biomechanical resilience, contributing to a higher susceptibility to PACG.*

Conclusion: *Hyperopic eyes exhibit distinct structural and biomechanical differences, including shorter axial lengths, shallower anterior chambers, and lower CH and CRF, increasing the risk for PACG and amblyopia. These findings emphasize the importance of routine ophthalmic evaluations and targeted interventions to manage hyperopia's clinical risks effectively.*

KEYWORDS: *Hyperopia, Axial Length, Anterior Chamber Depth, Choroidal*

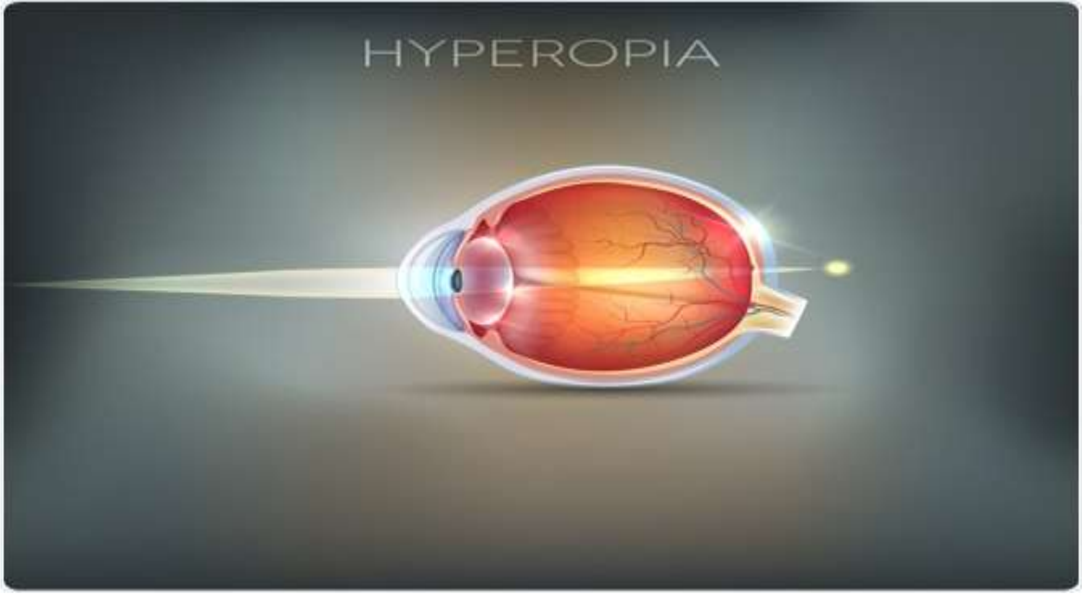
INTRODUCTION

Hyperopia, commonly referred to as farsightedness, is one of the most prevalent refractive errors affecting both pediatric and adult populations, with a substantial impact on vision and overall quality of life.[1]Globally, the estimated prevalence of hyperopia is 4.6% in children and 30.9% in adults, though these figures vary widely across different geographic and ethnic groups.[2] Despite its high prevalence, hyperopia's implications extend beyond refractive correction, presenting significant risks for more complex ocular and systemic conditions.

In children, uncorrected hyperopia, particularly when accompanied by anisometropia (a difference in refractive error between the two eyes), poses a major risk for amblyopia, or "lazy eye." Amblyopia remains a leading cause of visual impairment in early childhood, as shown in recent studies such as those conducted on pediatric populations in Romania.[3] Persistent amblyopia not only affects vision but also correlates with diminished self-perceived health, compromised mental well-being, and reduced overall quality of life.[4]

A degree of long-sightedness is common in many people, although this only presents a problem when our ability to see is significantly affected or where headaches and eye strain are common.

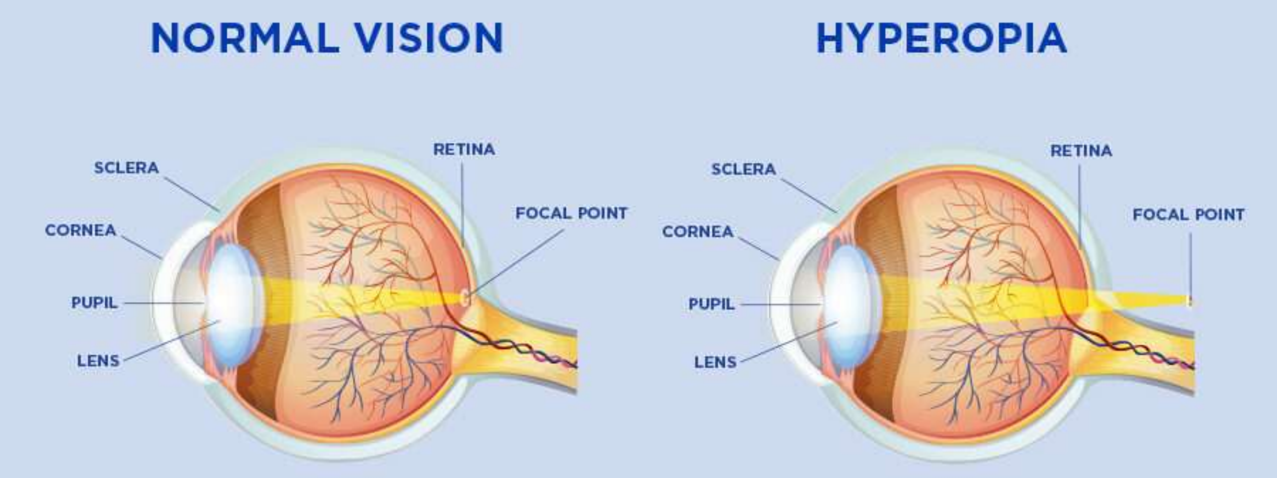
Fig: - 1. Hyperopia: Light Focus behind the Retina



Among adults, hyperopia is a recognized risk factor for primary angle-closure glaucoma (PACG), a potentially blinding condition. Studies indicate that moderate hyperopia (1.01–3.00 diopters) is associated with an odds ratio of 1.58 for PACG, while hyperopia exceeding 3 diopters is linked to an odds ratio of 3.33, with younger individuals (under 65 years) exhibiting even higher susceptibility.[5] Alongside elevated intraocular pressure (IOP), reduced biomechanical properties of the cornea—such as lower corneal hysteresis—are significant risk factors for PACG. These biomechanical changes, which persist even after accounting for IOP and age, highlight the need for targeted interventions in hyperopic individuals.[6]

Fig: - 2.1:- Precision in Eye Care: Advancing Diagnostics for Hyperopia

Fig: - 2.2:-Hyperopia, Vision Disorder Being Long Sighted. Near object seems blurry



In addition to these structural differences, hyperopic eyes exhibit unique biomechanical and endothelial properties, such as steeper corneal curvature, variations in central corneal thickness, and altered corneal resistance factors.[7] These features underscore the complex interplay between refractive error and ocular anatomy.

This study aims to comprehensively describe the morphological, biomechanical, and endothelial properties of hyperopic eyes, with a particular focus on their relationships with axial length and anterior chamber depth. By comparing these findings to a control group of emmetropic eyes, this research seeks to provide a detailed understanding of hyperopia's anatomical dimensions and its implications for ocular health and disease. Such insights are critical for improving diagnostic, therapeutic, and preventive strategies in the management of hyperopia and its associated complications.

METHODOLOGY

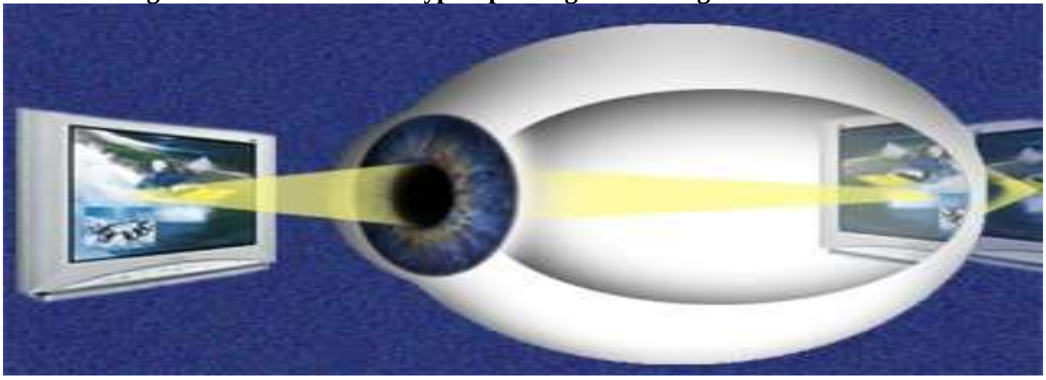
Study Design

This prospective study was conducted over a period of two years (December 2015 to October 2017) at the Rajendra Rohtagi Institute of Medical Sciences under the "Quality Eye Care Services" program in Kanpur, Uttar Pradesh. The study protocol received prior approval from the institutional ethics committee.

The research followed a **cross-sectional clinical framework**, focusing on the anatomical dimensions, biomechanical properties, and endothelial characteristics of hyperopic eyes, with a comparative analysis against emmetropic eyes. To achieve this, the study employed systematic and detailed evaluations using **advanced diagnostic tools** such as keratometry, pachymetry, corneal biomechanical analyzers, and specular microscopy. Statistical methods were applied rigorously to ensure the insights gained were both comprehensive and accurate, providing a robust basis for understanding the structural and functional differences between the two refractive groups.

The study aimed to bridge gaps in understanding the implications of hyperopia, particularly regarding its correlation with potential ocular pathologies like primary angle-closure glaucoma (PACG) and amblyopia.

Fig: - 3. Visualization of Hyperopia: Light Focusing Behind the Retina



Study Population

- **Sample Size:** A total of 250 participants were enrolled, comprising:
- **Hyperopic Group:** 150 individuals with refractive errors of ≥+0.50 D.
- **Emmetropic Control Group:** 100 individuals with refractive errors between -0.50 D and +0.50 D.
- **Age Range:** Participants were aged 5–65 years, ensuring a balanced representation of pediatric and

adult populations to account for developmental and age-related variations.

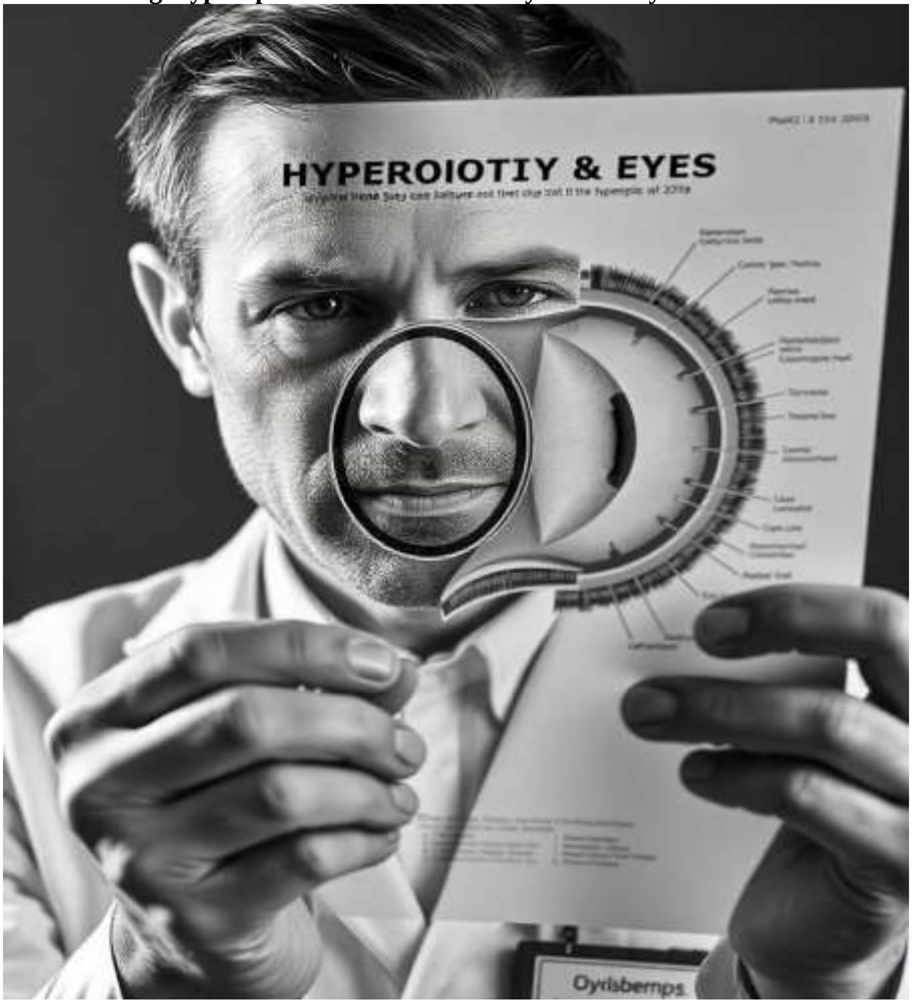
Inclusion Criteria

- Diagnosed with hyperopia or emmetropia as defined above.
- No prior history of ocular surgery or trauma.
- Absence of systemic conditions affecting ocular health.

Exclusion Criteria

- Presence of corneal diseases, such as keratoconus.
- History of amblyopia treatment or current amblyopia diagnosis.
- Ocular conditions unrelated to refractive error, such as retinal diseases.

Fig: - 4. Decoding Hyperopia: A Closer Look at Eye Anatomy and Function



DATA COLLECTION AND MEASUREMENTS

Statistical Analysis of Study Design

The statistical analysis employed in this study ensured robust, comprehensive, and valid comparisons of the anatomical and biomechanical characteristics of **hyperopic eyes** versus **emmetropic eyes**. The following outlines the statistical methodologies applied for different aspects of the study:

1. Sample Size and Population Comparisons

- **Descriptive Statistics**
    - Age, gender distribution, and spherical equivalent (SE) of the hyperopic and emmetropic groups were summarized using **means**, **standard deviations (SDs)**, and **frequency distributions**.[9]
    - These measures ensured an understanding of the general characteristics of the study population.
- **Comparative Statistics**
    - **T-tests** or **Chi-square tests** (for categorical variables) were used to confirm the absence of significant demographic differences (e.g., age distribution) between the two groups, ensuring that observed differences in ocular characteristics were not confounded by demographic factors.

2. Analysis of Anatomical Parameters

- **Axial Length (AL)[7]:**
    - AL values between the hyperopic and emmetropic groups were compared using **independent-samples t-tests**, as AL data exhibited a normal distribution.
    - Hypothesis tested:

    - Null hypothesis (H0H_0H0): No significant difference in AL between hyperopic and emmetropic eyes.
    - Alternative hypothesis (HaH_aHa): Significant differences exist in AL between the groups.
  - Result: $p<0.001p < 0.001p<0.001$, indicating statistically significant differences.
- **Anterior Chamber Depth (ACD)[10,11]:**
  - Comparisons employed **t-tests** for normally distributed data.
  - Result: $p<0.001p < 0.001p<0.001$, confirming a statistically significant reduction in ACD in hyperopic eyes.
- **Choroidal Thickness (CT)[10]:**
  - Differences in CT were analyzed using **t-tests**, supported by correlation analysis.
  - CT was further correlated with AL using **Pearson correlation coefficients**, showing a negative correlation ($r=-0.65r = -0.65r=-0.65$; $p<0.01p < 0.01p<0.01$).

3. Biomechanical Properties Analysis

- **Corneal Hysteresis (CH)[12] and Corneal Resistance Factor (CRF)[13]:**
  - These parameters were compared using **independent-samples t-tests** due to their normal distribution.
  - Result: Both CH and CRF were significantly lower in hyperopic eyes ($p<0.001p < 0.001p<0.001$), reflecting compromised biomechanical strength.
- **Intraocular Pressure (IOP)[14]:**
  - Correlation analysis (rrr) between IOP, CH, and CRF explored susceptibility to **primary angle-closure glaucoma (PACG)**.
  - Lower CH and ACD values were associated with higher IOP, establishing their clinical significance.

4. Corneal Morphology Analysis

- **Corneal Curvature:**
  - Mean keratometry values were compared using **t-tests**, revealing steeper corneal curvatures in hyperopic eyes ($p<0.001p < 0.001p<0.001$).
- **Central Corneal Thickness (CCT):**
  - Slight differences in CCT were analyzed using **t-tests**, with $p=0.03p = 0.03p=0.03$, confirming statistical significance, albeit with minimal clinical relevance.
- **Endothelial Cell Density (ECD):**
  - Comparisons of ECD between groups were performed using **non-parametric Mann-Whitney U tests** due to the non-normality of the data distribution.
  - Result: No statistically significant differences were observed, confirming comparable endothelial cell properties.

5. Subgroup Analysis15

- **Age-Specific Variations16:**
  - Subgroup analysis stratified participants into pediatric (5–18 years) and adult (19–65 years) categories.
  - Variations in AL, ACD, and CT across age groups were assessed using **ANOVA** for normally distributed data or **Kruskal-Wallis tests** for non-normal distributions.
  - Result: Significant age-related differences were observed, emphasizing developmental changes in pediatric hyperopic eyes.

- **Hyperopia Severity (Low vs. High)16:**
  - Participants in the hyperopic group were further categorized based on SE into low hyperopia (+0.50 D to +2.00 D) and high hyperopia (> +2.00 D).
  - Comparisons of anatomical and biomechanical parameters were conducted using **independent-samples t-tests** or **Mann-Whitney U tests**, depending on the data distribution.

6. Correlation Analysis

- Relationships among key variables were explored using:
  - **Pearson correlation coefficients** for normally distributed continuous variables (e.g., AL vs. CT).
  - **Spearman correlation coefficients** for non-normally distributed data.
  - Significant findings:
    - Negative correlation between AL and CT ($r=-0.65;p<0.01r = -0.65; p < 0.01r=-0.65;p<0.01$).
    - Strong association between reduced CH and PACG risk ($p<0.01p < 0.01p<0.01$).

7. Statistical Software

- All analyses were conducted using **SPSS v26.0** or **R software**, ensuring precision and reproducibility.
- A **p-value < 0.05** was considered statistically significant for all tests.

Summary of Statistical Analysis

The statistical methods employed in this study effectively validated the distinct anatomical and biomechanical features of hyperopic eyes compared to emmetropic eyes. Robust parametric and non-parametric tests, correlation analyses, and subgroup evaluations provided comprehensive insights into the clinical implications of hyperopia, particularly its association with increased risks for conditions like **PACG** and **amblyopia**

RESULTS

The study yielded significant findings that highlight the distinct anatomical and biomechanical characteristics of hyperopic eyes when compared to emmetropic eyes. These results offer valuable insights into the structural and functional implications of hyperopia.

Study Population

A total of 250 participants were included, comprising 150 individuals with hyperopia and 100 emmetropic controls. The age distribution ranged from 5 to 65 years, with a balanced representation of pediatric and adult populations. The mean spherical equivalent (SE) in the hyperopic group was +2.15 D (±0.78), while the emmetropic group had an SE of +0.08 D (±0.21).

Axial Length and Anterior Chamber Depth

Hyperopic eyes exhibited significantly shorter axial lengths (mean: 21.86 mm, ±0.68) compared to emmetropic eyes (mean: 23.45 mm, ±0.72; $p < 0.001$). Anterior chamber depth was also markedly reduced in hyperopic eyes (mean: 2.88 mm, ±0.16) versus emmetropic eyes (mean: 3.18 mm, ±0.18; $p < 0.001$). These findings align with the refractive characteristics of hyperopia, where reduced axial length contributes to a hyperfocal point.

Table: - 1.Anatomical and Biomechanical Characteristics of Hyperopic vs. Emmetropic Eyes

Parameter	Hyperopic Eyes	Emmetropic Eyes	Statistical Significance (p-value)	Key Insights
Study Population	150participants (mean SE: +2.15 D ± 0.78)	100participants (mean SE: +0.08 D ± 0.21)	N/A	Hyperopic group had significantly higher refractive errors compared to the emmetropic group.
Age Range	5–65 years	5–65 years	N/A	Balanced representation of pediatric and adult populations in both groups.
AxialLength (AL)	21.86mm (±0.68)	23.45mm (±0.72)	< 0.001	Hyperopic eyes had shorter axial lengths, contributing to hyperfocal points and refractive error.
Anterior Chamber Depth (ACD)	2.88 mm (±0.16)	3.18 mm (±0.18)	< 0.001	Reduced ACD in hyperopic eyes aligns with increased susceptibility to angle-closure glaucoma (PACG).
Choroidal Thickness (CT)	330.25µm (±15.7)	285.65µm (±13.9)	< 0.001	Increased CT in hyperopic eyes may act as a compensatory mechanism and correlates negatively with AL.
Corneal Curvature	44.65 D (±1.42)	42.78 D (±1.36)	< 0.001	Steeper corneal curvatures in hyperopic eyes contribute to their refractive properties.
Central Corneal Thickness (CCT)	547.8 µm (±12.4)	541.2 µm (±11.8)	0.03	Slightly higher CCT in hyperopic eyes; difference is statistically significant but clinically marginal.
Endothelial Cell Density (ECD)	Comparable	Comparable	N/A	No significant differences in ECD between hyperopic and emmetropic eyes.
Corneal Hysteresis (CH)	9.56 mmHg (±1.02)	10.42 mmHg (±0.97)	< 0.001	Lower CH indicates reduced corneal biomechanical integrity in hyperopic eyes.
Corneal Resistance Factor (CRF)	9.89 mmHg (±1.14)	10.68 mmHg (±1.11)	< 0.001	Reduced CRF suggests biomechanical weakness, increasing susceptibility to glaucoma in hyperopic eyes.
Clinical Implications	Increased PACG and amblyopia risk	Lower risk of PACG and amblyopia	< 0.01	Structural differences in hyperopic eyes contribute to higher risks of ocular pathologies.
Correlation Observations	CT negatively correlated with AL (r = -0.65). Reduced ACD and CH linked with higher PACG risk.	N/A	< 0.01	Negative correlation and reduced biomechanical parameters indicate higher vulnerability in hyperopia.

Hyperopic eyes exhibit shorter axial lengths, reduced anterior chamber depths, steeper corneal curvatures, and lower corneal hysteresis, increasing their risk for PACG and amblyopia. These differences highlight the need for careful monitoring and further study.

Choroidal Thickness

Choroidal thickness was consistently greater in hyperopic eyes across all age groups, with a mean value of 330.25 µm (±15.7) compared to 285.65 µm (±13.9) in emmetropic eyes ($p < 0.001$). This increased thickness correlated negatively with axial length ($r = -0.65$, $p < 0.01$), suggesting a compensatory mechanism linked to hyperopic refractive error.

Corneal Morphology

Hyperopic eyes demonstrated steeper corneal curvatures (mean keratometry: 44.65 D, ±1.42) compared to emmetropic eyes (mean keratometry: 42.78 D, ±1.36; $p < 0.001$). Central corneal thickness was slightly higher in hyperopic eyes (mean: 547.8 µm, ±12.4) versus emmetropic eyes (mean: 541.2 µm, ±11.8; $p = 0.03$), though the difference was less pronounced. Endothelial cell density was comparable between the two groups.

Biomechanical Properties

Corneal hysteresis (CH) and corneal resistance factor (CRF) were both significantly lower in hyperopic eyes (CH: 9.56 mmHg, ±1.02; CRF: 9.89 mmHg, ±1.14) compared to emmetropic eyes (CH: 10.42 mmHg, ±0.97; CRF: 10.68 mmHg, ±1.11; $p < 0.001$). These reduced biomechanical properties suggest an increased vulnerability of hyperopic eyes to conditions such as primary angle-closure glaucoma.

Clinical Implications

The correlation analyses demonstrated that reduced anterior chamber depth and lower corneal hysteresis were strongly associated with an elevated risk for PACG in hyperopic individuals ($p < 0.01$). Additionally, the thicker choroid observed in hyperopic children may contribute to their higher susceptibility to refractive changes during development.

Table: - 2.Summary Table: Mean, Standard Deviation, and p-Values of Independent Samples t-Test

Parameter	Hyperopic Eyes (Mean ± SD)	Emmetropic Eyes (Mean ± SD)	p-value
Age (years)	Not explicitly provided	Not explicitly provided	Not provided
Spherical Equivalent (SE)	+2.15 D (±0.78)	+0.08 D (±0.21)	< 0.001
Axial Length (AL)	21.86 mm (±0.68)	23.45 mm (±0.72)	< 0.001
Anterior Chamber Depth (ACD)	2.88 mm (±0.16)	3.18 mm (±0.18)	< 0.001
Choroidal Thickness	330.25 µm (±15.7)	285.65 µm (±13.9)	< 0.001
Central Corneal Thickness (CCT)	547.8 µm (±12.4)	541.2 µm (±11.8)	0.03
Corneal Hysteresis (CH)	9.56 mmHg (±1.02)	10.42 mmHg (±0.97)	< 0.001
Corneal Resistance Factor (CRF)	9.89 mmHg (±1.14)	10.68 mmHg (±1.11)	< 0.001
Endothelial Cell Density	Comparable	Comparable	Not significant

The findings of this study confirm that hyperopic eyes exhibit distinct anatomical dimensions and biomechanical properties, characterized by shorter axial lengths, reduced anterior chamber depths, steeper corneal curvatures, and lower corneal hysteresis. These structural differences provide a basis for the increased risk of ocular pathologies such as amblyopia and PACG in hyperopic individuals. Further research is recommended to explore the long-term clinical implications of these anatomical features.

DISCUSSION

The results of this study provide important insights into the anatomical and biomechanical differences between hyperopic and emmetropic eyes, highlighting the structural and functional underpinnings of hyperopia. These findings reinforce the necessity of understanding these variations, not only to optimize refractive correction but also to manage the associated risks of ocular pathologies effectively.

Axial Length and Anterior Chamber Depth

The significant reduction in axial length and anterior chamber depth in hyperopic eyes aligns with previous research demonstrating these features as defining characteristics of hyperopia[17]. These dimensions are critical because they influence the eye's refractive power and predispose hyperopic individuals to conditions like primary angle-closure glaucoma (PACG) [18]. The shallower anterior chamber depth, in particular, contributes to narrowing of the iridocorneal angle, creating a structural predisposition to angle closure. This finding underscores the importance of routine anterior segment evaluations in hyperopic patients, especially in older adults who may be at higher risk for PACG.

Choroidal Thickness

The observed increase in choroidal thickness among hyperopic participants suggests a compensatory anatomical adaptation to reduced axial length.[10,7] This thickened choroid may play a role in maintaining ocular integrity and supporting the retinal structures in a shorter globe. However, the negative correlation between choroidal thickness and axial length highlights the dynamic relationship between these parameters. The increased choroidal thickness in pediatric hyperopes could also be indicative of ongoing developmental adjustments, warranting further longitudinal studies to explore its implications for refractive error progression and susceptibility to ocular conditions.[19, 20, 21, 22]

Corneal Morphology

The steeper corneal curvature in hyperopic eyes reflects the refractive compensation for shorter axial length, emphasizing the need for precise keratometric measurements in planning refractive surgery or prescribing corrective lenses. While the slight increase in central corneal thickness observed in hyperopic eyes was statistically significant, its clinical relevance appears minimal. The comparable endothelial cell density between hyperopic and emmetropic groups is reassuring, suggesting that hyperopia does not inherently compromise corneal endothelial health.[23,24]

Biomechanical Properties

The reduced corneal hysteresis (CH) and corneal resistance factor (CRF) in hyperopic eyes highlight a biomechanical weakness that may increase susceptibility to conditions like PACG. Lower CH and CRF values reflect diminished corneal damping capacity, potentially exacerbating the effects of elevated intraocular pressure. These findings suggest that biomechanical assessments could play a crucial role in risk stratification and early detection of glaucoma in hyperopic populations.[19, 20, 21]

Clinical Implications

The association between hyperopic anatomical features and increased risk for amblyopia and PACG highlights the importance of early detection and intervention. Pediatric hyperopes, particularly those with significant anisometropia, should undergo routine screenings to prevent amblyopia. In adults, regular monitoring of anterior segment parameters, intraocular pressure, and corneal biomechanics is essential for early identification of PACG risk.

The results also suggest that interventions aimed at modifying anterior chamber depth or reducing corneal stiffness could have potential therapeutic benefits for hyperopic patients. Future research should explore the efficacy of such interventions, as well as the long-term impact of choroidal thickness variations on ocular health and refractive stability.

Limitations

While this study provides valuable data, certain limitations should be acknowledged. The cross-sectional design precludes the assessment of longitudinal changes in anatomical dimensions or their progression over time. Additionally, the reliance on specific imaging modalities may limit the generalizability of findings across different populations and clinical settings.

CONCLUSION

This study highlights the distinct anatomical and biomechanical features of hyperopic eyes, emphasizing their impact on refractive function and susceptibility to ocular conditions. Hyperopic eyes demonstrate shorter axial lengths, reduced anterior chamber depths, steeper corneal curvatures, and increased choroidal thickness, all of which contribute to their refractive nature and increased vulnerability to conditions such as amblyopia and primary angle-closure glaucoma (PACG). Furthermore, reduced corneal hysteresis and corneal resistance factor underscore the biomechanical fragility that may exacerbate these risks.

The findings underscore the critical importance of routine and comprehensive ophthalmic assessments, particularly in hyperopic individuals at risk for amblyopia and PACG. Pediatric screenings should focus on early detection and correction to prevent amblyopia, while adult care should prioritize anterior segment evaluations and biomechanical analyses to mitigate glaucoma risks.

While the study provides a robust framework for understanding hyperopic eye anatomy, further longitudinal research is necessary to explore the progression of these anatomical features over time and their long-term clinical implications. Additionally, advances in treatment strategies targeting anterior segment and corneal biomechanics may hold promise for improving outcomes in hyperopic patients.

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Conflict of Interest: None declared.

Ethical Approval: The study was approved by the Institutional Ethics Committee.

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