Pupil barycenter configuration in patients with myopia and hyperopia

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Research Article

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Abstract

Purpose

To compare the pupil barycenter configurations that can be used to calculate the kappa angle in terms of distance in patients with myopia and hyperopia.

Method

: This prospective study evaluated 394 eyes of 197 patients. The patients were divided into two groups according to their spherical equivalent values: the myopic group (mean spherical equivalent refraction < -0.50 D) and the hyperopia group (mean spherical equivalent refraction $> +0.50$ D). The two groups were further subdivided according to severity (myopic group: mild, < -0.50 and ≤ -3.00 D; moderate, < -3.00 and ≤ -6.00 D; severe, < -6.00 D; hyperopic group: mild, $\geq +0.50$ and $\leq +2.00$ D; moderate, $> +2.00$ and $\leq +4.00$ D; severe, $> +4.00$ D). The pupil and iris barycenter distance measurements and other parameters were obtained through optical low-coherence reflectometry.

Results

Of the 197 patients, 109 (55.3%) were female and 88 (44.7%) were male, and their age ranged from 7 to 60 years (mean, 35.16 ± 14.75 years). The average pupil barycenter measurements originating from the kappa angle distances were 0.38 ± 0.15 and 0.21 ± 0.11 mm in patients with hyperopia and myopia, respectively. Corneal and lens thickness measurements were higher in patients with hyperopia, whereas anterior chamber depth and pupil diameter measurements were higher in patients with myopia. No significant difference in astigmatism or white-to-white measurements was observed between patients with hyperopia and those with myopia.

Conclusion

The kappa angle distances are higher in hyperopia than in myopia. The pupil barycenter measurement from the kappa angle distance can be an alternative for the evaluation of the kappa angle.

Introduction

The kappa angle is generated by the intersection of the visual axis and the pupillary axis in the pupillary space. If the light reflex is in the nasal side, it is classified as positive; if it is in the temporal side, it is classified as negative [1–3]. The line perpendicular to the center of the corneal curvature at the entrance of the pupil is the pupillary axis, and the line joining the fixation point and the fovea is the visual axis [3].

The fovea is located somewhat temporally with respect to the point where the pupillary axis intersects the posterior pole of the globe. Therefore, the normal kappa angle is somewhat positive. Parallel to this, the corneal light reflex is somewhat on the nasal side, and the pupillary axis is more temporal [4, 5].

In refractive surgery, the kappa angle is a clinically important entity and may play a role in refractive results [6, 7]. A wide kappa angle (0.6 mm) may cause misalignment errors during photoablation in laser refractive surgery and lens decentralization after multifocal lens implantation, leading to irregular astigmatism, photic phenomena (glare and halo), and decreased best-corrected visual acuity [8].

Although different methods are used to measure the kappa angle, the corneal reflection method, using a synoptophore or major amblyoscope, is used to measure the true kappa angle [8]. Orbscan II (Bausch & Lomb, Rochester, NY, USA), Galilei (Ziemer Ophthalmic Systems, Port, Switzerland), and OPD Scan II (Nidek, Gamagori, Japan) are the newer devices used to determine the kappa angle [9].

The working principle of Lenstar LS 900 (Haag-Street AG, Koeniz, Switzerland) is based on optical low-coherence reflectometry using a wide-band light source with a central wavelength of 820 μm . Lenstar does not directly determine the kappa angle. Instead, it measures the pupil barycenter [3] by measuring the distance (x and y Cartesian values) between the corneal vertex and the pupillary center, from which the kappa angle can be determined according to the Pythagorean theorem [8].

The aim of this study was to compare the pupil barycenter configurations that can be used to calculate the kappa angle in terms of distance in patients with myopia and hyperopia.

Methods

Study design and patients

This prospective study was carried out at the Private Medipol University Faculty of Medicine and Kütahya Anadolu Hospital between September 2020 and January 2021. Patients with hyperopia or myopia > 0.50 D, normal slit-lamp and fundoscopy examination results, intraocular pressure levels < 21 mmHg, and with no history of systemic or ocular corticosteroid medication were included in the study. Patients with corneal astigmatism values > 1.00 D, irregular astigmatism, dry-eye syndrome, pupillary abnormality, corneal disease, glaucoma or intraocular inflammation history, or previous ocular surgery history were excluded. A total of 394 eyes from 197 patients were included in this study. The patients included in the study were divided into two main groups according to their spherical equivalent values: the myopic group (mean spherical equivalent refraction < -0.50 D) and the hyperopia group (mean spherical equivalent refraction $> +0.50$ D). The two groups were further subdivided according to severity (myopic group: mild, < -0.50 and ≤ -3.00 D; moderate, < -3.00 and ≤ -6.00 D; severe, < -6.00 D; hyperopic group: mild, $\geq +0.50$ and $\leq +2.00$ D; moderate, $> +2.00$ and $\leq +4.00$ D; severe, $> +4.00$ D).

The pupil and iris barycenter distance measurements and other parameters were obtained using Lenstar LS 900 optical low-coherence reflectometry. The distance (x and y Cartesian values) between the corneal

vertex and the pupillary center was also measured using Lenstar LS 900. After measuring the pupil barycenter (the x and y coordinates of the pupil; dx and dy), we used the Pythagorean theorem to calculate the kappa angle in terms of distance. The total kappa angle distance was calculated diagonally (hypotenuse), that is, the square root of the sum of the squares of the pupil dx and pupil dy [9]. Using the same theorem, we calculated the angle formed based on the distance between the corneal vertex and the center of the iris over the iris barycenter values. All measurements were made by the same experienced observer (i.C.).

Statistical analysis

The Number Cruncher Statistical System 2007 program (NCSS, Kaysville, UT, USA) was used for the statistical analysis. Descriptive statistical methods (mean, standard deviation, median, frequency, percentage, minimum, and maximum) were used to evaluate the study data. The suitability of the quantitative data to normal distribution was tested using the Shapiro-Wilk test and graphical analysis. Student's t test was used for comparisons of normally distributed quantitative variables between two groups, and one-way analysis of variance was used for three-group evaluations, and the Bonferroni test was used for post hoc comparisons. The Mann-Whitney U test was used to compare quantitative variables that did not show normal distribution between the two groups. The Kruskal-Wallis test was used in three group evaluations. Pearson's chi-square test was used to evaluate categorical variables. Statistical significance was set at $p < 0.05$.

Results

Of the 197 patients, 55.3% ($n = 109$) were female and 44.7% ($n = 88$) were male. The ages of the patients ranged from 7 to 60 years (mean, 35.16 ± 14.75 years). The characteristics of the patients are presented according to groups in Table 1. The spherical equivalent values were significantly different between the hyperopic and myopic groups ($p < 0.05$). The distributions of mild, moderate, and severe cases based on spherical equivalent values also showed statistically significant differences between the hyperopic and myopic groups ($p < 0.05$) (Table 2, Fig. 1). A statistically significant difference in corneal thickness was found between the hyperopic and myopic groups ($p < 0.01$), with higher values in patients with hyperopia (Table 3). A statistically significant difference in anterior chamber measurements was found between the hyperopic and myopic groups ($p < 0.01$), with higher values in patients with myopia. A statistically significant difference in lens thickness was found between the hyperopic and myopic groups ($p < 0.01$), with thicker lens in patients with hyperopia. There was no statistically significant difference in astigmatism or white-to-white measurement between the hyperopic and myopic groups ($p > 0.05$). A statistically significant difference in iris barycenter measurements was found between the hyperopic and myopic groups ($p < 0.01$), with higher values in patients with hyperopia (Fig. 2). A statistically significant difference in pupil diameter was found between the hyperopic and myopic groups ($p < 0.01$), with higher pupil diameter in patients with myopia. A statistically significant difference in pupil barycenter measurements was found between the hyperopic and myopic groups ($p < 0.01$), with higher pupil barycenter values in patients with hyperopia (Fig. 2). In hyperopic cases, a statistically significant

difference was found between iris barycenter measurements according to the spherical equivalent classification ($p < 0.01$). The iris barycenter measurements of the moderate and severe groups were significantly lower than those of the mild group ($p = 0.001$, $p = 0.001$, and $p < 0.01$)(Fig. 3). Meanwhile, the iris barycenter measurements of the moderate group were significantly lower than those of the severe group ($p = 0.018$ and $p < 0.05$). Although there was no statistically significant difference in pupil barycenter measurements between the groups according to the spherical equivalent classification ($p = 0.093$ and $p > 0.05$), the pupil barycenter measurements were significantly lower in the severe group ($p = 0.001$ and $p < 0.01$) and those of the moderate group were significantly lower than those of the severe group ($p = 0.002$ and $p < 0.01$)(Fig. 4). In patients with myopia, no statistically significant difference was found between the iris and pupil barycenter measurements according to the spherical equivalent classification ($p > 0.05$).

Table 1
Evaluation of descriptive characteristics according to groups

	Hyperopic (n = 99)	Myopic (n = 98)	P
Age (years)	40.71 ± 15.86	29.55 ± 11.04	0.001 ^{a,**}
Sex			
Male	46 (46.5)	42 (42.9)	0.611 ^b
Female	53 (53.5)	56 (57.1)	
^a Student's t test.			
^b Pearson's chi-square test.			
^{**} $p < 0.01$.			

Table 2
Evaluation of descriptive properties according to spherical equivalent

	Hyperopic (n = 198)	Myopic (n = 196)	P
Spherical equivalent			
Min/max (median)	0.25/12.1 (2.1)	-20.1/5.1 (- 2.9)	0.001 ^{a,**}
Mean ± standard deviation	2.81 ± 2.10	-3.32 ± 2.72	
Mild	98 (49.5)	106 (54.1)	0.009 ^{b,**}
Moderate	63 (31.8)	74 (37.8)	
Severe	37 (18.7)	16 (2.8)	
^a Mann-Whitney U test.			
^b Pearson's chi-square test.			
^{**} p < 0.01.			

Table 3
Evaluations by groups

	Hyperopic	Myopic	p ^a
Axial length (mm)			
Min-max (median)	19.4–25.3 (22.5)	22.2–30.2 (24.5)	0.001 ^{b,**}
Mean ± SD	22.37 ± 1.18	24.59 ± 1.27	
Corneal thickness (µm)			
Min-max (median)	476–633 (548)	412–614 (539.5)	0.001**
Mean ± SD	547.93 ± 31.94	538.42 ± 32.47	
Anterior chamber depth (mm)			
Min-max (median)	2.3–5 (2.3)	2.4–4.9 (3.6)	0.004**
Mean ± SD	3.19 ± 0.39	3.63 ± 0.34	
Lens thickness (mm)			
Min-max (median)	3.1–5 (4)	0.6–4.7 (3.7)	0.001 ^{b,**}
Mean ± SD	4.04 ± 0.44	3.70 ± 0.42	
Flat meridian (D)			
Min-max (median)	37.7–47.4 (42.9)	38.1–46.4 (43.3)	0.009**
Mean ± SD	42.84 ± 1.80	43.28 ± 1.54	
Steep meridian (D)			
Min-max (median)	40.3–48.9 (44)	39.1–54.8 (44.4)	0.002**
Mean ± SD	44.05 ± 1.73	44.63 ± 2.00	
Astigmatism (D)			
Min-max (median)	0–4.5 (1)	0–9.4 (1.1)	0.074 ^b
Mean ± SD	1.21 ± 0.97	1.35 ± 1.20	
White-to-white (mm)			
^a Student's t test.			
^b Mann-Whitney U test.			
**p < 0.01.			
SD, standard deviation.			

	Hyperopic	Myopic	p ^a
Min-max (median)	10.9–13.6 (12)	11.2–13.3 (12.1)	0.064
Mean ± SD	12.0 ± 0.48	12.08 ± 0.39	
Iris barycenter			
Min-max (median)	0.1–0.9 (0.5)	0.1–1 (0.4)	0.001**
Mean ± SD	0.50 ± 0.14	0.37 ± 0.13	
Pupil diameter (mm)			
Min-max (median)	3–6.9 (4.7)	3–8.1 (1.5)	0.001**
Mean ± SD	4.69 ± 0.85	5.14 ± 0.94	
Pupil barycenter			
Min-max (median)	0–0.9 (0.4)	0–0.7 (0.2)	0.001**
Mean ± SD	0.38 ± 0.15	0.21 ± 0.11	
^a Student's t test.			
^b Mann-Whitney U test.			
**p < 0.01.			
SD, standard deviation.			

Table 4
Iris and pupil barycenter evaluations according to spheric equivalent
classification in groups

	Spheric equivalent	n	Mean	SD	P
Hyperopic					
Iris barycenter	Mild	98	0.44	0.12	0.001 ^{a,**}
	Moderate	63	0.53	0.12	
	Severe	37	0.60	0.14	
Pupil barycenter	Mild	98	0.34	0.13	0.001 ^{a,**}
	Moderate	63	0.39	0.15	
	Severe	37	0.49	0.15	
Myopic					
Iris barycenter	Mild	106	0.38	0.14	0.672 ^f
	Moderate	74	0.36	0.12	
	Severe	16	0.38	0.14	
Pupil barycenter	Mild	106	0.21	0.11	0.702 ^f
	Moderate	74	0.22	0.12	
	Severe	16	0.21	0.10	
^a One-way analysis of variance.					
^b Kruskal-Wallis test.					
^{**} p < 0.01.					
SD, standard deviation.					

Discussion

The present study compared the pupil barycenter configurations that can be used to calculate the kappa angle in terms of distance in patients with myopia and hyperopia. Results showed that the kappa angle distance over the pupil barycenter distance was higher in hyperopic cases than in myopic cases. In another study, higher positive kappa angle values were found in patients with hyperopia than in patients with myopia and emmetropia [4]. A difference was observed between the mean kappa angle values of the right and left eyes [4]. The kappa angles of the left eyes of patients with emmetropia tend to be slightly

increased [4, 10, 11]. In our study, the mean distance of the pupil and iris barycenter origins was higher in the right eye in both myopic and hyperopic cases.

Evidence showing the importance of the kappa angle in refractive surgery, whether in laser surgery or in multifocal lens treatment, is increasing [12–15]. Generally, hyperopic eyes have a wide kappa angle, and these eyes are prone to decentralized treatment during laser ablation [16]. The mean kappa angles were 5.46° and 5.22° in the studies by Hashemi et al. [2] and Basmak et al. [4], respectively. The small difference between the angles is believed to be due to the age groups of the subjects included in the study, which was between 14 and 81 years in the study by Hashemi et al. [2] and between 20 and 40 years in the study by Basmak et al. [4]. The ages of the cases included in our study ranged from 7 to 60 years, and the mean pupil barycenter distance was 0.30 mm in our study.

In the study by Hashemi et al. [2], the mean kappa angles for patients with myopia, emmetropia, and hyperopia were $5.13^\circ \pm 1.50^\circ$, $5.72^\circ \pm 1.10^\circ$, and $5.52^\circ \pm 1.19^\circ$, respectively. A significant correlation was found between the refractive status of the patients and the kappa angle measurements, which was consistent with the findings of Hashemi et al. [2]. In the study by Basmak et al. [4], the values, which were obtained by with Orbscan II, were 4.51° , 5.55° , and 5.65° , respectively [4]. Qazi et al. [17] measured the preoperative kappa angles using Orbscan and reported values of 5.0° and 6.9° in myopic and hyperopic cases, respectively, with an average spherical equivalent of 3.50 D. The average kappa angles were 4.66° in myopia with refractive defects between -3.00 and -6.00 D and 5.45° in hyperopia with refractive defects between 2.00 and 4.00 D. In our study, the mean pupil barycenter origin kappa angle distances were 0.38 ± 0.15 and 0.21 ± 0.11 mm in hyperopia and myopia, respectively. The mean distance of the pupil barycenter originating from the kappa angle was 0.22 mm in myopia with refractive error between -3.00 and -6.00 D and 0.39 mm in hyperopia with refractive error between 2.00 and 4.00 D.

Kappa angle measurement may depend on the biometric, geometric, and optical properties of the cornea, globe, retina, crystalline lens, and anterior chamber depth. Depending on the corneal power, anterior chamber depth, and nodal point, we can expect that the optic axis and the entrance and exit of the pupil have specific localizations. Meanwhile, the visual axis also depends on the geometric and anatomical features of the fovea, nodal point, and pupil entrance. Thus, there seems to be some relationship in the geometric, optical, and biometric properties of the eye when there are changes in the kappa angle [2].

A synoptophore measures the kappa angle using the corneal reflection method, which is the most widely used method in clinical practice [5]. Basmak et al. [4] used both Orbscan II corneal topography and synoptophore to measure the basin and arc kappa angle. According to their results, the kappa angles obtained with Orbscan II were higher than those obtained with synoptophore. They also reported higher kappa angles in patients with hyperopia than those with emmetropia or myopia. Yeo et al. [18] used ultrasound biomicroscopy and corneal topography to measure the kappa angle and obtained reliable results. New instruments such as Galilei (Ziemer Ophthalmic Systems) and OPD Scan II (Nidek) are started to be used in the measurement of the kappa angle. If the kappa angle cannot be automatically and directly measured, the distance between the corneal vertex and the pupillary center (x and y Cartesian

values) can be used to calculate the kappa angle [16]. The Lenstar LS 900 (Haag-Streit AG) device can be used for this purpose. Although Lenstar LS 900 does not directly measure the kappa angle [8], we can apply the Pythagorean theorem to measure the pupil barycenter distances (x and y coordinates of the pupil center; dx and dy) and determine the kappa angle distance. Likewise, we evaluated the kappa angle distance using the iris barycenter distances (x and y coordinates of the iris center; dx and dy) and compared the pupil and iris barycenter origin kappa angle distances.

In our study, the kappa angle distances were higher in hyperopic cases when calculating the kappa angle distance of both the pupil and iris barycenter origins. Although the corneal and lens thickness values were higher in the hyperopic cases included in our study, the anterior chamber depth and pupil diameter were also found to be higher in myopic cases. Meanwhile, no significant difference was observed between hyperopic and myopic cases in terms of astigmatism and white-to-white measurements.

This study had several limitations. First, patients with emmetropia were not included in this study, and second, the study was not conducted according to age groups. More objective evaluations can be made by including primarily hyperopic and myopic cases as well as emmetropic cases. If the cases are according to age groups, age-related changes in the kappa angle can also be detected.

In conclusion, the kappa angle distances are higher in hyperopic cases than in myopic cases. We believe that the calculations of the pupil barycenter originating from the kappa angle distance can be used as an alternative in the evaluation of the kappa angle.

Declarations

Funding: The authors did not receive support from any organization for the submitted work.

Conflicts of interests/competing interests: The authors have no relevant financial or nonfinancial interests to disclose.

Ethics approval: The study was conducted in accordance with the principles of the Helsinki Declaration. The study was reviewed and approved by the Private Istanbul Medipol University Ethics Committee (17/09/2020/699).

Consent to participate: All patients provided written informed consent.

Consent to publish: The participant has consented to the submission of the case report to the journal.

Availability of data and materials: All data generated or analysed during this study are included in this published article.

Author contributions: Both authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Haci Koc and Faruk Kaya. The first draft of the

manuscript was written by Haci Koc, and both authors commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

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Figures

Figure 1

Distribution of iris and pupil barycenter measurements by groups

Figure 2

Iris barycenter measurements according to spherical equivalent groups

Figure 3

Pupil barycenter measurements according to spherical equivalent groups

Figure 4

Although there was no statistically significant difference in pupil barycenter measurements between the groups according to the spherical equivalent classification ($p=0.093$ and $p>0.05$), the pupil barycenter measurements were significantly lower in the severe group ($p=0.001$ and $p<0.01$) and those of the moderate group were significantly lower than those of the severe group ($p=0.002$ and $p<0.01$)(Figure 4).