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Original Article

CORRELATION OF ANGLE KAPPA, CORNEAL HIGH ORDER ABERRATIONS AND TOTAL EYE ABERRATIONS IN VARIOUS REFRACTIVE ERRORS

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Abstract

Purpose: To identify the correlation between angle kappa, corneal high order aberrations and total eye aberrations in myopic, hyperopic and astigmatic patients. ***Methods*:** An analytical cross-sectional study was conducted among 206 eyes of 103 patients with errors of refractions in the department of ophthalmology, Sohag university hospital in the period from March 2023 to September 2023. The studied cases were divided into 3 groups: Group (1) included 68 myopic eyes. Group (2) included 44 hypermytropia eyes. Group (3) included 94 astigmatic eyes. A comprehensive evaluation of refraction was conducted on all patients with an autokerato-refractometer. Following this, a series of topographic imaging procedures were conducted on all patients in order to get measurements of angle kappa and high order aberration of the cornea. In addition, higher-order aberrations of the total eye were recorded. ***Results****:* The study was conducted among 206 ametropic eyes of 103 participants. It was found that there was statistically significant difference between the studied groups according to visual acuity and angle Kappa. Also, there is statistically significant difference between the studied ametropia groups according to Coma and trefoil aberration of cornea and total eye while there is statistically insignificant difference between the groups regarding spherical aberration either of cornea or total eye. Assessment of correlation between corneal high order aberrations showed that there is significant moderate positive correlation between angle Kappa and Spherical aberration of cornea among astigmatism group. On the other hand, there is insignificant correlation between angle Kappa and HOAs of total eye among different ametropia groups. ***Conclusion:*** There was statistical significance between spherical aberrations of the cornea and angle kappa in the astigmatic group only. Also, there was a statistical significance between the UCVA and Angle kappa in cases of astigmatic groups which are consistent with each other and denote consideration of angle kappa measurements preoperatively especially in cases of astigmatic patients.

Keywords: *Angle Kappa, Refractive errors, Corneal high order aberrations, Total eye aberrations, Coma aberrations, Spherical aberrations, Trefoil aberrations*

1. Introduction

The human eye exhibits exceptional longevity and has intrinsic simplicity as an optical apparatus. The visual system has two main lenses, namely the cornea and the crystalline lens, which facilitate the reflection of images from the surrounding

environment onto the retina, therefore initiating the visual process. The ocular structure in mature humans has a broad spherical shape, measuring around 24 mm in diameter. The ocular structure is externally enveloped by a resilient and pliable tissue known as the sclera, with the exception of the anterior region where the clear cornea facilitates the transmission of light into the eye. In contrast to the majority of artificial systems, the eye fails to function as a centered optical system due to the non-spherical form and imperfect alignment of its ocular surfaces. Furthermore, the region of the retina that offers the greatest level of detail, known as the fovea, is temporally decentered [1]. The angle kappa is the numerical value that indicates the angle created between the segments of the pupillary and visual axis. The aforementioned measurement has considerable significance within the realm of refractive surgery, since it requires precise centration in order to get optimal results. Additionally, in some cases, the decentration of focusing objects (IOL) may be necessary based on the angle Kappa to ensure optimal results [2]. The diagnosis of this condition in a clinical setting entails the examination of the nasal displacement of the corneal light reflex from the central region of the pupil. The Angle Kappa has significant importance in the field of refractive surgery, particularly in cases of hyperopia, where accurate assessment of refraction plays a crucial role in determining the final result [3]. Refractive error refers to the issue of precisely focusing light onto the retina, which arises from the refractive power shown by the eye and/or cornea [4]. The most often seen forms of inaccuracies in refractions include: A condition known as myopia, or positive defocus, occurs when light rays are abnormally bent before reaching the fovea owing to the eye's high refractive power, causing them to focus in front of the retina. Hyperopia, also known as negative defocus, occurs when light rays are concentrated beyond the retina because the eye lacks the refractive power to bend the light enough to reach the fovea. Regular astigmatism is another condition that may exacerbate hyperopia. Asymmetry refers to the condition in which the refractive power of the eye is not uniformly distributed over the surface of the cornea [4]. The aforementioned disorders may also be categorized as low order aberrations, for which the primary method of therapy involves the use of lens correction devices [5]. The high order aberrations of the eye pertain to fine-scale visual irregularities. The aforementioned aberrations are intrinsic abnormalities within the ocular structure that impede the effective concentration of light onto the retina, hence resulting in visually distorted images. The correction of higher order aberrations (HOAs) in the eye cannot be effectively addressed using cylinder or spherical techniques. The aforementioned conditions include spherical aberrations, coma, trefoil, and tetrafoil [6]. In this study we identify the correlation between angle kappa, corneal high order aberrations and total eye aberrations in myopic, hyperopic and astigmatic patients.

2. Patients and methods

2.1. *Study design*

Analytical cross-sectional study

2.1.1. Subjects

The study was conducted among 206 eyes of 103 patients with errors of refractions in the department of ophthalmology, Sohag university hospital in the period from March 2023 to September 2023. The participants were provided with information on the objective of the research, and their informed consent was obtained

prior to the beginning of the investigations. The study gained approval of Medical Research Ethics Committee (MREC), Sohag university under IBR registration number: Soh-Med-23-02-12, furthermore, the study gained the clinical trial number: NCT05741190. Data collection conformed to all local laws and was compliant with the principles of the Declaration of Helsinki. The studied cases were enrolled in the study after fulfilling the eligibility criteria.

2.1.2. Inclusion criteria

This study was conducted on patients with Various refractive errors not associated with other pathologies in the department of ophthalmology, Sohag university.

2.1.3. Exclusion criteria

We excluded patients aged below 18, with systemic disease and corneal diseases, with history of previous ocular surgery, with Mixed refractive errors and hyperopic Astigmatism

2.2. *Methods*

2.2.1. Patient evaluation

Each participant was subjected to. ***)** Detailed ophthalmological history (complaint, history of previous ocular surgeries, ocular trauma or any ocular medications) and medical history. ***)** Visual acuity assessment: un corrected and best correct visual acuity using Landolt C chart the decimal version ***)** Slit lamp examination for assessment of the anterior segment. ***)** Intraocular pressure (IOP) measurement. ***)** Dilated fundus examination.

2.2.2. Methods of study

The patients were divided into 3 groups: *Group (1)*: included 68 eyes of cases with myopia. *Group (2)*: included 44 eyes of cases with hypermetropia. *Group (3):* included 94 eyes of cases with astigmatism

2.2.3. Patient refraction and imaging

Refraction was taken for all patients using auto kerato-refractometer (NIDEK AR 1, 34-14 Maehama, Hiroishi-cho, Gamagori, Aichi 443-0038, JAPAN.). Then topographic imaging was done to all patients using Sirius ® topographer (CSO SIRIUS –50018 Scandicci, Firenze | Italy) to obtain angle kappa by measuring the pupil offset which can be cross referenced as angle kappa. The principle of measurement of angle kappa By CSO SIRIUS topographer: The distance between the center of the pupil and the vertex of the cornea (pupillary offset) is used to represent the angle kappa which was measured by Sirius topographer and was also used as a substitute of angle kappa. High order aberrations of the cornea were also captured by using Sirius ® topographer (CSO SIRIUS - 50018 Scandicci, Firenze | Italy). High order aberrations of the total eye were captured using iDesign ® advanced wave scan studio (iDesign, 100 Abbott Park Road Abbott Park, IL 60 064, Illinois, Chicago, United States)

2.3. *Statistical analysis*

The analysis of the data was conducted using SPSS (version 25). The numerical data was expressed using measures such as mean, standard deviation, median, and range. An analysis of variance (ANOVA) test was used to compare the means of the groups. The Kruskal-Wallis test was used when the data did not exhibit a normal distribution. The study used Spearman's correlation analysis to examine the relationship between the Kappa angle and many other factors. The graphs were generated with Microsoft Excel. A p-value was deemed statistically significant if it fell below the threshold of 0.05.

3. Results

The study was conducted among 206 ametropic eyes of 103 participants at Ophthalmology department, Sohag Univ. Hospital. **Regarding demographic characteristics of the studied participants,** there is statistically insignificant difference between ametropic eye groups (Myope, hypermetropia and astigmatism) according to age. A mean age of 26.2 ± 6.7 years was found among the participants in the study, with a range of 18 to 43 years. The mean age of myope, hypermetrope and astigmatism participants was (25.9 ± 6.2, 27.7 ± 6.7 and 25.6 ± 7) respectively, as shown in tab. (1). The analysis of **visual acuity** in the participants under investigation indicated a statistically significant disparity between the groups based on UCVA and BCVA measurements. As regards UCVA, the mean of UCVA was found to be higher in the astigmatic group than other groups (0.25 ± 0.2, 0.24 ± 0.16 and 0.11 ± 0.13). However, the mean of BCVA among myopic eyes has significantly increased in comparison to other groups (0.78 ± 0.21, 0.76 ± 0.25 and 0.66 ± 0.25). Furthermore, as regard to **Angle Kappa**, there is a statistically significant disparity across the three groups' Angle Kappa values. The mean of angle Kappa among hypermetropic eyes has significantly Higher in comparison to astigmatic and myopic eyes (0.39º ± 0.19º), (0.35º ± 0.49º and 0.23º ± 0.11º) respectively, as shown in tab. (2). With respect to the high order aberration (HOAs) of the cornea seen in the ametropia groups under investigation, a statistically significant difference was observed across all groups in terms of coma and trefoil aberrations of the cornea. Nevertheless, the observed spherical aberrations in all groups were found to be statistically negligible, tab. (3). With respect to **high order aberrations (HOAs) of the total eye** seen in the subjects under investigation, the data presented in tab. (4) indicates a statistically significant disparity across all ametropic groups in terms of coma and trefoil aberrations. Nevertheless, with respect to the root mean square (RMS) of spherical aberrations, there was no statistically significant difference seen across any ametropic groups. Assessment of correlation between angle Kappa with age and visual acuity showed that there is insignificant correlation between angle Kappa with age, UCVA and BCVA of the studied participants Assessment of correlation between angle Kappa and HOAs of cornea showed that there is significant moderate positive correlation between angle Kappa and Spherical aberration of cornea among astigmatism group. An evaluation of the correlation between angle Kappa and HOAs of the total eye across all ametropia groups revealed that there is no significant correlation between these two variables.

Table 1: Demographic characteristics of the studied population

Variable		Summary statistics (n = 206)			Total	P-value
		Myope (n = 68)	Hypermetrope (n = 44)	Astigmatism (n = 94)		
Age (years)	**Mean ± S. D**	25.9 ± 6.2	27.7 ± 6.7	25.6 ± 7	26.2 ± 6.7	0.2
	Median (Range)	23 (18 – 40)	28 (18 – 42)	23 (18 – 43)	24 (18 – 43)	

Table 2: Visual acuity of the studied participants

Variable		Summary statistics (n = 206)			P- value
		Myope (n = 68)	Hypermetrope (n = 44)	Astigmatism (n = 94)	
UCVA	**Mean ± S. D**	0.11 ± 0.13	0.24 ± 0.16	0.25 ± 0.2	< 0.001
	Median (Range)	0.05 (0.03 – 0.8)	0.2 (0.05 – 0.6)	0.2 (0.03 - 0.9)	
BCVA	**Mean ± S. D**	0.78 ± 0.21	0.66 ± 0.25	0.76 ± 0.25	0.02
	Median (Range)	0.9 (0.3 - 1)	0.7 (0.08 - 1)	0.9 (0.15 – 1)	
Angle Kappa (º)	**Mean ± S. D**	0.23 ± 0.11	0.39 ± 0.19	0.35 ± 0.49	< 0.001
	Median (Range)	0.2 (0.03 – 0.6)	0.35 (0.16 – 0.95)	0.26 (0.03 – 3.4)	

Table 3: Corneal High order aberrations (HOAs) among the studied participants

Variable		Summary statistics (n = 206)			P- value
		Myope (n = 68)	Hypermetrope (n = 44)	Astigmatism (n = 94)	
RMS Coma aberration of cornea	Mean ± S. D	0.13 ± 0.05	0.32 ± 0.23	0.17 ± 0.07	0.001
	Median (Range)	0.13 (0.03 – 0.25)	0.27 (0.12 – 1.02)	0.17 (0.04 – 0.34)	
RMS Trefoil of cornea	Mean ± S. D	0.15 ± 0.11	0.26 ± 0.24	0.21 ± 0.29	0.04
	Median (Range)	0.14 (0.05 – 0.69)	0.18 (0.04 – 0.99)	0.14 (0.04 – 2.03)	
RMS Spherical aberration of cornea	Mean ± S. D	-0.13 ± 0.03	-0.17 ± 0.12	-0.14 ± 0.05	0.4
	Median (Range)	-0.13 (-0.22: -0.08)	-0.14 (-0.63: -0.02)	-0.14 (-0.39: -0.01)	

Table 4: High order aberrations (HOAs) of total eye among the studied participants

Variable		Summary statistics (n = 206)			P- value
		Myope (n = 68)	Hypermetrope (n = 44)	Astigmatism (n = 94)	
RMS Coma aberration of total eye	Mean ± S. D	0.07 ± 0.05	0.016 ± 0.13	0.06 ± 0.03	0.001
	Median (Range)	0.06 (0.01 – 0.26)	0.12 (0.03 – 0.5)	0.05 (0.01 – 0.17)	
RMS Trefoil of total eye	Mean ± S. D	0.07 ± 0.04	0.1 ± 0.06	0.06 ± 0.03	0.02
	Median (Range)	0.07 (0.01 – 0.2)	0.08 (0.02 – 0.2)	0.06 (0.01 – 0.2)	
RMS Spherical aberration of total eye	Mean ± S. D	0.004 ± 0.03	0.01 ± 0.08	-0.003 ± 0.04	0.6
	Median (Range)	0.001 (-0.05: 0.07)	0.008 (-0.12: 0.24)	0 (-0.12: 0.06)	

Table 5: Correlation between angle Kappa and age of the studied participants.

Variable	Angle Kappa	
	r value	P-value
Age	0.02	0.7
UCVA	0.01	0.8
BCVA	-0.07	0.2

Table 6: Correlation between angle Kappa and HOAs of cornea among different ametropia groups

Variable		Angle Kappa		
		Myope	Hypermetrope	Astigmatism
Coma aberration of cornea	r value	0.15	0.3	0.3
	P-value	0.4	0.1	0.08
Trefoil of cornea	r value	0.3	-0.3	-0.2
	P-value	0.1	0.2	0.2
Spherical aberration of cornea	r value	- 0.01	-0.04	0.4
	P-value	0.9	0.8	0.007

Table 7: Correlation between angle Kappa and HOAs of total eye among different ametropia groups.

Variable		Angle Kappa		
		Myope	Hypermetrope	Astigmatism
Coma aberration of cornea	r value	0.1	0.3	0.01
	P-value	0.5	0.1	0.9
Trefoil of cornea	r value	- 0.1	- 0.03	- 0.2
	P-value	0.5	0.9	0.2
Spherical aberration of cornea	r value	- 0.3	- 0.2	- 0.2
	P-value	0.2	0.3	0.1

4. Discussion

Higher-order aberrations (HOAs) refer to minute optical imperfections occurring inside the eye, which may significantly affect the overall quality of the retinal retinal picture. In their attempt to enhance visual acuity, ophthalmologists and optometrists now place more emphasis on corneal higher order aberrations due to recent developments in ocular diagnostic and treatment methods [7]. The correlation between hyperopia (HOA) and refractive error is a subject of considerable scholarly attention owing to the hypothesized influence of retinal defocus and HOA signals

on ocular neurodevelopment. An estimated 90% of visual abnormalities may be ascribed to variations in the cornea [8]. The angle kappa, which refers to the angle formed between the visual axis and the center of the pupil, is a measurement that has considerable therapeutic significance. Patients exhibiting a high angle kappa, such as those with hyperopia, may encounter alignment inaccuracies while undergoing pupil-centered photoablation in the context of refractive procedures. These mistakes are linked to an elevated susceptibility to visual impairments, including halos and glare [2]. Our study aimed to identify the correlation between angle kappa, corneal high order aberrations and total eye aberrations in myopic, hyperopic and astigmatic patients. To achieve this aim, a cross sectional study was conducted among 206 ametropic eyes of 103 participants at Ophthalmology department, Sohag university hospital from March 2023 to September 2023. In this study we found that there was insignificant difference between myopia, hypermetropia and astigmatism groups in refractive ranges. The current study shows matching in age as we intended that to be more concise and to avoid confounding effect of age. Our results weren't in agreement with Shahraki who determined the age- and sex-adjusted prevalence of refractive errors and its related factors as in our study age was constant not a variable to be measured [9]. In the present study, the examination of angle Kappa measurements revealed a statistically significant disparity among the three groups with respect to angle Kappa. The magnitude of the average angle Kappa measurement in hypermetropic eyes shown a significant increase in comparison to astigmatic and myopic eyes (0.39 ± 0.19, 0.35 ± 0.49, and 0.23 ± 0.11) respectively. Furthermore, a statistically significant difference was seen between myopia and hypermetropia in terms of angle Kappa. The results of our study were consistent with a study that was conducted by Sivakumar who revealed that 33 patients among myopic eyes of 35 patients had an angle kappa of below 0.4 mm while observing the angle kappa in 20 hyperopic individuals 16 of them had an angle kappa with a more value [10]. Furthermore, our research aligns with the findings of Koc et al., who reported that the kappa angle distance across the pupil barycenter distance was greater in individuals with hyperopia compared to those with myopia (0.38 ± 0.15 and 0.21 ± 0.11 respectively) [11]. Our study assessed angle Kappa by using Sirius ® topographer and measured in mm. Other studies assessed angle Kappa in degrees [12,13] and a study that was done by Holladay who revealed that the conversion used is 1.0 mm = 7.5 degrees = 15 prism diopters [14]. Our results were in agreements with the results of Hashemi et al. and Basmak et al. who reported that higher kappa angles in patients with hyperopia than those with myopia [12, 13]. The present study provided evidence of the existence of corneal high order aberrations (HOAs) among the selected ametropia groups being examined. The research indicates that the average value of the root mean square (RMS) for coma aberrations is 0.13 ± 0.05 in the myopia group, 0.32 ± 0.23 in the hyperopia group, and 0.17 ± 0.07 in the astigmatism group. Furthermore, a statistically significant difference was seen across all ametropic groups in terms of coma aberrations. A root mean square (RMS) analysis of trefoil aberrations revealed that the average value was 0.15 ± 0.11 in the myopia group, 0.26 ± 0.24 in the hyperopia group, and 0.21 ± 0.29 in the astigmatism group. The root mean square (RMS) values for spherical aberrations were found to be -0.13 ± 0.03 in the myopia group, -0.17 ± 0.12 in the hyperopia group, and -0.14 ± 0.05 in the astigmatism group. However, there was no statistically significant difference seen across all ametropic groups in terms of spherical aberrations. The find-

ings of our investigation were consistent with the research done by Salman et al., which revealed a statistically significant difference among ametropia groups with regards to corneal high order aberrations (HOAs). Notably, the highest values of RMS trefoil and RMS coma were observed in individuals with astigmatism (0.15 ± 0.12 and 0.17 ± 0.14). Additionally, the highest value of RMS spherical aberrations was found to be identical in individuals with myopia and hypermetropia (0.03 ± 0.14) [7]. The difference between our results and the results of Salman et al. regarding the highest value of RMS coma and trefoil could be explained by low value of cylinder among astigmatic group (-1.56 ± 1.42) D in their study which is lower than ours (-3.07 ± 1.3) D. The current investigation aligns with the findings of Anbar et al., who categorized the examined cases into five distinct groups based on their refractive errors: mild-to-moderate myopia, high myopia, hyperopia, simple myopic astigmatism, and simple hypermetropic astigmatism. The study demonstrated a statistically significant disparity in coma aberration frequency among all five groups. Notably, the hypermetropia group had the greatest coma aberration (0.26 ± 0.12 ± m) when compared to the other groups. The hypermetropia group had the lowest spherical aberration, which was shown to be substantially different from the other groups. However, the trefoil metric did not demonstrate statistical significance when comparing all groups [15]. As regard to the high order aberrations of the total eye our study shows the RMS of coma aberrations to have a mean of (0.07 ± 0.05) in myopia group, a mean of (0.016 ± 0.13) in hyperopia group and a mean of (0.06 ± 0.03) in astigmatism group , and there was statistically significant difference between all ametropic groups regarding coma aberrations, the RMS of trefoil aberrations to have a mean of (0.07 ± 0.04) in myopia group a mean of (0.1 ± 0.06) in hyperopia group and a mean of (0.06 ± 0.03) in astigmatism group. The study found that the root-mean-square (RMS) values for spherical aberrations were as follows: the mean observed in the myopia group was 0.004 ± 0.03, in the hyperopia group it was 0.01 ± 0.08, and in the astigmatism group it was -0.003 ± 0.04. Furthermore, no statistically significant difference was seen among the ametropic groups in relation to coma aberrations. The results of our investigation were in line with the conclusions stated by Khan et al., who documented that the hypermetropia cohort had the highest magnitude of spherical aberration (0.30 ± 0.42) [16]. In the current study the highest value of RMS spherical aberration of total eye was found among hypermetropia in comparison to other ametropia groups (0.01 ± 0.08), however, it was statistically insignificant difference in comparison between all groups. Our results were in line with the results of Liorente et al who revealed that RMS for spherical aberration was significantly higher for the hyperopic eyes [17]. This is in line with a study that was conducted by Kim et al. and the cases under investigation were categorized into two groups: Group 1, consisting of 20 individuals with a UCVA of 20/12, and Group 2, including 54 eyes of 36 myopic patients with a UCVA more than -6 diopters. The analysis revealed that there was no statistically significant disparity between the two groups in relation to total SA. However, their findings were consistent with our own, as there was a statistically insignificant difference observed in the RMS of Coma and Trefoil. This insignificance can be attributed to the larger sample size employed in our study and the inclusion of subjects with super vision, a category that was not included in our prior investigation [18]. The present investigation diverged from the research conducted by Li et al., which demonstrated that there were negligible

disparities in the root mean square (RMS) values of total higher-order aberrations observed among the groups exhibiting spherical equivalent refraction (SER) ranging from +0.5 D to -6.0 D and astigmatism below -1.00 D. This disparity may be explained by the fact that all participants in the aforementioned research had myopia, while our investigation included all refractive abnormalities [19]. This study results align with the findings of Kim et al, who demonstrated a higher prevalence of spherical aberration in individuals with hyperopia compared to those with myopia. [18]. The difference in statistical significance could be explained by our sample size was larger which allowed more accurate result in addition to difference in pupil size as in our work we assessed aberration for 6 mm. The current investigation demonstrated a lack of substantial link between the angle Kappa and the age of the subjects under examination. The present investigation corroborated the findings of Hashemian et al., who observed a reduction in the angle kappa with advancing age. However, our research used age as a constant variable to provide a more comprehensive examination of other variables influencing HOA [20]. One potential limitation in the comparison of results from previous studies pertaining to this study may be attributed to the use of different measuring aberrometers, the absence of consistent pupil size across the observed eyes, variations in age groups, and disparities in the visual and refractive profiles of the participants. A multitude of elements exert influence on the reliability of comparisons, therefore requiring meticulous deliberation. In conclusion to the best of our knowledge our study was the first to discuss the triple relationship between high order aberrations, angle kappa and errors of refractions and it shows that there was statistical significance between spherical aberrations of the cornea and angle kappa in the astigmatic group only also there was a statistical significance between the UCVA and angle kappa in cases of astigmatic groups which are consistent with each other and denote consideration of angle kappa measurements preoperatively especially in cases of astigmatic patients. The limitations of this study can be summarized as follows: the study employed a cross-sectional design without a control group, the absence of a classification system for myopia degrees, and the study was limited by the analysis of a small visual field. It is crucial to examine aberrations across a larger visual field as they tend to increase with field angle, potentially impacting the observed differences between refra--ction groups. **Strengths were** evaluation of both of corneal and total HOAs as most studies evaluated either total or corneal HOAs only, large sample size and age was a fixed parameter

5. Conclusion

The highest value of RMS of coma, trefoil and tetrafoil aberrations of cornea was found among hypermetropia group. The highest value of RMS of coma aberration was found among myopia group while the highest RMS of trefoil and tetrafoil were found among hypermetropia group. Moreover, evaluation of angle Kaapa showed that the highest value was found among hypermetropia group.

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