Research Square

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Corneal higher order aberrations by Sirius topography and their relation to different refractive errors

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Research Article

Keywords: Zernike coefficients, Corneal Higher order aberrations, Refractive errors, Sirius, Astigmatism

Posted Date: July 21st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1851734/v1

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at BMC Ophthalmology on March 16th, 2023. See the published version at https://doi.org/10.1186/s12886-023-02841-4.

Abstract

Purpose: to compare the root mean square (RMS) of anterior corneal higher-order aberrations (HOAs) in patients with refractive errors.

Methods: This retrospective observational study was conducted at Department of Ophthalmology, Tishreen University Hospital, Latakia, Syria. The eyes were divided into four groups based on refractive error: mild-to-moderate myopia, hypermetropia, myopic astigmatism, and emmetropic eyes as controls. The following anterior corneal HOAs were evaluated using the Scheimpflug-Placido Sirius (CSO, Italy) topographer over 6 mm pupil: Root mean square (RMS) total corneal HOAs, RMS trefoil, RMS coma and RMS spherical aberrations.

Results: RMS values of total HOAs, trefoil and coma showed a statistically significant difference in all four groups ($P < 0.05$, all). They were lowest in the control group (0.18± 0.09, 011± 0.08 and 0.09± 0.08 µm, respectively) and highest in the myopic astigmatism group (0.31± 0.16, 0.15± 0.12, 0.17± 0.14 µm, respectively). RMS spherical aberration was lowest in the astigmatism group (0.00± 0.16 µm) with a statistically significant difference from that in the control groups (0.05± 0.07 µm, $P = 0.049$).

Conclusion: The mean RMS values of total HOAs, trefoil and coma were highest in the astigmatism group and lowest in the control group. However, spherical aberration was minimal in the astigmatism group.

Introduction

Higher-order aberrations (HOAs) are small optical irregularities of the eye which can impact on the quality of the retinal image (1). However, these errors cannot be corrected with regular spectacles and most contact lenses. In recent years, advances in ocular diagnostic and treatment modalities have brought corneal higher order aberrations to the forefront of ophthalmologists and optometrists in enhancing visual quality. The ability to measure wavefront aberrations of the eye and incorporation of this data into treatment profiles has led to a significant improvement in the quality of vision following refractive surgery and the ability to correct surgical-induced HOAs, in addition to lower order aberrations (sphere and cylinder) (2, 3). Furthermore, evaluation of HOAs in the normal eyes has been demonstrated to be helpful in the early detection of pathologic conditions such as keratoconus (KC) (4, 5, 6).

Several studies have shown that higher HOAs may differ with ethnicity (7, 8). To the best of our knowledge, no study has yet reported the distribution of HOAs in the Syrian population.

Corneal aberrometry has the ability to evaluate the anterior corneal surface which is the most effective refractive surface of the eye optical system (4). The Sirius Scheimpflug–Placido topographer (Costruzione Strumenti Oftalmici, Florence, Italy) provides anterior and posterior corneal topography, corneal wavefront analysis, as well as corneal pachymetry.

This study aimed to investigate anterior corneal HOAs in relation to refractive error in a population with refractive errors and to aid further understanding of the profile of HOAs.

Material And Methods

This retrospective observational comparative study was conducted at the Department of Ophthalmology, Tishreen University Hospital, Latakia, Syria. Ethical approval for the study was obtained from the University of Tishreen Research Ethics Committee and the research followed the tenets of the Declaration of Helsinki, with written informed consent obtained.

Details of the sampling strategy has been published elsewhere (9). The data of 573 participants were included in this analysis. One eye from each candidate was used (573 eyes) according to a random-number sequence. Of the total 573 eyes, 104 eyes were emmetropic (controls) and 469 were ametropic. Emmetropic eyes consisted of those with manifest refraction spherical equivalent (MRSE) within ±0.5 D. All emmetropic subjects had normal corneal topography in both eyes with uncorrected distance visual acuity (UDVA) of 20/20 or better. Ametropic eyes were divided into three groups according to their refractive errors: mild to moderate myopia (−1.0 : −5.9D) (211 eyes), simple myopic astigmatism (cylinder ≤-1D) (175 eyes), and hypermetropes (+1 : +4D) (83 eyes). only ametropic eyes with corrected distance visual acuity (CDVA) of 20/20 or better were included.

Patients were excluded if they had previous ocular surgery (cataract, glaucoma, corneal cross-linking, excimer laser surgery, intra stromal corneal rings, phakic intraocular lens). Ocular Conditions which could also confound corneal HOAs were also excluded (amblyopia, ocular surface inflammation, dry eye disease, KC, KC-suspect, corneal dystrophys, or intraocular inflammation). Systemic autoimmune diseases, current or recent pregnancy (within 1 year), active lactation were also excluded. Prior to evaluation, contact lens-wearing patients were asked to discontinue wearing their lenses for 3-weeks and 1-week for rigid and soft contact lenses, respectively.

Evaluation included the measurement of UDVA, CDVA, MRSE, slit-lamp biomicroscopy, retinoscopy and fundoscopy. Corneal topography and corneal aberrometry were obtained using the Sheimpflug-Placido topographer (Sirius, Phoenix software v. 1.2.6 Costruzione Strumenti Oftalmici, Florence, Italy). The accuracy of Sirius corneal topographer has been previously reported (10). Anterior corneal higher order aberrations were measured at the central 6.0 mm. Three well-focused, aligned and centred images were obtained for each eye. In order to optimise image capture, patients were asked to blink before each image capture to eliminate the effect of corneal surface dryness. Placido disc mires up to the 17^{th} ring had to be continuous to consider videokeratography of good quality and satisfactory for calculation of the Zernike coefficients for 6.0 mm simulated pupil(11). Software acquisition was uniform for all data points for consistency (Phoenix v.2.6). Figure 1 illustrates a sample of Sirius HOAs values.

The collected HOAs data included: Root mean square (RMS) total HOAs, RMS trefoil Z (3, ±3), RMS coma Z (3, ± 1), and RMS spherical aberration I Z (4, 0).

Statistical Analysis

Quantitative data were represented as mean and standard deviation. ANOVA test was used to compare variables of four groups. Analyses were performed using SPSS software (version 21.0, International Business Machines Corp.). P-values of less than 0.05 were considered significant.

Results

Demographic and refractive data for each group is presented in table 1. A total of 573 eyes of 573 subjects were included in this study. Two hundred and twenty-four subjects (39.09%) were males. Age of the subjects ranged from 18 to 40 years with a mean age of 23.0±4.9 years. The mean age of controls was 21.49±2.33 years, while the other three groups were 22.74±3.70, 23.11±5.46 and 25.27±7.27 years for myopia, myopic astigmatism and hypermetropia, respectively. There was a significant difference between the mean age of hypermetropic and control eyes (P = 0.0001), between hypermetropic and myopic eyes (P = 0.0001), and between astigmatic and control eyes (P = 0.041).

The mean and standard deviation of HOAs of anterior corneal aberrations for all groups is shown in Table 2. Statistical analyses of anterior corneal HOAs in the different groups of refractive errors revealed that the mean RMS values of total HOAs, trefoil and coma were at their lowest levels in the control group (0.18± 0.09, 011± 0.08 and 0.09± 0.08 μm, respectively). In contrast, the mean RMS spherical aberrations value was highest in the control group (0.05± 0.07 μm) .

The highest level of RMS total HOAs value was seen in the astigmatism group (Figure 2) (0.31± 0.16 μm), with a statistically significant difference between myopic and control eyes (P = 0.01), between astigmatic and control eyes (P = 0.0001), between hypermetropic and myopia eyes (P = 0.0001), and between hypermetropic and astigmatic eyes (P = 0.03).

RMS trefoil highest in the astigmatism group (Figure 3), with statistically significant differences with all other groups (P < 0.05, for all).

RMS Coma was highest in the astigmatism group (Figure 4), with statistically significant difference between astigmatism and control groups, astigmatism and myopia groups(P < 0.05, for all).,
Hypermetropic eyes also demonstrated a statistically significant difference with controls (P < 0.05).

Figure 5 demonstrates the spherical aberration findings, showing the lowest levels in the astigmatism group (0.00 ± 0.16 μm), and the highest in the control group (0.05 ± 0.07 μm). When comparing two groups individually, a statistically significant difference was found only between the astigmatism and control group (P = 0.049).

Discussion

Accurate measurements of higher-order aberration are essential to clinical studies evaluating refractive error and image quality (12). The relationship between HOA and refractive error is of particular interest as it has been suggested that retinal defocus and cues from HOA may affect the growth of the eye (13). Furthermore, HOAs are responsible for glare, halos and reduction in contrast sensitivity following corneal refractive surgery (14). Approximately 90% of aberrations are caused by the cornea (1). In our study, we investigated corneal HOAs in emmetropic, myopic, hypermetropic and astigmatic eyes. We had a particular focus on corneal higher order aberrations that are most relevant to clinical practice, namely coma, trefoil and spherical aberrations (11). There are few similar studies that evaluate corneal HOAs (9, 15, 16).

Some studies found no significant differences among different refractive groups in terms of aberrations (17, 18), while other studies showed that myopic patients have more aberrations than astigmatic and hypermetropic patients (19, 20). Kasahara et al. evaluated HOAs in patients with myopia and found that highly myopic eyes had more HOAs than emmetropic eyes due to the increased internal aberrations (21). Our results showed no statistically significant differences in coma, trefoil and spherical aberrations between myopic and emmetropic eyes. However, the discrepancy in findings could be attributed to the fact that our study evaluated corneal HOAs in low to moderate myopia while Kasahara et al evaluated ocular (internal and corneal) HOAs in highly myopic eyes. Mohammadpour et al. reported an increase in HOAs, correlating with an increase of ocular astigmatism (22). Similarly, Zhang et al. found that an increase in astigmatism was associated with an increase in coma, trefoil and total HOAs (23). These findings were similar to our results, where we found that total HOAs, coma and trefoil were at their highest levels in the astigmatism group.

Total HOAs in our study were comparable to an Egyptian study by Anbar et al. where they used the Scheimpflug–Placido topography (Sirius, CSO, Italy) to obtain corneal HOAs in 750 patients with mild-to-moderate myopia, high myopia, hypermetropia, simple myopic astigmatism, and simple hypermetropic astigmatism (9). They found that total HOAs were highest (0.99 ± 0.70 μm) in hypermetropes. In contrast, our results showed that total HOAs were at their highest level (0.31 ± 0.16 μm) in the myopic astigmatism group. A possible explanation for this difference would be the age difference between the two studies; the mean age reported by Anbar et al. was (27.8 ± 9.4 years) higher than that reported in our study (23.0±4.9 years), and older age is associated with increasing amounts of HOAs (8).

In concordance with previous report (24), we observed that total HOAs (0.26±0.17 μm) in hypermetropic eyes were mainly due to coma aberrations (0.15±0.15 μm). The angle kappa is known to be larger in hypermetropes compared to myopes and emmetropes, and a larger displacement of the pupillary axis from the visual axis is responsible for higher levels of coma in hypermetropic eyes (25). Our findings are consistent with this, where we found that coma aberration was significantly higher in hypermetropic eyes when compared to emmetropic and myopic eyes.

Zhao et al. found that spherical aberrations of astigmatic corneas were similar to those of non-astigmatic (26). Interestingly, our results showed that spherical aberrations were at their lowest level (0.0±0.16 μm) in astigmatic eyes. He et al. used ray-tracing technique to investigated HOAs aberrations in adult patients with refractive errors and found higher spherical aberrations in myopic eyes as compared to emmetropic eyes (19). Marcos observed that intraocular spherical aberrations became more negative in high myopia due to the crystalline lens (27). Our results revealed positive spherical aberrations values in all groups. Studying HOAs in 675 adolescents, Philip et al. found no significant difference in corneal spherical aberrations among the myopic, hypermetropic and emmetropic groups (28). These findings are consistent with our, as spherical aberrations were not significantly different between emmetropic, myopic and hypermetropic groups

These conflicts in the literature comparing HOAs and refractive error may exist due to the variety of sample size, differing classifications of refractive error, differences in subject age, ethnicity, and data acquisition methodology.

The most important limitation of this study was that the distribution of refractive error groups was not homogeneous. Since our study included population-based randomized subjects, differences between the sample numbers across different refractive error groups could not be avoided.

To the best of our knowledge, this study is the first to investigate the distribution of HOAs in patients with refractive error in a Syrian population.

Conclusion

Our findings confirm that there is a difference in corneal higher-order aberrations between different refractive groups. Notably, the mean RMS values of total HOAs, trefoil and coma were highest in astigmatic eyes and lowest in emmetropic eyes. Spherical aberration was minimal in the astigmatism group. Results of this study must be considered in diagnostic and therapeutic refractive procedures.

Declarations

Ethics approval and consent to participate

This study was approved by the research ethics committee of Tishreen University in accordance with tents of the Declaration of Helsinki. Informed consent, in Arabic language, to participate in this study was obtained from all participants.

Consent of publication

Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due their containing information that could compromise the privacy of research participants but are available from the corresponding author (AS) on reasonable request.

Competing interests

The authors declare that they have no conflicting interests.

Funding

None

Acknowledgement

None

Contributions

AS was the major contributor, interpreted the data.

AS and OK wrote the manuscript.

MG, RO, TD, RS, HI, HA and HK reviewed the manuscript.

All author(s) read and approved the final manuscript.

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Tables

Table 1. Demographic and Refractive Data of all Groups.

	Refractive Errors							
	Control		Myopia		Astigmatism		Hypermetropia	
N	104		211		175		83	
Sex, M/F	44/60		79/132		77/98		24/59	
	mean	SD	Mean	SD	mean	SD	mean	SD
Age	21.49	2.33	22.74	3.70	23.11	5.46	25.27	7.27
Sphere	-0.04	0.25	-1.72	1.38	-1.10	2.87	1.52	1.37
Cylinder	-0.49	0.20	-0.50	0.18	-1.56	1.42	-0.40	0.39
Spherical equivalent	-0.25	0.22	-1.91	1.40	-1.78	2.98	1.38	1.46

N: number; F: female; M male; SD: standard deviations.

Table 2. RMS ± Standard Deviations of Anterior Corneal Higher-Order Aberrations of All Groups.

	Refractive Errors							
	Control		Myopia		Astigmatism		Hypermetropia	
N	104		211		175		83	
mean ± SD	Mean	SD	Mean	SD	mean	SD	mean	SD
RMS Total HOAs	0.18	0.09	0.24	0.14	0.31	0.16	0.26	0.17
RMS Trefoil	0.11	0.08	0.11	0.07	0.15	0.12	0.12	0.08
RMS Coma	0.09	0.08	0.12	0.11	0.17	0.14	0.15	0.15
RMS Spherical Ab	0.05	0.07	0.03	0.14	0.00	0.16	0.03	0.14

RMS: Root Mean Square; N: number; SD: standard deviation; Ab: Aberrations.

Figures

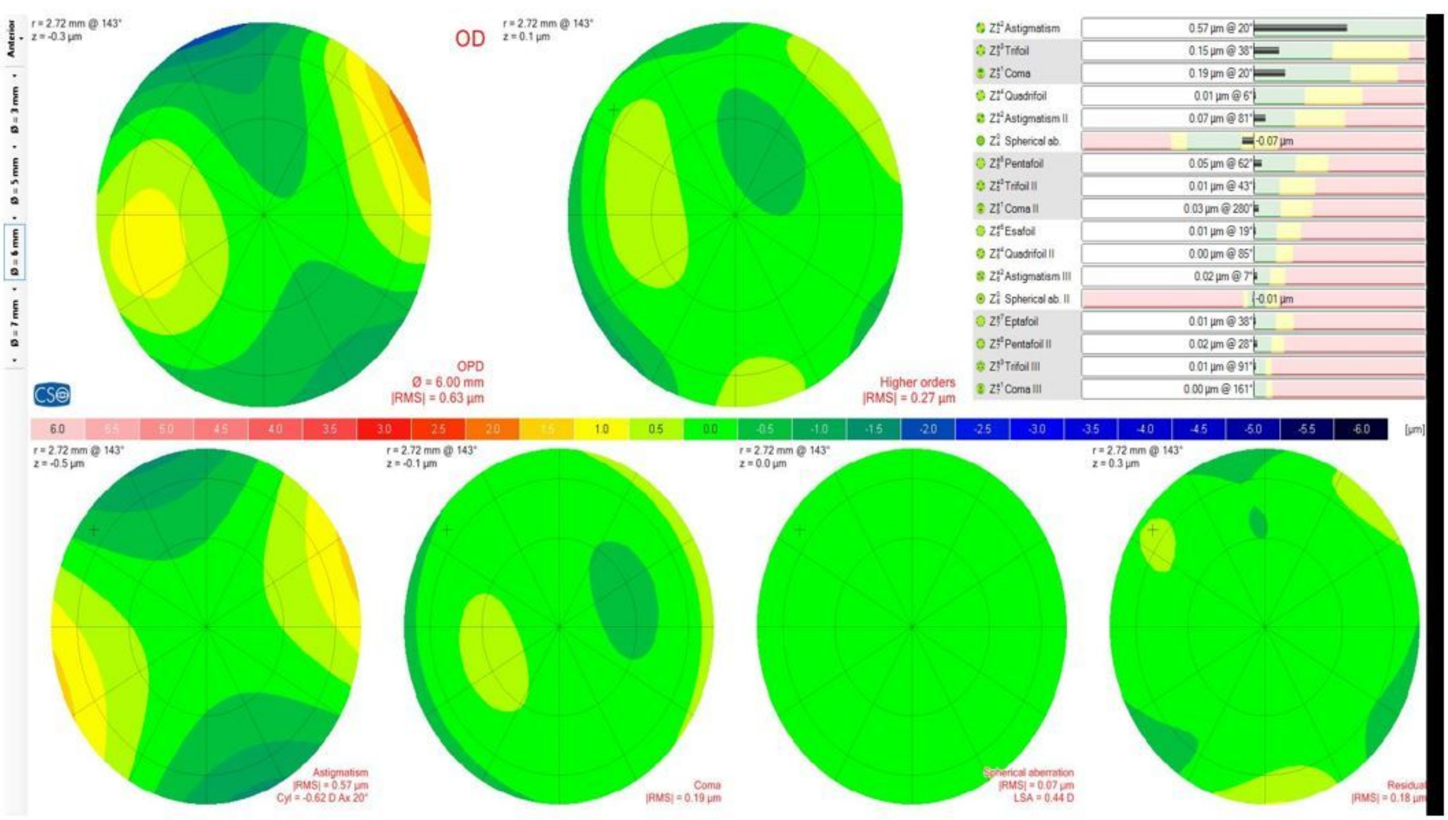

Figure 1

Sirius Aberrometer Output Display for Anterior Corneal-higher Order Aberrations.

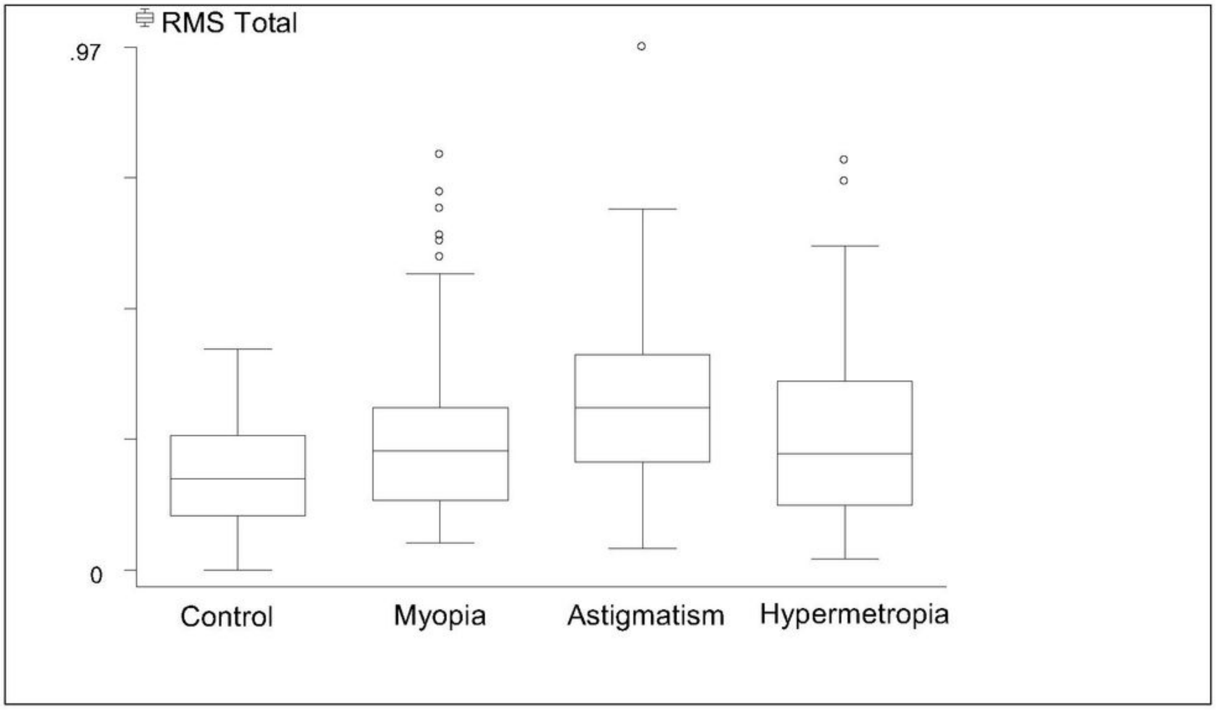

Figure 2

RMS Total HOAs Distribution Among Different Groups.

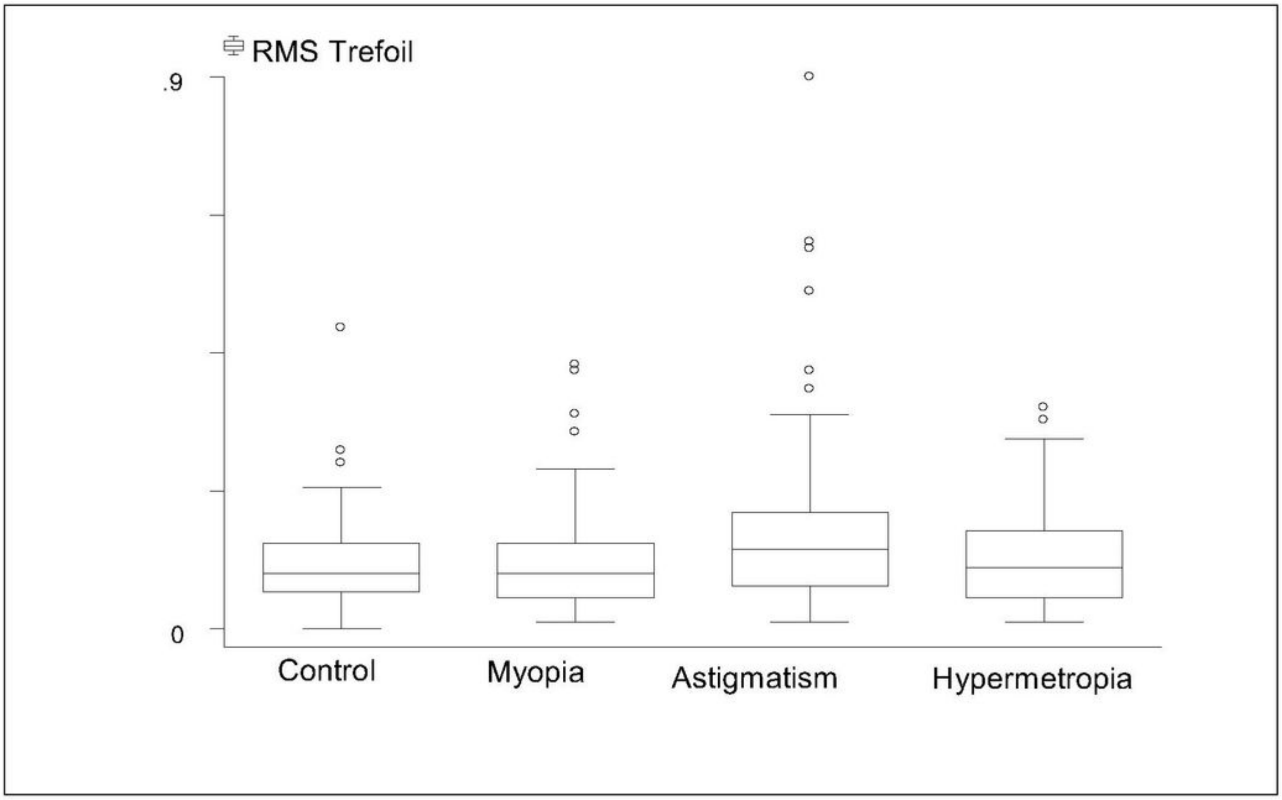

Figure 3

Trefoil Distribution Among Different Groups.

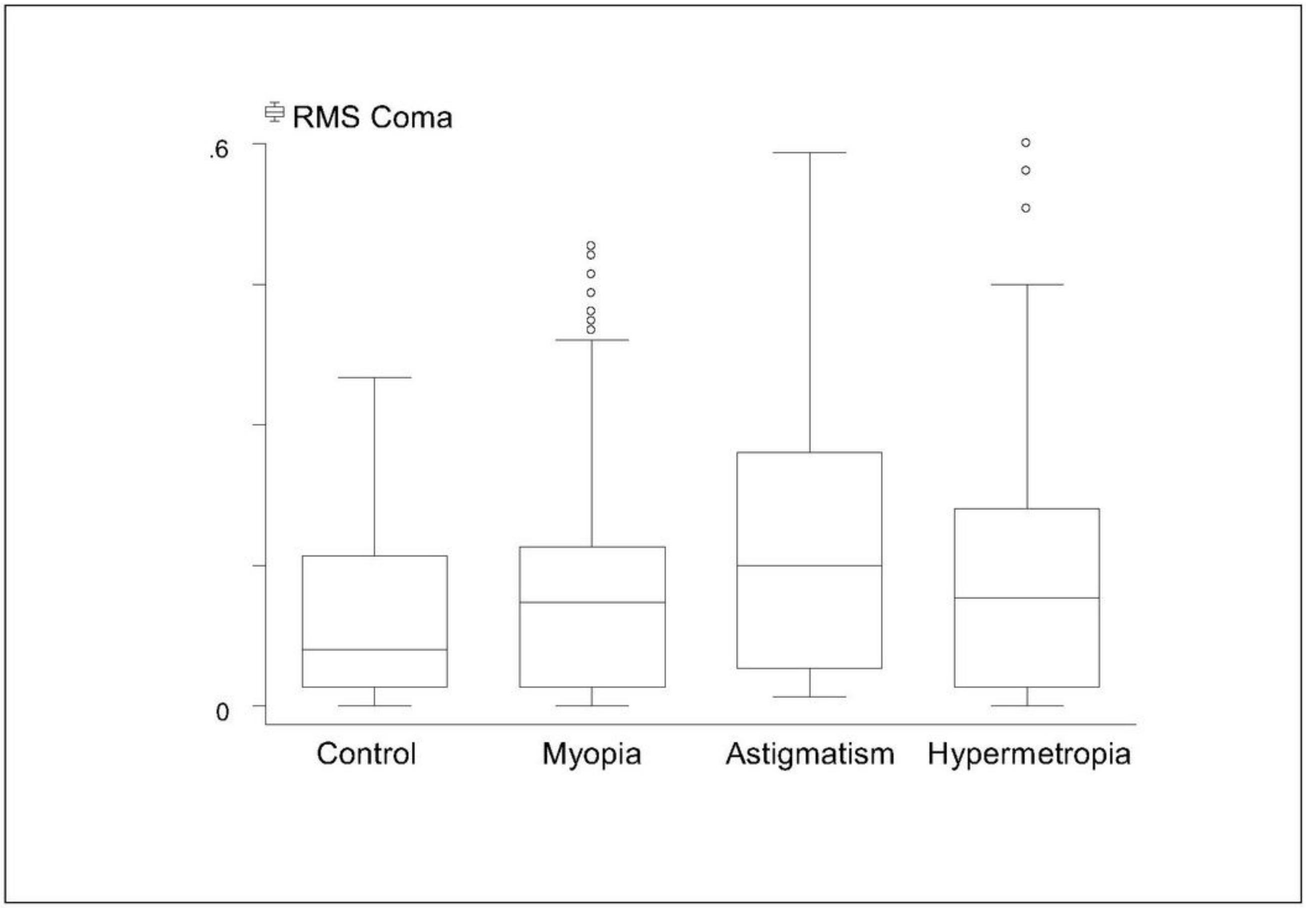

Figure 4

Coma Distribution Among Different Groups.

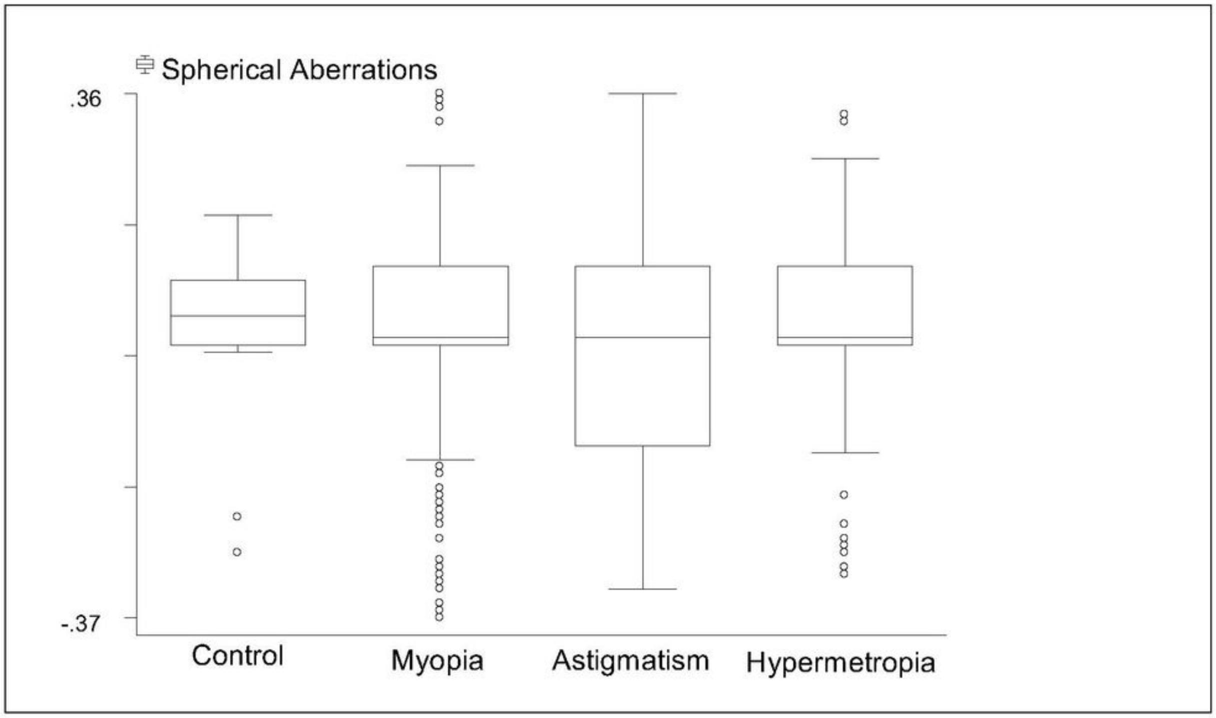

Figure 5

Spherical Aberrations Distribution Among Different Groups.